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THE BIOMECHANICAL AND PHYSIOLOGICAL DEMANDS OF ROLLER HOCKEY MATCH PLAY.

JOANNA KINGMAN

PhD THESIS

School of Sports Studies

Submitted: October 1999.

This thesis has been completed as a requirement for a higher degree of the University of Southampton.

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ABSTRACT

School of Sports Studies

Doctor of Philosophy

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There is a lack of scientific research into roller hockey. The aim of this thesis was to analyse the muscular demands of roller hockey match play, using four techniques. These were a) Match analysis: Two Premier League roller hockey matches were recorded using two stationary video cameras. Manual, field-by-field analysis established all the actions performed by players in a match situation, the percentage of match time spent performing each action, their frequency and the mean duration of each action. Also recorded was the direction travelled, while the intensity of each action was subjectively assessed. b) Heart rate analysis (n=5): heart rate was recorded every 5 s during training and competition. Heart rate and performance were also measured during a maximal progressive 20-m shuttle skate test and oxygen consumption ($\dot{V}O_2$) was calculated. c) Kinesiology analysis (n=1): Two-dimensional video analysis was used to establish the phases, joint actions, and muscular activity of each roller hockey action. d) Telemetric surface electromyography (EMG) analysis (n=6): activity was monitored in 8 muscles during training practice and training matches.

The results of the match analysis showed 71% of match play was spent rolling, and 70% was spent travelling forwards; 22% was conducted at high intensity. Minor differences were found in match play activity between forwards and defenders, and between winners and losers. Comparisons between activity in the 1st and 2nd halves showed significantly more sprinting in the 1st half ($p<0.05$) and significantly more rolling and low intensity activity in the 2nd half ($p<0.05$). Mean heart rates during competitive matches (176 beats/min) were significantly higher ($p<0.05$) than during training matches (166 beats/min). The maximal 20-m shuttle skate test produced a mean predicted $\dot{V}O_{2max}$ of 54 ml/kg/min, and maximal heart rates similar to competitive matches. The kinesiology analysis established 8 muscles central in roller hockey; these muscles were monitored in the EMG analysis. Electromyography revealed that performance of roller hockey actions during training produced the greatest EMG activity in the pectoralis major, while sprinting and forehand slap shots were the most demanding actions. Combining the results of the electromyography analysis with the match analysis revealed the high physical demands of shooting and the skating actions of pushing and sprinting. This thesis constituted the first long-term study of roller hockey, and it provided evidence that may be used in developing technique and improving sport specific fitness.

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CHAPTER 1

THE SPORT OF ROLLER HOCKEY
AND ITS HISTORICAL DEVELOPMENT.

The purpose of this chapter is to introduce the minority sport of roller hockey. It begins with an outline of the sport, the rules and the equipment used, followed by a historical review of the sport, from its origins in 1885 in England, up to the present day. Wherever possible the international status of roller hockey during this time is included.

Roller hockey is a non-contact sport similar to ice hockey, only that it is played on roller skates, with a ball, on a rectangular level surface of wood, asphalt, concrete or any other suitable material (National Roller Hockey Association, of England, NRHA, 1997). Roller hockey is a five-a-side sport, including the goalkeeper, but a squad may consist of up to eight outfield players, and two goalkeepers (four substitute outfield players, and one substitute goalkeeper). Players may be substituted during play, but goalkeepers must be substituted during a stoppage.

Roller hockey is played on a rink of 40 ± 4 metres in length and 20 ± 2 metres in width. The rink must be surrounded on all sides by barriers or walls (at least 20 cm high), from which the ball may rebound. The two goals consist of a round iron cage, 105 cm in height (see figure 1.1). The goals are positioned at either end of the pitch in a central position, with room to pass behind them (NRHA Rule Book, 1997).

The duration of roller hockey matches varies. Minors (males aged 9 - 13 years and females aged 9 - 14 years) and intermediates (males aged 11 - 15 years and females aged 11 - 17 years) play 15 minutes each half; schoolboys (13 - 17 years), juniors (15 - 20 years), seniors (15+ years) and ladies (13+ years) play 20 minutes each half. In all of these matches the time runs from the referee's first whistle, until the allotted time is up. Premier league matches and international matches are 20 or 25 minutes each half; however, the time is stopped with every blow of the referee's whistle and started when play resumes, this is known as 'stop-clock' (NRHA Rule Book, 1997, p7). Local and regional matches are usually officiated by one referee, whereas national and international matches are usually officiated by two referees.

The basic rules allow players to play the ball, only with their stick, which may not be raised above shoulder height. Kicking, picking up, carrying, pushing or dragging the ball with any part of the body is prohibited. The ball can be played with either side of the stick. When shooting, it is forbidden to hit the ball with the acute edge of the stick; this procedure is known as chopping. The ball must not rise above 1.524 m, except when it ricochets off two sticks outside the penalty area. The goalkeeper is allowed to play the ball within the penalty area with any part of the body, including the hands, but must not deliberately trap the ball. Players are not allowed to interfere with play if the wheels of the skates are not running freely, when any part of their body is touching the rink, and when holding the barrier, the goal cage, or another player. Fouls are committed by charging unfairly, obstructing deliberately, fighting, tripping, kicking, throwing, holding an opponent, and unfair tackling (Wilkinson, 1974).

The equipment used by roller hockey outfield players (See figure 1.0) consists of specially designed roller skates that permit maximum ankle movement (Arlott, 1975); the boots themselves must be bolted to the skate plates. They are made of leather for comfort and to lessen the chance of injuring another player, and they have hardened toecaps for protection. The toe stops are much lower (closer to the floor) than conventional roller skates. The permitted diameter of all wheels is 3 cm (NRHA Rule Book, 1997), and they are specially formulated to give a balance between grip and slide on the rink surface. Outfield players wear shin pads (a maximum thickness of 5 cm), leather kneepads, and leather gloves, whilst elbow pads and gum shields are optional. The sticks must be between 90 cm and 115 cm in length, 5 cm in width, and must weigh no more than 500 grams (NRHA Rule Book, 1997). The stick is made of wood and is flat on both sides. The ball has a plastic outer shell, and a core of compressed cork, and is 23 cm in circumference, and 155 grams in weight (Wilkinson, 1974). The ball colour must be of a single contrasting colour to the roller hockey rink.

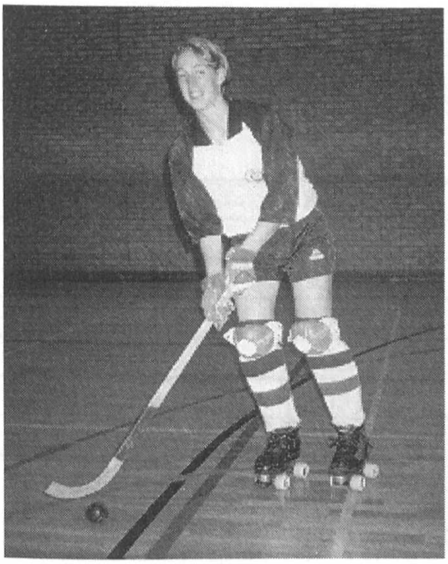


Figure 1.0: Roller hockey outfield player (with permission).

The goalkeepers (See figure 1.1) wear skates similar to the outfield player, but they may use smaller wheels to reduce movement. The protective padding worn by the goalkeeper consists of large leg pads covering the skates, a chest pad with shoulder protectors, and large gloves used both for protection when stopping the ball and redirecting the ball in the desired direction (hence the flat palm on the right hand). Finally a helmet with face guard and throat protector is worn. The goalkeeper may use a normal roller hockey stick, or one specially designed for the goalkeeper, which is shorter and wider than that used by outfield players.

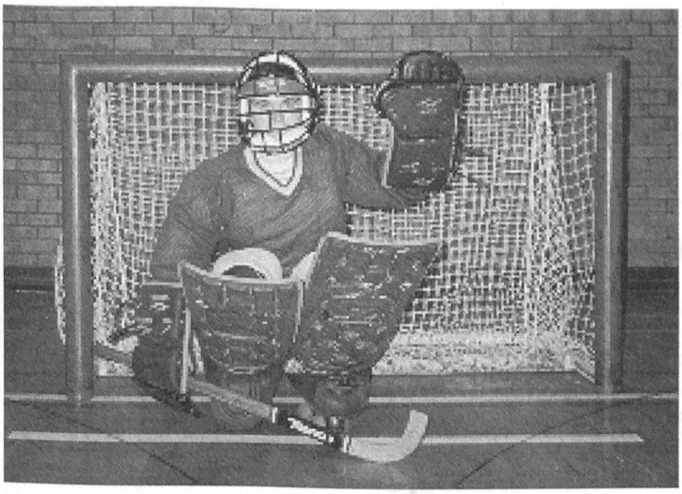


Figure 1.1: Roller hockey goalkeeper (with permission).

Roller hockey is a minority sport in England, with a relatively low number of registered players (see table 1.0). The sport receives little publicity and almost no sponsorship in England.

Table 1.0: National Roller Hockey Association membership figures from 1991 - 1998.

SEASON	REGISTERED PLAYERS	NRHA MEMBERS	AFFILIATED CLUBS
91/92	838	943	39
92/93	962	1085	35
93/94	936	1062	36
94/95	854	1006	34
95/96	936	1230	38
96/97	1051	1652	43
97/98	936	1081	37

Roller hockey is also under threat by other sports adopting the term roller hockey; these other sports have developed with the recent increase in popularity of in-line roller-skating (skates with the wheels in a longitudinal line, one in front of the other, under a rigid boot). A number of variations of this so-called roller hockey involve in-line skates, with ice hockey sticks, pucks and protective clothing. A similar sport using ice hockey equipment is played on conventional roller skates and is known as 'Street Hockey'.

In the context of this project roller hockey is not a new sport and has been played in a similar form for almost a century (Arlott, 1975). At present roller hockey is played on a much wider scale in other countries, which has led to the belief that roller hockey is an up and coming sport, newly introduced to the England. This chapter will dispel this myth by studying the history of roller hockey, using an excellent review by Pout (1993), concerning English Roller Hockey before the First World War.

The first English game recorded of "knocking a ball around with sticks on roller skates" (Pout, 1993, p7) was reported in 1885 and took place in London. These first games were played with a tennis ball and ordinary walking sticks or umbrella handles. Later, bent ash sticks were used, similar to early field hockey sticks but with their backs shaved off. Goals were oblong and easily overturned, skates were crude and lacked friction reducing ball-bearings; there were ten men on each side, and this game was known as 'rink polo' (Pout, 1993, p7).

Another game called 'roller polo' (Pout, 1993, p228) was being played around the same time in the United States of America (USA). This game was different to English rink polo; the sticks were much thinner and the players hit the ball one-handed, much like a polo player on horseback. A National Roller Polo League was established in 1882, in Ohio, USA, but ceased completely in the 1920s (Pout, 1993).

The sport known today as roller hockey was first played on an organised basis in London, England, in 1896 when a small band of enthusiastic roller skaters drew up rules for playing the game, known then as Rink Hockey. Rink hockey originated with the boom in roller-skating and the sudden development of skating rinks and parlours across England. Goalkeepers wore cricket pads and outfield players wore no knee-pads, their skates had no toe stops and were secured to their shoes by leather straps. They used wooden ash hockey sticks, bound at the handle (Pout, 1993).

The Amateur Rink Hockey Association (ARHA) was formed in 1904. The rules of the game were established as the sport developed. There were always five men on each side; all matches were 15 minutes each half, and they always used a hard ball. In 1905, following the success of the First London Cup Competition, the ARHA decided to organise and run the first rink hockey league. Following the success of the London Rink Hockey League, other leagues evolved. The larger leagues were generally created in the North of England, the Northeast Lancashire Amateur Rink Hockey League comprised of 15 teams.

In 1909 the first full set of rules was issued by the ARHA. In the same year the ARHA was reorganised into three sections, the Northern Counties, the Southern Counties, and the Midland Counties Rink Hockey Associations. In this year there were 19 affiliated Rink Hockey Leagues throughout the country (Pout, 1993).

On the international scene Gallen (1991, p78) reported that in 1905, "thanks to English nationals living on the continent roller hockey was extended to other countries", in particular, Switzerland, France, Germany, and Belgium. The first ever recorded international rink hockey match was in 1910, between Ireland and England, in Dublin, which England won 7 –2 (Pout, 1993). Following this match, the first International

Tournament was held in Paris in 1910, under the English ARHA rules. Participating teams were club sides from Switzerland, Belgium, Flanders, France, England and Ireland. For the following three years this International Tournament was held in Ilford, England, all four tournaments being won by English teams (Pout, 1993).

The popularity of the sport grew, not only among players, but also among spectators. In 1910 crowds of 3000 were reported at the Burnley Coliseum rink, for a match between the Scottish Champions and the Champions of the North. Similar crowds were also reported for an international match, England against Ireland, in London, in 1911. Between 1911 and 1914 the average attendance at the Pier Pavilion Rink, Herne Bay, for a Saturday night match was 800 spectators. During a local derby between Burnley Coliseum Rink Hockey Team and the Preston Marathon Rink Hockey Team, 6000 - 7000 spectators were reported, with several hundred turned away. In 1914 the ARHA re-formed as The National Rink Hockey Association disbanding the North, South, and Midland Counties Rink Hockey Associations (Pout, 1993).

Ladies rink hockey was first played in London, around 1903. Most of the ladies' teams were formed around 1909, and friendly matches were played. However, Pout (1993) found no reports of a Ladies Rink Hockey League in this country. There were at least 14 ladies' teams in England around this period, although ladies rink hockey was not recognised by the ARHA. Ladies rink hockey faded away as quickly as it had started, partly due to a lack of recognition, but also due to the gradual closure of rinks (Pout, 1993).

In 1908 - 1912 the popularity of roller-skating peaked and rink hockey was an established sport with a large number of rink hockey players, 19 affiliated leagues, 54 affiliated clubs in the Southern Counties, 18 in the Northern Counties, and an unknown number in the Midland Counties. After 1912 the roller-skating and rink hockey craze in England tailed off and for financial reasons roller-skating rinks began to close rapidly. With the outbreak of the First World War, all rink hockey came to an end and most of the skating rinks closed (Pout, 1993).

The first meeting of the National Rink Hockey Association after the First World War took place in London, in 1919. This saw the re-establishment of what is now known as Roller Hockey (Arlott, 1975) and The National Roller Hockey Association (NRHA).

Gallen (1991) reported that the popularity of roller hockey continued to increase internationally and in 1924 in Montreux, Switzerland the International Skate Federation (FIRS) was established. The founder and President was Renkewitz, born in Newcastle, England. This federation incorporated three modalities of skating, namely figure skating, speed skating, and roller hockey. The founder countries were Switzerland, France, Germany and Great Britain, followed shortly after by Belgium and Italy. With the success of FIRS came the first European Championships in 1926 in Herne Bay, England. The success of the First European Championships was such that there was the possibility of roller hockey becoming an Olympic Sport (Gallen, 1991). England won these Championships and retained the European Championships title every year until 1939 (Matthews and Morrison, 1987).

In 1929 Portugal joined FIRS (Gallen, 1991). In 1936 in Stuttgart, Germany, the First World Championships were amalgamated with the ninth European Championships. England added the first four World Championship titles (1936, 1937, 1938, and 1939) to its impressive record in international roller hockey (Arlott, 1975).

The outbreak of the Second World War disrupted roller hockey competition again, both nationally and internationally. The Second World War claimed the lives of many of England's greatest players (Arlott, 1975). Following the war English roller hockey participation declined, whilst internationally it was a very different story. In Portugal, Spain, Switzerland and Italy, roller hockey advanced considerably (Arlott, 1975). In 1946 Spain joined FIRS (Gallen, 1991). In 1947 after the Second World War, international roller hockey re-commenced in Lisbon with the combined World and European Championships. For the first time since the start of the Championships the title was taken from England by a very young, well trained Portuguese side (Arlott, 1975). Roller hockey began to expand to countries such as Argentina, Chile, Uruguay, Brazil, Colombia, Venezuela, and Japan amongst others (Gallen, 1991). The 1950s saw a rapid increase in the popularity of roller hockey in Spain and in 1951 Spain won the

World and European Championships in Spain, in front of 13,000 spectators. The World Championships and the European Championships remained amalgamated until 1957.

In 1966 the European Cup of Clubs was created, with clubs from Germany, France and Italy, losing to a Spanish club (Gallen, 1991). In 1976 the Re-copa International competition was created and was won by Portugal. The European governing body of roller-skating is the European federation of roller-skating (CERS), with the European committee of roller hockey (CERH) responsible for roller hockey. In 1980 the CERS cup was created; this was also won by Portugal (Gallen, 1991). Portugal dominated the post-war international meetings, winning 12 World Championships (1947 - 50, 1952, 1956, 1958, 1960, 1962, 1968, 1974, and 1982) and 15 European Championships (1947 - 50, 1952, 1956, 1959, 1961, 1963, 1965, 1967, 1971, 1973, 1975, and 1987). The 1980s saw Argentina become a strong international force in roller hockey. The 1982 World Championships had 22 countries participating and roller hockey was now truly a worldwide sport (Gallen, 1991). Due to the vast difference in ability levels between the participating teams (for example, Switzerland beat India 56 - 0) there was a division of the teams into two groups according to ability; this commenced at the 1984 World Championships (Gallen, 1991).

In 1986 Italy joined the international elite in roller hockey, winning two World Championships and European Championships (1986 and 1988). Since losing the World title to Portugal in 1939, England has not won any World or European Championships (See table 1.1).

Table 1.1: Male international roller hockey results table, 1926 - 1999.

WORLD CHAMPIONSHIPS (MEN'S)		
First held in 1936.		
Wins:		
14	Portugal	1947-50, 1952, 1956, 1958, 1960, 1962, 1968, 1974, 1982, 1991, 1993
10	Spain	1951, 1954-55, 1964, 1966, 1970, 1972, 1976, 1980, 1989
4	England	1936-39
4	Argentina	1978, 1984, 1995, 1999
4	Italy	1953, 1986, 1988, 1997

EUROPEAN CHAMPIONSHIPS (MEN'S)		
Preceded the World Championships, with which it was amalgamated from 1936 to 1957.		
Wins:		
21	Portugal	1947-50, 1952, 1956, 1959, 1961, 1963, 1965, 1967, 1971, 1973, 1975, 1977, 1987, 1992, 1994, 1996, 1998
12	England	1926-32, 1934, 1936-39
8	Spain	1951, 1954-5, 1957, 1969, 1979, 1981, 1983, 1985
2	Italy	1953, 1990

In 1987 The National Roller Hockey Association of England (NRHA) had 7 affiliated regional associations (Eastern, Kent, Midlands, South, Yorkshire, Northwest, and South West). Ten years later this had been reduced to 6 affiliated regional associations (Eastern, Kent, Northern Counties, South Eastern Counties, Southern and Northern). As shown in table 1.0, the participation level of English roller hockey has fluctuated over the last 7 seasons. It is interesting to compare current participation levels with those before the First World War when participation was much higher with 19 affiliated leagues, 54 affiliated clubs in the Southern Counties, 18 in the Northern Counties, and an unknown number in the Midland Counties (Pout, 1993).

England's current ranking in international roller hockey is 13th in the World, with Argentina number 1. Currently Spain, Italy, Portugal and Argentina are the dominant countries both at National team level and at club level (Gallen, 1991).

In 1991 the First Ladies Roller Hockey European Championships were held in Geneva, Switzerland, and England finished in 4th place with Italy winning the Championship. The First Ladies Roller Hockey World Championships were held in Germany with 13 countries participating. England finished in 10th place, with Canada taking the title. A summary of the international status of Ladies roller hockey can be seen in table 1.2. The England Ladies' roller hockey team are currently ranked 9th in the world.

Table 1.2: Female international roller hockey results table, 1991 - 1998.

WORLD CHAMPIONSHIPS (LADIES)
Bi-annually, starting in 1992

Wins:

2	Spain	1994, 1996
1	Canada	1992
1	Portugal	1998

EUROPEAN CHAMPIONSHIPS (LADIES)
Biannually (alternative years to the World Championships), starting in 1991.

Wins:

2	Italy	1991, 1993
1	Spain	1995
1	Portugal	1997

Year	**Championship**	**Location**	**Winners**	**England's place**
1991	European	Switzerland	Italy	4th
1992	World	Germany	Canada	10th
1993	European	Italy	Italy	5th
1994	World	Portugal	Spain	13th
1995	European	Spain	Spain	7th
1996	World	Brazil	Spain	Didn't attend
1997	European	Portugal	Portugal	8th
1998	World	Argentina	Portugal	9th

Roller hockey was a demonstration sport in 1992 at the Barcelona Olympics. Argentina won this competition, but the fate of roller hockey as a fully-fledged Olympic sport is still uncertain. Currently roller hockey is practised in all five continents with over 50 countries affiliated to FIRS (Gallen, 1991). Since its original domination, England's international roller hockey success has diminished.

CHAPTER 2

RATIONALE

The general standard of roller hockey in England is well below that of countries such as Spain, Italy, Portugal, and Argentina, which are the dominant countries in international roller hockey (Gallen, 1991). The English national team remains in the Group B World Championship, unable to gain promotion into the ten teams of Group A. Despite the dynamic nature of the sport and the dedication of its associates, it is suggested that England's poor performance both at club level and national team level is due to a lack of support. This lack of support includes financial, participation, sponsorship, publicity, and coaching aspects. The coaching support available to English roller hockey players is lacking for two main reasons, firstly a lack of finance and facilities, and secondly a lack of experience and knowledge. This lack of knowledge may be attributed to a shortage of available coaching material. The coaching material that is available is seldom based on scientific research, and therefore coaches are often forced to base training and rehabilitation programmes on information from other sports, and common sense.

Due to the lack of financial support, roller hockey players have little 'on-rink' training time; they are therefore forced to train for roller hockey in other ways, such as running, cycling, weight training, and so on. A player may spend as much as 80% of his or her training time performing activities other than roller hockey (England Ladies Roller Hockey Squad, 1997; England Men's Roller Hockey Team, 1998). Consequently the specificity of the activities undertaken during this 'off-rink' training is crucial to the player's match performance. Due to a lack of information and research, on many occasions both coaches and players neglect the components of this 'off-rink' training. Players are often provided with muscular training programmes based on other sports or on hearsay (England Ladies Roller Hockey Squad, 1995, 1997), or they are left to train as they feel appropriate.

Therefore, the overall aim of this thesis is to investigate the muscular demands of roller hockey match play, to aid English players match performance by improving training techniques. Four discrete studies will be used to fulfill this overall aim. Firstly, in order to investigate muscular activity during roller hockey match play it is necessary to establish all the actions performed by roller hockey players in a match situation. Secondly, analysis of heart rate activity provides important information on physiological activity during roller hockey. Thirdly, having established the actions involved in match play it is then necessary to determine the muscles used to perform each of these actions and finally it is useful to monitor the activity of the muscles central to roller hockey play in a match environment. This research could then be used to aid training both on and off the rink. 'On-rink' this information will aid roller hockey specific warm ups and warm downs both for training and match play. During 'off rink' training this information may suggest the specific muscles that should be considered in the design of roller hockey specific training programmes.

The aim of the first discrete study within this thesis is to establish the characteristics of roller hockey match play. Match analysis will describe all the actions performed by roller hockey players during match play, the percentage of the match spent performing each of these actions, their frequency and mean duration, the intensity of each action, and the direction of the movement. Having established a basic understanding of roller hockey match play, roller hockey could then be compared to other sports. Additionally, such a match analysis would enable comparisons of match play activity between the first and the second half, and between winners and losers, and also between forward, attacking players and defending players. This type of information would provide a wider understanding of roller hockey and it may also aid the development and application of training techniques.

The second discrete study within this thesis has three aims, firstly to analyse physiological activity during English roller hockey match play, by analysing players' heart rates. Analysing roller hockey players' heart rates during competitive matches may provide information on the appropriate intensity of training sessions. The second aim of this study is to analyse and compare players' heart rates during competitive match play and typical roller hockey training sessions. The final aim of this study is to evaluate top English roller hockey players' performance and heart rate values during the progressive maximum shuttle skate test used by Rodriguez (1991) and Blanco *et al.* (1995), and to calculate $\dot{V}O_2$ values during this test using the equation proposed by Blanco *et al.* (1995) and compare results.

Having identified all the actions involved in roller hockey match play, and assessed the physiological activity; the aim of the third discrete study within this thesis is to determine the muscles used to perform each roller hockey action. This investigation into the kinesiological activities during roller hockey match play will be undertaken using a two-dimensional video analysis of each action. Each action will be broken down into phases, each phase will be broken down into joint movements, and the muscles responsible for each joint movement will then be theoretically established. Using the information from the match analysis on the percentage of a match spent performing each action and the knowledge gained from the kinesiological analysis of the muscles responsible for these actions, a hierarchy of muscles central to roller hockey match play will then be established.

The aim of the final discrete study within this thesis is to monitor the activity of the muscles defined as central to roller hockey match play using electromyography, during training and a match environment. Electromyography monitoring will provide information on the pattern of muscular recruitment, and the relative muscular activity levels for each muscle during roller hockey specific actions.

To summarise, this thesis aims to improve English roller hockey players' training techniques and consequently match performance, by providing information on muscular activity during roller hockey. To continue to improve performance, not only is more scientific research required, but also this research must be applied in a practical manner.

CHAPTER 3

REVIEW OF LITERATURE ON ROLLER HOCKEY AND RELATED SPORTS.

Before investigating muscular activity during roller hockey match play, it is important to investigate the scientific research that already exists in respect to this sport and other related areas.

This chapter begins with a review of the available, albeit limited, scientific research in roller hockey. Due to a general lack of specific literature in roller hockey, it is also worthwhile to analyse the research in other related sports. For example, ice hockey involves similar biomechanical and physiological demands, and similar technical and tactical skills to roller hockey. In roller speed skating, the actions performed by the roller skaters may also be used during roller hockey. 'Ice speed skating' involves movements similar to roller-skating, and finally in-line skating again involves similar movements to roller-skating and ice-skating. Therefore this chapter will also consider research within these areas. Field hockey is quite different to roller hockey in that it is played on foot, the size of the pitch is much larger, it is eleven-a-side as opposed to roller hockey's five-a-side, the sticks are shorter and wider, the ball is lighter and the goals are much larger. The biomechanical and physiological demands are different, as are the technical and tactical demands; consequently the scientific research within field hockey is considered irrelevant to most aspects of roller hockey and therefore will be omitted from the literature review.

This thesis consists of four discrete studies, match analysis, heart rate analysis, kinesiological analysis and electromyography analysis. Within this literature review research concerning these four areas is summarised, and a more detailed review is given at the beginning of each relevant chapter.

The majority of literature in roller hockey consists of historical reviews of the sport, (Hollander and Clark, 1975; Turner, 1978; Kelemen, 1980; Schulze, 1981; Matthews and Morrison, 1987; Gallen, 1991; and Pout, 1993) and descriptive reviews (Wilkinson, 1974; Arlott, 1975; Hollander and Clark, 1975; Turner, 1978; Hoffecker, 1980; Arnold, 1982; Mehlmon, 1982; Dupertuis, 1984; Herbst, 1985; Blome, 1987; Hemphill, R, 1989; Lucas, 1992; Andreson, 1993; Clark, 1993; Feineman, 1993; Greenwood, 1993; Hemphill, B, 1994; and Stewart, 1994). These reviews contain basic descriptions of roller hockey and its history, with only a few scientific findings reported. Arlott (1975) reported sprint speeds of approximately 12.5 m/s in roller hockey match play. A few studies were located concerning the strategies and techniques of individual players (Kirk and Laurinat, 1986; and Torti, 1986).

Less attention, however, has been given to scientific research. Palmi-Guerrero (1994) performed a study of group cohesion in roller hockey, and Galantini and Busso (1992) looked at the physical fitness of young roller hockey players. Aguado (1991) quantified the movements of roller hockey players during competitive matches; this report will be discussed in more detail in chapter 4.

Rodriguez (1991) was interested in the physical condition of roller hockey players, and began by citing Porta and Mori (1983) who acknowledged the importance of both anaerobic and aerobic capacity during roller hockey; however they stated that the anaerobic capacity was slightly more important during roller hockey match play. Rodriguez (1991) noted the difficulty in quantifying the total energy demand of roller hockey match play due to the continuous acceleration and deceleration. This investigation aimed to establish 'on rink' and 'off rink' tests to evaluate the physiological condition and adaptations to training, of top Spanish roller hockey players (The World Champions, The European Champions, and The Spanish Pre-Olympic team). Players' anthropometric characteristics were presented; the mean height was 175 cm, the mean mass was 71 kg and the mean body fat was 8% of total body weight. From these data it was reported that top Spanish outfield players showed average height and mass, with below average body fat and good muscular development, on average goalkeepers were shorter than outfield players. Somatotype analysis of roller hockey players showed a prevalence of mesomorphs.

Rodriguez (1991) used two 'off rink' tests, namely a maximal and progressive cycle ergometer test and a maximal and progressive treadmill test, to evaluate the physiological condition of top roller hockey players. Though it was noted that "these tests do not allow the speciality of movement (of roller-skating), we still do not know a specific ergometer which allows the valuation of an individual moving on skates" (p 55). During these tests heart rate, oxygen consumption ($\dot{V}O_2$), ventilation ($\dot{V}_E$) and power output were recorded. In the cycle ergometer test, top Spanish players had mean maximum heart rates of 188 beats/min, mean $\dot{V}O_{2max}$ of 50 ml/kg/min and mean power output of 298 W. The results of the treadmill test were 12 – 15% higher than the values reported for the cycle ergometer test, with $\dot{V}O_{2max}$ values of 58 ml/kg/min; however mean maximum heart rate values were lower (183 beats/min) than for the cycle ergometer test. The author concluded that the treadmill test was preferred over the cycle ergometer test for the evaluation of top roller hockey players.

Rodriguez (1991) also used two 'on rink' tests, the first of which was designed by Martin (1989) to simulate the physiological demands of roller hockey match play on skates. This test involved various skating, stopping, shooting and hockey movements. Blood lactate levels were analysed at 1, 3, 5, 7, 10 and 12 minutes after the test. For top roller hockey players, the time taken to complete the test decreased over a season and the maximum blood lactate concentrations increased. The second 'on rink' test was a maximal and progressive shuttle skate test, which aimed to measure power and aerobic capacity. After a warm up players skated 20-m shuttles, starting at a speed of 8 km/h and increasing 0.5 km/h every minute. The speed was regulated using a computerised audio output signal, which indicated the time to skate the 20-m shuttles. During the test heart rate was recorded every 5 seconds, and blood lactate levels were monitored before, and after the test. It was concluded from the results of the maximal and progressive shuttle skate, that this test is specific to roller hockey, as it is on skates, on the rink, and involves "acceleration on studs (toe stops), acceleration due to propulsive slip (pushing), braking and changing direction. This is characteristic of roller hockey match play" (Rodriguez, 1991, p 61).

Over a 14-month period, Rodriguez (1991) repeated the progressive maximal shuttle skate test four times with a top Spanish roller hockey team. The results showed a decrease in the mean total duration of the test and an increase in the mean maximum blood lactate levels (13 mmol/l – 16 mmol/l over two seasons). The philosophy of the progressive maximal shuttle test is the longer the duration of the test, the higher the level reached. The results of this investigation showed a progressive decrease in performance over 14 months for top Spanish roller hockey players, but the author does not comment on this result.

Rodriguez (1991) concluded that these evaluation tests "must form part of the process of physical preparation of roller hockey players. These tests can determine the direction of training, the intensity, the selection of players according to physical condition and the efficiency of specific preparation programmes" (p 61). This comment raises the question of player selection due to performance during physiological tests. This is a contentious issue within team sports because other variables may also determine good performance. Therefore it is suggested that the coach should subjectively assess the results of physiological testing alongside other performance measures.

The results obtained during this investigation for the maximum treadmill test and the maximum progressive shuttle skate test for the Spanish Pre-Olympic team were presented by Rodriguez *et al.* (1991). The aim of this second investigation was to describe and validate the maximum 'on rink' shuttle skate test for predicting $\dot{V}O_{2max}$ related to body weight, as suggested by Leger and Lambert (1982) and Leger *et al.* (1988) during running. The calculated $\dot{V}O_{2max}$ values related to body weight for the skate test did not show a very high correlation with the $\dot{V}O_{2max}$ values reported for the same subjects during the continuous maximum treadmill test ($r = 0.58$), although the correlation was statistically significant ($p = 0.01$). Rodriguez *et al.* (1991) attributed the lack of a strong correlation to the difference between running and skating movements and also the difference in the physiological demand of continuous exercise and movement with changes of direction, e.g. shuttles, which include deceleration and acceleration. The validity of using an equation designed to predict $\dot{V}O_{2max}$ values during a maximum progressive shuttle run test (as proposed by Leger and Lambert, 1982 and Leger *et al.*, 1988) to calculate $\dot{V}O_{2max}$ values during a maximum progressive shuttle skate test was not questioned. It may be that this equation is not a reliable measure for calculating $\dot{V}O_{2max}$ during the skating test. More research in this area is needed before conclusions can be drawn from the relationship between $\dot{V}O_{2max}$ values in continuous treadmill running and progressive maximum shuttle skate tests.

Martinez *et al.* (1993a) studied the morphological and physiological changes in roller hockey players during a season. Six subjects (male, top level Spanish roller hockey players) performed a maximal and progressive treadmill test, during which heart rate, blood lactate, and expired air were measured. Also recorded were the subjects' weight and anthropometric measurements to calculate body composition (bone weight, fat weight, residual weight, and muscle weight). These measurements were performed pre-season and two weeks before the end of the season. The results showed pre-season mean (S.D. ±) maximum heart rates of 194 ± 8 beats/min, mean maximum treadmill velocity of 15 ± 1 km/h, mean $\dot{V}O_{2max}$ values of 56 ± 3 ml/kg/min, and mean maximum blood lactate levels of 9 ± 1 mmol/l. The second test, at the end of the season, showed significantly higher $\dot{V}O_{2max}$ values (61 ± 5 ml/kg/min), while heart rate and blood lactate levels had decreased to a mean of 190 ± 10 beats/min and 8 ± 3 mmol/l, respectively (although this decrease was not statistically significantly). Generally the results showed an improvement in the physical condition of roller hockey players during the season. Fat percentage and fat weight decreased during the season. Heart rate and somatotype values were similar to those reported by Rodriguez (1991). It was noted that the majority of the changes observed in this investigation were due to the increase of the training during the season. In conclusion, Martinez *et al.* (1993a) "registered a global improvement of the aerobic metabolism.... this proves the importance of the aerobic training in the basic physical preparation" for roller hockey. However, the number of subjects was limited and the authors acknowledged the need to continue research in this area with more subjects.

Vazquez (1991) also investigated the characteristics of the physical condition of roller hockey players by a) assessing the difference in physical condition of forwards and defenders, b) analysing how the physical condition of roller hockey players developed over three years and c) assessing the validity of the tests used to measure roller hockey players' physical condition. The tests that were used during this investigation were the maximal progressive shuttle skate test to analyse aerobic power (the same as used by Rodriguez, 1991; Rodriguez *et al.*, 1991; and Blanco *et al.*, 1995 and Blanco *et al.*, 1996a); a two-footed standing long jump and a triple jump to measure dynamic force; a 30-second press up test to measure resistance force; and explosive force was measured by a 3 kg ball-throwing test. Speed was measured over 15 m on and off skates, while blood lactate was measured during a maximum 2-minute skate test. Anaerobic capacity was measured during a maximum 20-second skate test, and the strength of the upper extremities were measured by a 15-second press-up test. Fourteen subjects of the Spanish Pre-Olympic team performed these tests over 3 years. The results apparently showed no significant differences between forwards and defenders in any of the tests, although significance levels were not reported. The results of each test showed an improvement in the physical condition of the subjects during the three years, but this improvement was not always statistically significant. Vazquez (1991) stated that the improvement in performance during each of the tests over the three years might have been due to the number of times the players had performed each test (a learning effect). Finally, to assess the validity of the tests at measuring roller hockey players' physical condition, a correlation matrix was used. The relationship between performances in each test was analysed, but no significant relationships were found. However, a significance level of $p \leq 0.005$ was used, which led to the rejection of a number of correlations that would have been significant at $p \leq 0.05$. The use of a correlation matrix to assess the validity of each test for monitoring roller hockey players' physical condition may be questioned, and this study may have benefited from assessing the validity of each test individually and its specificity to roller hockey performance.

Blanco and his colleagues in Barcelona have undertaken the majority of physiological research in roller hockey. Blanco *et al.* (1993) analysed heart rate and blood lactate accumulation related to observations of match play during both roller hockey training and competition. The activity during the roller hockey training sessions was divided into four categories: warm up, physical preparation, technical exercises, and training matches. The competitive matches were analysed according to the frequency and duration of play, the frequency and duration of stoppages, and the number of attacks and defences (crossing the central line). Unfortunately the actual movements of the players were not categorised. The results for competitive matches (25 minutes each half) showed that a full match lasted on average 81 ± 9 minutes, with 63% actual playing time and 37% "unlawful stoppage time". Unlawful stoppage time referred to infringements of the rules causing the referee to blow the whistle; there was an average of 96 stoppages in a match, with 54% of these stoppages for fouls, and only 6% for goals. The average durations of stoppage times were between 10-20 seconds. The most common duration of playing time was 1-10 seconds. Analysis of playing time and stoppage time enabled the calculation of a 1:1.05 ratio of work to rest, indicating, "stoppage time is almost identical to the work time". This differed from that reported for ice hockey (Green, *et al.*, 1976a) where the ratio of work to rest was 1.05:1, suggesting that ice hockey is more demanding than roller hockey. The heart rate and blood lactate values recorded in this study were similar during training matches and competitive matches. Blanco *et al.* (1993) stated that this confirmed the importance of match play during training "to get used to the competition rhythm, to put into practice tactical systems in real situations and to acquire specific resistance [endurance]". It was concluded that as actual play lasted typically between 1-30 seconds, training sessions should consist of short sprints, frequent stops, and few movements from one net to the other. The results also highlighted the need for further investigations into the demands of roller hockey, "to achieve a better knowledge of the activity and to make the best of the training programmes".

In a later report Blanco *et al.* (1994) compared training and competition heart rate and blood lactate levels as indicators of the physiological stress on roller hockey players. The subjects were professional roller hockey players of the highest standard in Spain. During training the heart rate was recorded every 5 seconds and blood samples were collected from the ear lobe 30 seconds after each training exercise in eight subjects (7 field players and 1 goalkeeper). During competition, heart rates were recorded every 5 seconds and blood samples were taken during time outs, substitutions, and at the end of each half for three subjects (2 field players and 1 goalkeeper). This routine was repeated during 7 competitive matches. All training and competitive matches were recorded on videotape. The results of this study yielded mean heart rate values during tactical training exercises, attacking exercises and shooting exercises of between 100 - 170 beats/min; this implied a low to moderate level of exercise intensity. Higher levels of exercise intensity were reported during defensive exercises and training matches, with heart rate values ranging from 140 to 190 beats/min. Roller hockey training displayed a low accumulation of blood lactate, with average values between 0.85 - 2.65 mmol/l. During competitive matches the mean heart rate for field players was 158 beats/min, with a range of 110 - 190 beats/min. For 73% of a match, field players displayed heart rate values of between 150 - 180 beats/min. Results showed that throughout the match the heart rate never fell below 110 beats/min, and from this it was concluded that time outs (1-minute break in play called by either coach at any time) "do not allow a total recuperation of the cardiac system". Green *et al.* (1976a) reported mean heart rates of 174 beats/min during ice hockey and Blanco *et al.* (1994) acknowledged ice hockey as having a "higher cardiac demand than roller hockey". Blanco *et al.* (1994) also showed that skating in defence displayed significantly lower heart rate values than attacking, dribbling, and shooting. The goalkeeper's heart rate ranged between 110-170 beats/min, significantly lower than field players and for 71% of a competitive match the goalkeeper displayed a heart rate of less than 140 beats/min. The accumulation of blood lactate during competitive roller hockey matches was similar for field players and goalkeepers despite the different types of activity. Moderate blood lactate levels were recorded during competitive matches (3.64 ± 0.74 mmol/l), with values during the second half significantly higher than in the first half. Blood lactate accumulation of around 4 mmol/l indicated a greater participation of the aerobic metabolism than the anaerobic metabolism, whilst being close to the aerobic - anaerobic transition area. Ice hockey again demonstrated higher energy demands than roller hockey with blood lactate levels of up to 8 mmol/l during competition (Green *et al.*, 1976a). Blanco *et al.* (1994) concluded that roller hockey was a repeated effort sport relying on aerobic and anaerobic energy sources. Roller hockey displayed similar results to other indoor team sports played in similar dimensions, such as basketball, volleyball, and handball.

In a third study Blanco *et al.* (1995 and 1996a) analysed the changes in $\dot{V}_E$, $\dot{V}O_2$, energy cost, blood lactate accumulation, heart rate, and performance time, of roller hockey players during a maximal and progressive shuttle skate test. The aim of this study was to establish an equation to calculate oxygen uptake during this test, when a portable gas analyser is not available. This investigation was similar in many respects to that of Rodriguez (1991), aiming to validate a sports specific 'on rink' $\dot{V}O_{2max}$ test, to examine the physical condition of roller hockey players. Fifteen subjects, male amateur roller hockey players (of the highest standard in Spain), completed a similar maximal and progressive shuttle skate test. A portable telemetric analyser (Cosmed K2) was used to record $\dot{V}_E$ and $\dot{V}O_2$ directly every 15 seconds and heart rate was recorded every 5 seconds. Blood samples (n=6) were taken from the ear lobe 1, 3, and 5 minutes after the test. Both $\dot{V}_E$ and heart rate increased progressively with the rise in pace, reaching a maximum of 124.9 (±22.8) l/min and 197.7 (±7) beats/min, respectively. As $\dot{V}_E$ increased so did the standard deviation, showing a higher individual variability; but as heart rate increased the standard deviation decreased showing less individual variability. Oxygen consumption reached maximum value of 50.5 (±4.4) ml/kg/min (mean for all subjects), increasing progressively during the first part of the test, but demonstrating a plateau towards the end. The oxygen costs displayed a similar pattern reaching a maximum of 3.5 (±0.3) ml/kg/min. Blood lactate reached a peak value of 9.2 (±1) mmol/l. A regression equation was proposed using the data obtained in this study to calculate oxygen consumption during this test:

$$\dot{V}O_2 \text{ (ml/kg/min)} = [1.326 * \text{Number of level}] + [0.167 * \text{HR level maximum}] + 0.767$$

The $\dot{V}O_2$ requirements of this skating test were compared to those reported by Leger (1981) and Leger *et al.* (1984) during running at each speed. This comparison showed that roller-skating displayed $\dot{V}O_2$ values that were 10 ml/kg/min lower than running. The values achieved during the skate test were also lower than those obtained by the same players during treadmill running tests. Blanco *et al.* (1995 and 1996a) suggested that these lower $\dot{V}O_2$ values might be because "the K2 tends to overestimate its values at high intensities" (Blanco *et al.*, 1995; p 25). It was concluded that the strain of the test was indeed maximal, as demonstrated by high heart rate values (198 beats/min) and blood lactic acid values of 9.2 mmol/l, but fatigue of the active muscles and the cleanness of the skate-floor interface may affect the peak values reached. The data also indicated that when a portable gas analyser was not available, the shuttle skate test enabled reliable calculation of oxygen consumption using the proposed regression equation. This test was regarded as easy to apply and very specific for roller hockey players. Further consideration of this work occurs in chapter 5 of this thesis.

In another study Blanco *et al.* (1996b) compared the energy cost to roller hockey players, of skating with and without the ball. Twelve subjects, male amateur roller hockey players, performed three 5-minute skates at sub-maximal speeds of 11, 13, and 15 km/h. This was repeated while dribbling a roller hockey ball. Heart rate was recorded, $\dot{V}O_2$ and $\dot{V}_E$ were measured using a telemetric oxygen analysis system (Cosmed K2), and perceived exertion was measured using the Borg scale (Borg, 1970). The energy cost, $\dot{V}_E$ and heart rate increased linearly as the speed increased and all variables were greater whilst dribbling the ball. The increased energy costs of dribbling the ball were attributed to postural factors (position of spinal flexion) and to the skills themselves requiring the activation of more muscle groups. It was concluded that dribbling significantly increased the energy cost, the physiological demands and the perceived exertion of roller-skating. Accordingly, Blanco *et al.* (1996b) noted that the physiological cost of roller hockey might be underestimated if the strain of hockey skills and the body posture are not considered.

The recent increase in popularity of in-line roller-skating has raised the question of the suitability of in-line roller skates for roller hockey. Conventional roller skates (two parallel wheels on a front axle and two on a rear axle) have always been worn by roller hockey players (Blanco *et al.*, 1997a). In a fifth report by Blanco *et al.* (1997a and b), the effects of skating using conventional roller skates and in-line roller skates on heart rate, $\dot{V}O_2$ and $\dot{V}_E$ were compared at varying speeds. Seven experienced male roller hockey players skated for 3 minutes around a rectangle (20 x 10 m) at 13, 15, and 17 km/h, wearing either in-line roller skates or conventional roller skates. After a 30-minute rest this procedure was repeated wearing the other type of skate. The speed was controlled by a computerised audio output signal. Heart rate was recorded every 15 seconds and a portable gas analyser (Cosmed K2) was used to measure $\dot{V}O_2$, and $\dot{V}_E$, every 15 seconds.

The results showed a significant increase in $\dot{V}O_2$ with both types of skates as speed increased. In both conditions heart rate and $\dot{V}_E$ also increased as speed increased, but there was not a significant increase at every speed. During the highest intensity (17 km/h) all variables displayed lower values than expected, suggesting that 17 km/h was not a maximum speed for roller hockey players. Blanco *et al.* (1997a, p100) stated that the test should be repeated at higher speeds, "up to 28kn/h as this is often reached during roller hockey matches". When comparing the two types of skates, in-line skating was associated with higher levels of $\dot{V}O_2$, $\dot{V}_E$, and heart rate, but significant differences ($p < 0.05$) only existed between $\dot{V}O_2$ at 13 km/h, and heart rate at 15 km/h and 17km/h. It was therefore concluded that the physiological demand of in-line skating was similar to conventional roller-skating, probably due to "the similarity of the technical gesture used with both types of skates, the same muscle groups are involved, a similar body posture, with only small mechanical and technical differences. These differences are most probably the result of the players not being used to in-line skates". Blanco *et al.* (1997a) acknowledged the need to use subjects experienced with both types of roller skates in such an experimental study. The specificity of the tests used in this study may be questioned; skating in a rectangular movement is an exercise that occurs infrequently (if ever) during roller hockey match play. This study was indeed a valuable initial investigation into the difference in the physiological cost to roller hockey players of skating using conventional roller skates and in-line roller skates; however, due to the nature of the tests used the results are of limited value to roller hockey match play. Future research in this area may benefit from using more roller hockey specific tests such as the maximum and progressive shuttle skate test.

Having considered the limited research available in roller hockey, it is essential to assess the research in other related areas. Ice hockey has the greatest similarity to roller hockey, not only from a biomechanical and physiological viewpoint, but also because both sports involve similar techniques and tactics. There are, however, differences between the two sports. Ice hockey is played on ice therefore there is less friction than between roller skate wheels and the floor. Ice hockey is a full contact sport whereas roller hockey is non-contact. Also ice hockey players use a larger amount of protective clothing compared to roller hockey players; they also use a longer stick, a puck instead of a ball, and they play for three 20-minute periods rather than two halves. The physiological demands of ice hockey have been described as, "metabolically unique... The sport demands not only intense glycolytic activity related to bursts of intense muscular activity, but also exceptional aerobic power and endurance.... Besides well - developed aerobic and anaerobic energy pathways, the nature of the game also requires a large, lean body mass and exceptional muscular strength" (Cox *et al.* 1995, p185).

Seliger *et al.* (1972) characterised ice hockey as "an activity showing mostly a sub-maximal metabolic rate with a great participation of anaerobic metabolism (69%), but simultaneously with high requirements for aerobic metabolism (31%)". Green (1979) stated that due to the constantly changing demands of an ice hockey match, the degree to which the anaerobic processes dominated was intimately dependant on the intensity and duration of the activity, and recovery time.

A number of authors have researched physical fitness in ice hockey. Watson and Sargeant (1986) used two tests on-ice to measure the anaerobic power and capacity of ice hockey players. Seliger *et al.* (1972) examined the energy expenditure in ice hockey players during a 'model' training match. The results of this investigation demonstrated that the anaerobic energy system represented approximately two thirds of the total energy expenditure, with a mean heart rate of 152 beats/min during actual play in the 'model' training match.

Seliger (1972) estimated the total energy expenditure during an ice hockey match as 820 kJ (ranging from 450 – 1170 kJ) based on actual playing time of 18 minutes. Green (1987) reported a total energy expenditure of between 880 - 1200 kJ, based on a playing time of between 21 - 28 minutes. However, Green (1987) acknowledged (as did Blanco *et al.* 1996b in roller hockey), that this might be a gross underestimation, as it was based on velocity and time, ignoring any complex hockey or skating activities.

Marino and Weese (1979) analysed skating during ice hockey and concluded that the speed at which the players skate is very important and may influence success in certain situations. During maximum speed skating tests mean horizontal velocity of 8.8 m/s was reported with a mean stride rate of 3.5 strides per second and mean stride length of 2.48 m for ice hockey players. Green *et al.* (1976a) demonstrated an overall average skating velocity of 3.8 m/s, during ice hockey match play. Greer (1990) reported that increased skating velocity in ice hockey match play is associated with a larger angle of propulsion between the blade and the direction of motion, more forward lean, and a greater stride length. It is also positively correlated with stride rate and negatively correlated with single support and double support times, meaning that in a match situation a player makes more strides with less gliding, which emphasises the importance of physical fitness.

The hockey skills involved in ice hockey are similar to those in roller hockey despite the fact that the sticks are different and a puck is used instead of a ball. The research identified on ice hockey skills mainly involves shooting (Alexander *et al.*, 1963; Dore and Roy, 1976; Roy and Dore, 1976) and these studies are reviewed in more detail in chapter 6.

Roller-skating has received little scientific attention. The roller-skating stride is similar to the ice-skating stride and is a function of double and single support, with propulsion occurring during the double support phase (Wilson *et al.*, 1987). During the propulsive phase the extension leg is rotated at the hip and extended perpendicularly to the direction of motion. The leg is then lifted before full extension and abducted for the start of the double support phase. Single support ranges from 35 - 47% and double support ranges from 2 - 13% of the total support phase. The speed of pushing is determined by propulsive effects, stride length, stride frequency, rolling friction, and air drag (Wilson *et al.*, 1987). Despite a relationship between speed, maximum knee flexion, and maximum knee extension angles in 'ice speed skating' (Van Ingen Schenau and Bakker, 1980; Van Ingen Schenau *et al.*, 1983; Van Ingen Schenau *et al.*, 1989; Greer, 1990; De Koning *et al.*, 1991b), no such relationship was observed in roller-skating (Wilson *et al.*, 1987). Instead higher speeds in roller-skating were associated with a smaller trunk angle (mean trunk angle 40° to the horizontal), a greater gliding distance (single support phase), maximum elbow extension, and a high straight trail arm.

With the aim of establishing a single laboratory test to assess the physical fitness, and training prescriptions, for roller skaters, Martinez *et al.* (1993b) compared the physiological responses during roller-skating, treadmill running, and ergometer cycling. Blood lactate levels were significantly lower during running, but similar for cycling and skating. Heart rate levels were significantly higher during running and similar during cycling and skating. The heart rate - blood lactate relationship observed during cycling and skating in this study supported similar observations by Daub *et al.* (1983), De Boer *et al.* (1987b), De Groot *et al.* (1987) and Van Ingen Schenau *et al.* (1983). From this finding it was concluded that the data collected from a discontinuous graded cycle ergometer test was appropriate in the prescription of the training intensities for roller skaters.

The biomechanical and physiological similarities between roller-skating and ice-skating are contentious, with a number of investigators comparing these skating modalities. De Boer *et al.* (1987b) compared the local adaptations in the muscle cells during roller-skating and ice-skating and found similar adaptations during both skating exercises. They also reported peak power output for roller-skating of 2000 W, compared to 2500 W for 'ice speed skating'. Roller-skating displayed a 5.5% increase in oxygen consumption compared to 'ice speed skating', a 4.5% increase in the minimum knee angle, a 4.5% decrease in the maximum knee angle, 20.4% decrease in angular velocity of the knee, and 15.1% decrease in angular acceleration of the knee. The increase in oxygen consumption during roller-skating was attributed to higher pre-extension knee angles. Despite these differences it was concluded that roller-skating imitates the mechanical characteristics of 'ice speed skating'. Giorgi (1998), however, stated that caution should be used when comparing roller-skating and ice-skating, and suggested that it is not possible to transfer models between the two skating modalities as "roller skaters move against resistance due both to air and to the friction of their skate wheels" (p 109).

Foster and Thompson (1990) reported that just maintaining the position adopted by roller speed skaters caused a rise in blood lactate levels to 5 -7 mmol/l. As speed increased blood lactate accumulated in a curvilinear pattern. The blood lactate curve for roller-skating displayed many of the same characteristics as speed skating on ice. They also reported maximum roller-skating speed to be approximately 82% of ice-skating speed during a 4 - 5 minute skate. Wilson *et al.* (1987) reported average speeds of 7.2 - 9.4 m/s for international female roller speed skaters and 7.0 - 9.7 m/s for international male roller speed skaters.

The similarities between roller-skating and ice-skating may be contentious, but the majority of the literature reviewed suggests that these skating modalities are comparable in some aspects. Consequently, it is considered valuable to summarise the research that exists in 'ice speed skating'. 'Ice speed skating' has accrued the largest amount of scientific attention of all the skating sports. As already mentioned roller hockey players, ice hockey players, and roller skaters perform a similar skating action as ice speed skaters, but in a less advanced state.

It is generally recognised in the literature, that speed during ice-skating is determined by a number of factors; a) a smaller pre-extension knee angle, mainly caused by a more horizontal upper leg position; b) a considerably greater amount of work per stroke and slightly higher stroke frequency; c) higher knee extension velocity; d) smaller decreases in successive lap times; e) a brief, but powerful push-off; and f) a more horizontally directed push-off. Van Ingen Schenau *et al.* (1989) suggested that these factors might then be used to predict performance.

A large majority of literature in 'ice speed skating' focuses on either the biomechanical or the physiological demands of the sport. Biomechanical researchers have analysed angular displacement, angular velocity, and angular acceleration of the body, in a bid to improve performance (Marino, 1977; Van Ingen Schenau and Bakker, 1980; Van Ingen Schenau *et al.*, 1983; Van Ingen Schenau *et al.*, 1985; De Boer *et al.*, 1986; Delnoij *et al.*, 1987; Van Ingen Schenau *et al.*, 1989; De Koning *et al.*, 1991(a); De Koning *et al.*, 1991(b); Rajala *et al.*, 1994). Kinematic analyses of 'ice speed skating' revealed that the skating action is unusual for a number of reasons. In most forms of locomotion the required propelling force is more or less in the same direction as the desired direction of movement. In 'ice speed skating' and roller-skating the centre of gravity is displaced perpendicular to the gliding direction of the push-off skate, following a course similar to a sine wave (Van Ingen Schenau *et al.* 1989). Novice ice skaters often try to push off in a similar manner to walking or running with a linear hip, knee, and plantar flexion (Van Ingen Schenau and Bakker, 1980).

The majority of physiological research in 'ice speed skating' focuses on the energy demands in a bid to improve performance (Marino, 1977; Van Ingen Schenau and Bakker, 1980; Van Ingen Schenau *et al.*, 1983; Van Ingen Schenau *et al.*, 1985; De Boer *et al.*, 1986; De Groot *et al.*, 1987; Delnoij *et al.*, 1987; Van Ingen Schenau *et al.*, 1989; Greer, 1990; Van Ingen Schenau *et al.*, 1990; De Koning *et al.*, 1991(a); De Koning *et al.*, 1991(b)). Van Ingen Schenau and Bakker (1980) developed a mathematical model to describe the speed skating technique in mechanical terms. Delnoij *et al.* (1987) questioned the validity of some of these models of power output and work, due to the velocity being measured in a straight line and not accounting for the sideways displacement of the centre of gravity. Delnoij *et al.* (1987) stated that this may lead to 2% underestimation of power output when calculated with a straight line trajectory.

The final skating activity worthy of review in this chapter is in-line skating. The popularity of in-line skating has increased dramatically in recent years, creating a new area of research. In-line skating involves a similar skating action to roller-skating and ice-skating. Hoffman *et al.* (1992), Snyder *et al.* (1993), Wallick *et al.* (1995) and Melanson *et al.* (1996) compared the physiological demands of in-line skating to other forms of exercise such as running, cycling, and roller skiing. Melanson *et al.* (1996) and Snyder *et al.* (1993) found $\dot{V}O_2$ was significantly lower during in-line skating than running. Wallick *et al.* (1995) also found $\dot{V}O_{2max}$ and heart rate were lower during maximal progressive discontinuous in-line skating compared to maximal progressive discontinuous treadmill running.

Having reviewed all the scientific research within roller hockey and related areas, it is evident that there is a general lack of research regarding muscular activity. Nevertheless, some studies have been identified in ice hockey (Alexander *et al.*, 1963; Gauthier *et al.*, 1979; and Reed *et al.*, 1979) and in 'ice speed skating' (De Groot *et al.*, 1987; Greer, 1990; De Koning *et al.*, 1991a; and De Koning *et al.*, 1991b). These studies will be reviewed in greater depth in chapter 7.

In summary, the scientific literature dealing with biomechanical and muscle activity in roller hockey is limited. This thesis consists of four discrete studies, match analysis, heart rate analysis, kinesiological analysis and electromyography analysis. The literature relevant to each of these areas will be discussed in more depth in the respective chapters.

Match analysis has been used to assess the match play activity of many sports. The value of match analysis has changed in recent years. Olsen and Larsen (1995) reported that ten years ago match analysis was considered with suspicion in soccer, but today the majority of coaches in the English soccer Premier League use match analysis in one way or another. Match analysis has emerged as both a reliable and objective measure of the 'effectiveness' of an individual or team. Match analysis can prove a most useful diagnostic aid to both coach and player (Andrews, 1985).

Many different match analysis techniques have been used including manual notation, computer aided notation, video recording, live analysis and so on. Blanco *et al.* (1993 and 1994) analysed match play activity during roller hockey and Aguado (1991) quantified the movements of roller hockey players during match play. Green *et al.* (1976a), Montgomery and Vartzbedian (1979) and Lafontaine *et al.* (1998) conducted match analyses of ice hockey. Aguado (1991) in roller hockey, Ali and Farrally (1991) in soccer, Docherty *et al.* (1988) in rugby union, Green *et al.* (1976a) in ice hockey, Lafontaine *et al.* (1998) also in ice hockey, Lothian and Farrally (1994) in field hockey, and Treadwell (1988) in Rugby Union, investigated the influence of player position on match play activity. Saltin (1973) in soccer and Lothian and Farrally (1994) in field hockey, reported differences in the match play activity between the first and second halves. This literature will be discussed in more detail in chapter 4.

The second discrete study in this thesis is an analysis of roller hockey players' heart rate. Heart rate has been used to assess the physiological demands of many sports, it provides reliable, valuable and easy to measure information on the demands of activity. Blanco *et al.* (1993) and (1994) compared heart rate levels during Spanish elite level roller hockey training and competition. This literature will be reviewed in more detail in chapter 5.

The third area of research in this thesis is a kinesiological analysis to investigate muscular activity during actions specific to roller hockey. No research has been identified in this area in roller hockey. In ice hockey, Alexander *et al.* (1962), Alexander *et al.* (1963), Dore and Roy (1976), Roy and Dore (1976), and Yabe (1976) assessed the kinesiological and biomechanical demands of shooting. Research has also been identified on the kinesiological and biomechanical demands of 'ice speed skating' (Marino, 1977; Song, 1979; De Boer *et al.*, 1986; Rajala, 1994). This literature will be discussed in more detail in chapter 6.

In the fourth and final study within this thesis electromyography (EMG) is used to assess the activity of the muscles identified during the kinesiology analysis as central to roller hockey performance. No research in this area has been identified within roller hockey, ice hockey, roller-skating, or in-line skating. Muscular activity in 'ice speed skating' has been assessed using EMG to establish electrical activity and muscle co-ordination patterns (De Boer *et al.* 1987a; De Koning *et al.*, 1991a; and De Koning *et al.*, 1991b). A review of the EMG system and the relevant scientific research within this area is presented in chapter 7.

CHAPTER 4

ANALYSIS OF ROLLER HOCKEY MATCH PLAY

INTRODUCTION AND REVIEW OF LITERATURE

In order to perform a detailed analysis of muscular activity during roller hockey, it is essential to gain a full understanding of the demands of competitive match play. This information may then form a base upon which further research can reflect. This chapter begins by introducing match analysis and the various techniques used to assess match play in different sports. Three studies analysing roller hockey match play have been located and are discussed. Following this a number of studies analysing ice hockey match play are reviewed. Finally research has revealed factors (such as the position played) that may influence the characteristics of match play, these are discussed.

When watching sport everyone makes an analysis of the match, and each analysis may be different. A coach needs to be able to make objective observations of match play, as an aid to improving future performance. The accuracy with which the coach observes events in a match may be influenced by a number of factors such as the coach's state of arousal, the perceived seriousness of competition, the nature of the observational medium (video tape or live event) and the focus of attention and priming for anticipated events (Franks and Goodman, 1986a). The importance of match analysis in helping the coach make objective observations has already been discussed and match analysis is now a vital tool used universally to assess match play activity in many different sports.

Match analysis techniques have been used to gain time and motion data in many sports: soccer (Reilly and Thomas, 1976; Mayhew and Wenger, 1985; Treadwell, 1988; Ali and Farrally, 1991), Rugby Union (Docherty *et al.*, 1988; Treadwell, 1988), field hockey (Andrews, 1985; Franks and Goodman, 1986b; Macheath, 1987; Lothian and Farrally, 1994), ice hockey (Green *et al.*, 1976a; Green *et al.*, 1976b; Montgomery and Vartzbedian, 1979; Lafontaine *et al.*, 1998;), squash (Hughes, 1995), netball (Borrie *et al.* 1995) and roller hockey (Aguado, 1991; Blanco *et al.*, 1993; Blanco *et al.* 1994).

Many different techniques have been used to analyse matches, but no definitive system has been successfully or universally designed and used for match analysis. Green *et al.* (1976), Montgomery and Vartzbedian (1979), Andrews (1985), and Lafontaine *et al.* (1998) used manual notation to record the events of matches. Mayhew and Wenger (1985), Franks and Goodman (1986b), Docherty *et al.* (1988), Treadwell (1988), Aguado (1991), Ali and Farrally (1991), Blanco *et al.* (1993) Blanco *et al.* (1994), Lothian and Farrally (1994), Borrie *et al.* (1995), Hughes (1995) and Lafontaine *et al.* (1998) used match analysis computer software packages. Andrew (1985), Mayhew and Wenger (1985), Docherty *et al.* (1988), Treadwell (1988), Ali and Farrally (1991), Blanco *et al.* (1993) and Blanco *et al.* (1994), Hughes (1995) and Lothian and Farrally (1994) video recorded matches and subsequently analyse them, whilst others (Green *et al.*, 1976a; and Reilly and Thomas, 1976; and Montgomery and Vartzbedian, 1979) analysed live matches. Due to these different research techniques caution should be applied when comparing match analysis literature.

Three studies have been located in roller hockey that analyse match play characteristics, Aguado (1991) and Blanco *et al.* (1993 and 1994). Aguado (1991) aimed to quantify the movements of roller hockey players during two top international roller hockey matches (Spain against Germany and Spain against Italy). One stationary video camera with a static field of view was used to record the two matches. Analysis of match play activity was divided into the two halves of the match. When the player being tracked was substituted "the new player is now followed in the same way because the study tries to compare position of the game and not players between themselves", (p 72). For each match the distance skated in metres, the speed, the average duration of the movements and stoppages, and the number of accelerations for each player were entered into a computer. Distances and speed were established using a digitiser. The results showed that roller hockey players in top international matches skated an average of 16 km, in short movements averaging 10 m. The majority of the distance was covered at low to medium speeds (2 – 6 m/s). Due to the small number of matches analysed in this study, further research is required to substantiate these results.

Blanco *et al.* (1993 and 1994) analysed heart rate activity and blood lactate levels during competitive roller hockey matches, as previously reviewed. The time and motion activity of the players during these competitive matches were also monitored and reported. For each team, analysis consisted of the duration of actual play, the duration of stoppages, and the number of attacking and defending plays (defined as crossing the central line). The competitive matches were 25 minutes each half 'stop-clock'. Blanco *et al.* (1993 and 1994) reported average match durations of 81 minutes (S.D. 9 minutes), with 63% actual play and 37% "unlawful stoppage time" (p 37).

There was an average of 96 stoppages in a match. Average heart rate levels were 158 beats/min, with a range of 110 – 190 beats/min, and blood lactate levels were on average 3.6 mmol/l (S.D. 0.7 mmol/l) during competitive match play.

Ice hockey is technically and tactically similar to roller hockey. Green *et al.* (1976a), and Montgomery and Vartzbedian (1979) analysed ice hockey match play in an attempt to define the associated physiological stresses placed on the players. Green *et al.* (1976a) divided the activity in an ice hockey match into continuous play, stoppage time and recovery periods between shifts. Results showed that during the three 20-minute periods actual playing time averaged 25 minutes, with average heart rates of between 170 and 174 beats/min for all the playing positions. Values for blood lactates were highest during the first and second periods, and then declined considerably during the third period. Blood glucose showed a similar tendency.

During ice hockey match play Montgomery and Vartzbedian (1979) studied the heart rates of forward players in three conditions: a) on the bench, b) on the ice during stoppage of play, c) during playing time. Their results showed that actual playing time averaged 29% of the total game time (65 minutes and 12 seconds) which is considerably lower than the 63% Blanco *et al.* (1993 and 1994) reported during roller hockey match play. Montgomery and Vartzbedian (1979) reported a mean heart rate of 161 beats/min during ice hockey. Details of the type of movements being performed, and the duration and intensity of these movements were not reported.

Match analysis may also provide additional information on match play by investigating factors that influence players' activity during a match. For example, Aguado (1991) suggested that match analysis should consider the different demands placed on players of different positions, "top competition requires a high speciality of the players. Each position during the game has, in principle, different physical requirements and therefore requires different training" (p 71). The study by Aguado (1991) previously mentioned also aimed to assess differences in the time and motion activity between roller hockey forwards and defenders. They found that defenders consistently skated further than forward players during top international roller hockey match play. In soccer, Reilly and Thomas (1976) found a significant positional effect for the distance covered between centre-backs, full-backs, mid-fielders and strikers. They also noted that full-backs performed a significantly smaller number of sprints than mid-fielders and strikers, while mid-fielders and strikers covered a significantly greater distance during sprinting than full-backs and centre-backs. Also in soccer, Ali and Farrally (1991) reported a significant positional effect for the time spent in various match play activities among attackers, defenders, and midfielders. Treadwell (1988) and Docherty *et al.* (1988) also reported a positional effect in rugby. For women's field hockey, Lothian and Farrally (1994) reported only one positional effect; midfielders were involved in significantly more changes in activity ($p < 0.05$) than either defenders or strikers. Green *et al.* (1976a) reported differences in the time and motion activity between forwards and defensemen in ice hockey, with defensemen playing for longer periods than forwards (+21.2%), due to a greater number of shifts (+26.1%), and a much shorter recovery period (-37.1%). However, for defensemen each shift was shorter in duration (-7.4%), shorter in continuous play time (-10.1%), and longer in the time taken to resume play (+12.9%). Green *et al.* (1976a) also reported a large difference in the average velocity of each shift, with defensemen only obtaining 61.6% of the velocity values obtained by forwards. Differences in the heart rate data for forwards and defensemen were also reported in this study with defensemen displaying heart rates of 10–15 beats/min lower than forwards, during a shift.

In a later study on ice hockey match play, Lafontaine *et al.* (1998) aimed to determine the frequency of skating skills between players of different positions and different playing levels. The authors stated that establishing the frequency at which ice hockey players perform certain skating skills during match play may be useful in the development of training, technique, strategy and skate design. Two Canadian men's ice hockey teams were analysed over ten matches, using 6 cameras tracking individual players. When the player being tracked was substituted the camera followed the replacement. The teams were of two different standards, one a junior team and the other a university team. The results showed no significant difference in the frequency of skating skills between the two levels of players, in fact the results showed a high correlation between the two datasets. There was only one significant positional effect; defensemen showed an increase in backward skating. This result was expected due to the defenders' priority of keeping the play in front of them, hence skating backwards. Playing condition (attacking, defending, power plays, possession of the puck and so on) had the greatest effect on the frequency of skating skills. Despite the minor positional effect that was reported in this study, Lafontaine *et al.* (1998) concluded that due to the varying skating demands, forwards and defenders should be trained differently. Based on the evidence presented, this conclusion may be questioned. Also this study did not analyse the duration of the skating skills; Lafontaine *et al.* (1998) acknowledged the need for future research to incorporate this variable. This study also excluded the influence of hockey skills, which may have led to an underestimation of the demands of match play.

The effect of various playing levels on the time and motion activity of match play has also been investigated in Rugby Union. Agar (report by the Rugby Football Union, 1978 - 1979, cited in Docherty *et al.*, 1988) found considerable differences in match play activities for players of different standards. However, Docherty *et al.* (1988) found no significant differences in the match play activity of players of different standards in Rugby Union.

Investigations in some sports have also reported significant differences in players' activity between the first half and the second half. For example, Reilly and Thomas (1976) and Saltin (1973) both reported significantly greater distances were covered in the first half of soccer matches when compared with the second half. Ali and Farrally (1991), and Lothian and Farrally (1994), found a significant decrease in the time spent at high intensity activity in the second half, in soccer and women's field hockey, respectively. Finally, another factor that may influence the time and motion variables of a match is the score. However, Lothian and Farrally (1994) reported that the score had no effect on the match play activity in women's field hockey.

Research on muscular activity during roller hockey needs to be based on a comprehensive knowledge of the time and motion activity of roller hockey players during competitive match play. Therefore the aim of the first discrete study within this thesis is to establish the characteristics of roller hockey match play, and to analyse the effect of playing position, match half, and match score on these characteristics.

METHODS

The focus of this study was the English Roller Hockey Premier League, 1996/7 season. Two Premier League matches (with a combined score of 11:8) were recorded using three Sony 9100P video camcorders with fixed visual fields and full audio recording systems. These stationary camcorders were located on one side of the pitch, in an elevated spectator gallery, 2.7 m above the rink and 1 m from the side of the rink. The positioning of the camcorders (one in the left half of the rink, one in the middle and one in the right half of the rink) enabled all parts of the entire pitch to be filmed simultaneously. Written agreement to the filming of the matches was obtained from all the players and officials.

During these two matches, all the players excluding the goalkeepers were analysed, giving a total of 16 subjects. All subjects were male, free from injury, and were regular members of the teams. Due to the large amount of data obtained from each player (an average of 1004.7 actions), it was felt sufficient to analyse the collective data from just two roller hockey matches, and draw conclusions from these.

Data Analysis.

Using a three-screen editing desk and three video players, the two matches were analysed field by field, by an international roller hockey player (J. Kingman). The three video recordings were synchronised using the whistle at the start of each half. Each player was tracked across the three cameras during the entire match (including stoppage time). The actions of the player were recorded manually every field (0.04 s) in code form. If the analyser was unsure of any movement, the videotape was rewound and observed as many times as necessary to obtain accurate data. The coded data were then entered into Microsoft Excel for statistical analysis. To analyse the effect of player position, match half and score on the time and motion characteristic of match play, multiple one-way analysis of variance tests were performed on the data.

Due to rolling substitutions, players were categorised by position, for example if the player being tracked was substituted and replaced, analysis would continue on the replacement player (methodology cited in Aguado, 1991 in roller hockey and

Lafontaine *et al.*, 1998 in ice hockey). This was done to standardise the time on the pitch and permit comparisons between positions. Players' *positions* were recorded as either forwards or defenders, depending on the position they occupied for the majority of that half. All the teams analysed defended in a box formation or a diamond formation making identification of position reasonably easy (see figure 4.0).

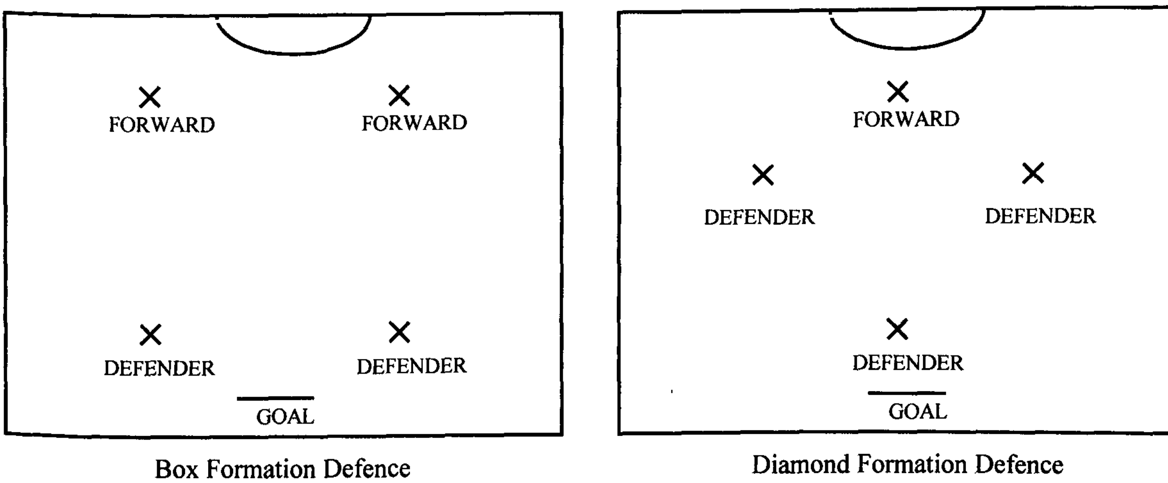


Figure 4.0: Defensive formations in roller hockey.

To analyse the effect of the *score* on match play activity, players were classed as either winners or losers of that half (there were no draws). To analyse the effect of the *half* on players' activity, the data were divided into first and second halves.

Preliminary analysis of the matches enabled the identification of all the actions performed by a roller hockey player in a match situation. These actions were divided into two categories, skating activities and hockey activities. *Skating activities* consisted of rolling, pushing, sprinting, slide stopping, falling and stationary. *Hockey activities* may be performed in unison with skating activities and consisted of tackling, passing, receiving a pass, collecting lose ball, dribbling, travelling with the ball and shooting.

Rolling is an eight-wheel glide, forwards or backwards, and includes cruising. Cruising was defined by Marino (1977) in ice hockey, as one or two forward utility strides with minimal effort, used to maintain speed or to adjust position on the rink with almost no forward lean. In roller hockey, cruising includes the gentle application of the toe stops when going backwards.

Pushing defines both a forward and backward propulsive movement. Marino and Wease (1979) described pushing in ice hockey, as bi-phasic, with each stride consisting of alternate periods of single support (the gliding/recovery period) and double support (the propulsive period).

Sprinting is defined as running on the skates, pushing off the toe stops.

Slide stopping is an action adopted by roller hockey players to stop in a fast and effective manner, whilst being ready to sprint in another direction. The action itself is similar to a 'snow plough' stop in skiing, and can be performed on the left (with left side forward), and the right (with right side forward).

Falling has a duration which is from the start of the fall until the player returns to a standing position ready to resume play.

Stationary involves no skating movement.

Tackling incorporates, tackling another player or being tackled; this often includes body contact, lunging for the ball, and blocking the ball or a player with the body.

Passing the ball may be performed whilst stationary and whilst skating.

Receiving a pass again may be performed whilst stationary and whilst skating, it also includes intercepting the ball.

Collecting loose ball is defined as an unchallenged, low intensity retrieval of the ball.

Dribbling the ball is a deliberate, challenging movement of the ball in order to maintain possession.

Travelling with the ball is classed as a passive rolling whilst in possession of the ball.

Shooting consists of two standard roller hockey shots:

The flick shot is similar to the wrist shot in ice hockey. The ball is positioned behind the back leg and remains in contact with the stick through the shot. Momentum is gained by dragging the ball forwards. This shot may be performed on the forehand or the backhand and whilst the player is stationary or skating.

The slap shot is the same as the ice hockey slap shot or snap shot. It involves a back-swing, fore-swing, contact and follow-through phase. Momentum is imparted to the ball from the sudden impact of the stick. This shot is also performed on the forehand or the backhand and whilst the player is stationary or skating.

A number of variables were recorded for each action: the *duration* (recorded to hundredths of a second, using the time code on the video recordings); the *intensity* (rated individually for each action, as either high intensity or low intensity; this was a subjective measure determined by the analyser, based on experience and perceived exertion); and finally the *direction* (divided into four categories, forwards, backwards, stationary, and forwards + backwards; this last category refers to individual actions such as tackling that consist of both forwards and backwards movement).

To test the reliability of the data collection, the analysis of a random 10-min segment of one match was repeated. The results were compared with the original values producing a significant correlation ($r = 0.91$, $p = 0.008$). Duration was the only parameter that differed between the two sets of results, but the differences were small (hundredth of a second).

RESULTS

The results are divided into two sections. The first section is concerned with the overall activity of players during match play. The second section is concerned with the effect of the player's position, the score and the match half on match play activity.

Section 1: Analysis of roller hockey match play

The duration of the Premier League 'stop-clock' roller hockey matches analysed in this study was 25 minutes each way. Due to the clock stopping the average match time was 61 minutes 26 seconds; hence the mean stoppage time was 11 minutes and 26 seconds (19%). The mean number of individual actions performed by each player in a roller hockey match was 1004.7, and the mean duration of each of these actions was 3.7 seconds.

The time and motion analysis for the skating actions of all positions is presented in Table 4.0. All positions refer to the left and right forward players and the left and right defending players, for 2 teams over 2 matches giving a sample size of 16. The most frequent skating activity with the longest mean duration was rolling, which accounted for 71% of match time. Sprinting occurred for only 4% of match play. The overall mean duration for a skating activity was 3.1 s. Standard errors are presented for frequency and total time, but mean duration and percentage of match time were calculated using frequency and total time; therefore standard errors are not presented for these variables.

Table 4.0: Analysis of skating activity for all positions (n=16)

ACTIVITY CATEGORY	MEAN, ±S.E. FREQUENCY	MEAN, ±S.E. TOTAL TIME (S)	MEAN DURATION (S)	MEAN % OF MATCH TIME
ROLLING	345.88 ±10.89	2625.00 ±55.98	7.59	71.22
PUSHING	221.38 ±6.04	526.38 ±16.67	2.38	14.28
SPRINTING	95.50 ±8.01	147.60 ±10.15	1.55	4.00
SLIDE STOP RIGHT	57.94 ±3.70	70.63 ±4.26	1.22	1.92
SLIDE STOP LEFT	37.00 ±3.35	52.72 ±5.76	1.42	1.43
STATIONARY	13.44 ±1.08	47.21 ±4.73	3.51	1.28
FALLING	4.69 ±0.53	18.75 ±2.39	4.00	0.51
ALL SKATING ACTIVITY	**775.83**	**3488.29**	**3.10**	**94.64**

The time and motion analysis for hockey actions (excluding shooting) is shown in table 4.1. The most frequent hockey activities were travelling with the ball, and tackling, equivalent to 4.4% and 4.3% of match time, respectively. Table 4.1 indicates that for all positions the mean total time spent performing hockey-related activities (excluding shooting) was 12.8% of the match, and the mean duration for a hockey activity excluding shooting was 1.34 seconds.

Table 4.1: Analysis of hockey activity (excluding shooting) for all positions (n=16).

ACTIVITY CATEGORY	MEAN FREQUENCY ±S.E.	MEAN TOTAL TIME (S) ±S.E.	MEAN DURATION (S)	MEAN % MATCH TIME
TRAVELLING WITH BALL	87.81 ±6.85	160.69 ±10.17	1.83	4.36
TACKLING	96.57 ±2.4	158.28 ±7.28	1.64	4.29
PASSING	68.19 ±3.21	71.49 ±8.72	1.05	1.94
RECEIVING A PASS	66.38 ±3.23	48.20 ±2.77	0.73	1.31
COLLECTING LOOSE BALL	20.06 ±0.86	20.92 ±1.57	1.04	0.57
DRIBBLING	6.63 ±0.92	11.74 ±1.67	1.77	0.32
ALL HOCKEY ACTIVITY EXCLUDING SHOOTING	**345.64**	**471.32**	**1.34**	**12.79**

Table 4.2 indicates the total time spent shooting in a roller hockey match and the total number of shots performed. The most common shot was the forehand flick shot (with a mean frequency of 91 in a match), and the forehand slap shot was the longest shot to execute (mean duration of 1.18s). The overall percentage of the match spent shooting was 0.4%, this gives a total of 13.2% of the match spent performing hockey actions.

Table 4.2: Analysis of shooting activity for all positions (n=16).

SHOTS	TOTAL NUMBER OF SHOTS IN MATCH	TOTAL TIME SPENT SHOOTING IN MATCH (S)	MEAN DURATION OF A SHOT (S)	PERCENTAGE OF MATCH SPENT SHOOTING
FOREHAND SLAP SHOT	86	101.68	1.18	0.17
FOREHAND FLICK SHOT	91	79.60	0.87	0.13
BACKHAND SLAP SHOT	47	41.36	0.88	0.07
BACKHAND FLICK SHOT	21	17.34	0.83	0.03
TOTAL SHOOTING	**245**	**239.98**	**0.94**	**0.40**

The percentage of match time spent performing all the skating and hockey activities during a match is displayed in figure 4.1.

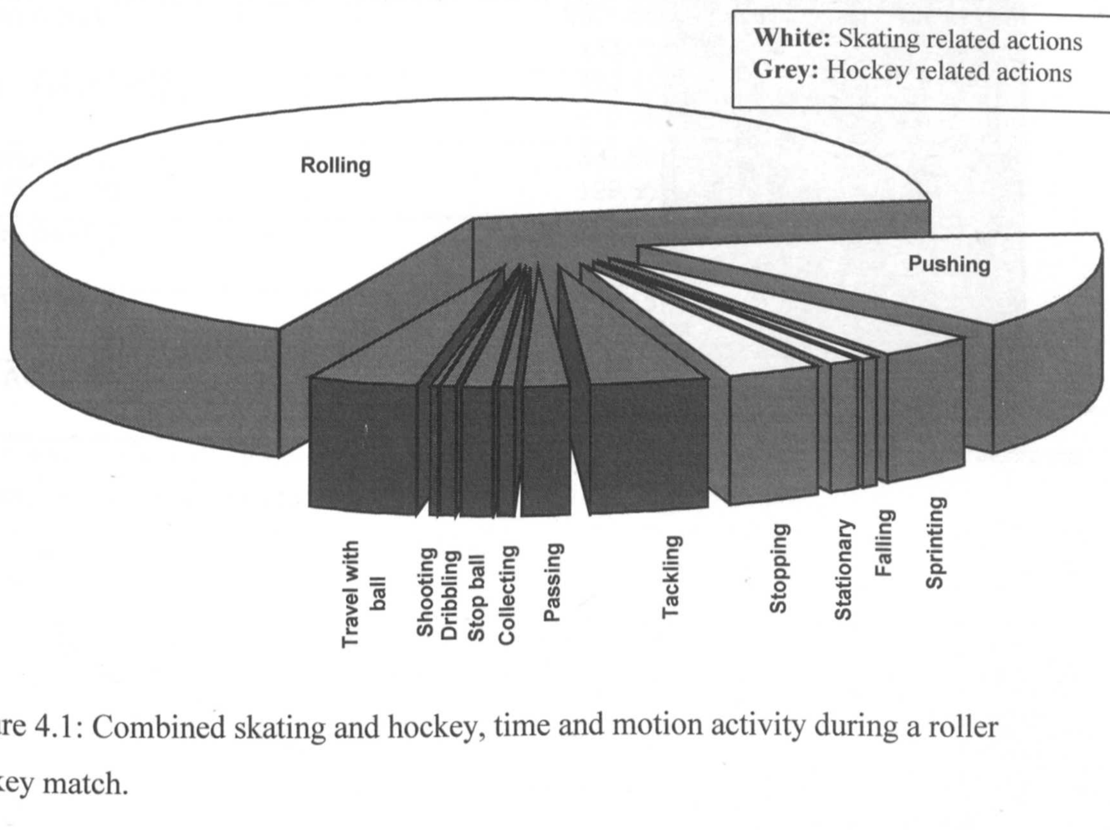


Figure 4.1: Combined skating and hockey, time and motion activity during a roller hockey match.

Table 4.3 shows the results for the intensity analysis, with 22% of the match classed as high intensity and 77% as low intensity activity. The mean total time spent performing high intensity activities, ranged from 3 min 12 s to 14 min 26 s, while much longer times were spent performing low intensity activity (15 min 34 s to 39 min 31 s).

Table 4.3: Analysis of the intensity of match play activity for all positions (n=16).

INTENSITY	MEAN, ±S.E. TOTAL TIME (S)	MEAN, ±S.E. DURATION (S)	MEAN % OF MATCH TIME
LOW	2822.00 ±71.68	7.15 ±0.54	76.56
HIGH	829.00 ±35.43	1.49 ±0.12	22.49
ALL ACTIVITIES	**3686**	**4.32**	**99.05**

Table 4.4 and figure 4.2 show that 70% of the skating motion during a roller hockey match was in a forwards direction, whereas backwards motion accounted for only 7% of the match.

Table 4.4: Analysis of the direction of motion for all positions (n=16)

DIRECTION	MEAN, ±S.E. TOTAL TIME (S)	MEAN % OF MATCH TIME
FORWARDS	2575.68 ±33.73	69.88
OTHER ACTIVITIES	434.42 ±19.28	11.79
FORWARDS AND BACKWARDS	367.68 ±29.66	9.98
BACKWARDS	264.07 ±14.46	7.16
STATIONARY	44.15 ±5.88	1.20
ALL ACTIVITIES	**3686.00**	**100.00**

Note: Other Activities, included actions where no direction was determined i.e. passing, receiving the ball, falling and slide stopping, these were obtained by subtraction.

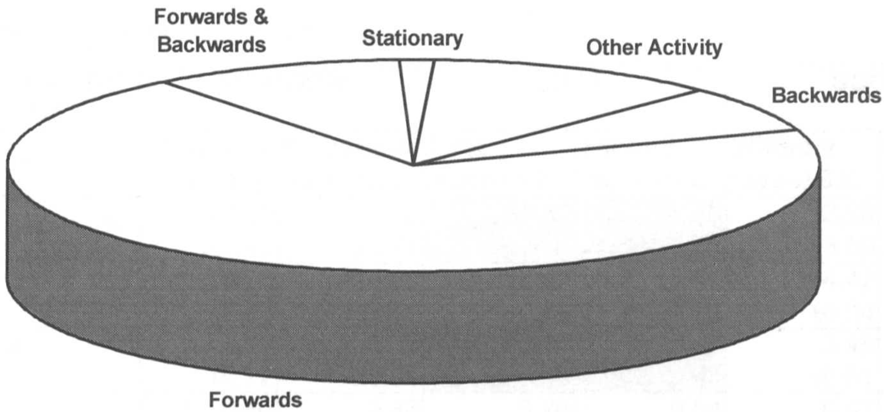


Figure 4.2: Percentage of time spent travelling in each direction.

Section 2: The effect of position, half, and score on roller hockey match play

The results presented in section 1 of this study were used to analyse the effect of three factors; position, half, and score on the type of actions performed in a roller hockey match (tables 4.5a, 4.5b, and 4.5c).

The results of the study are presented principally in terms of the percentage of a half spent performing each activity, as this was considered to give the most valuable representation of the time and motion characteristics of match play. The percentage of a match spent performing each activity was calculated from the frequency and the mean duration of the activity; nevertheless the frequency and the mean duration provide additional information on match performance and consequently are also presented. To preserve the integrity of the data, all tabular data were derived from the raw data sets.

Table 4.5a: The effect of position, half, and score on the percentage of time in each half spent performing roller hockey actions.

ROLLER HOCKEY ACTIONS	POSITION		HALF		SCORE	
	Forwards mean±S.E	Defenders mean±S.E.	First mean±S.E	Second mean±S.E	Winners mean±S.E	Losers mean±S.E
ROLLING	68.89 ±1.89	73.62 ±3.71	66.82 ±2.86	75.40 ±3.21	72.88 ±3.59	69.33 ±1.88
PUSHING	14.76 ±0.69	13.50 ±1.21	14.87 ±0.79	13.47 ±0.86	14.42 ±0.94	13.92 ±0.98
SPRINTING	4.35 ±0.72	3.38 ±0.54	5.18 ±0.65	2.62 ±0.43	3.45 ±0.51	4.34 ±0.77
FALLING	0.46 ±0.13	0.33 ±0.12	0.26 ±0.13	0.54 ±0.13	0.47 ±0.14	0.33 ±0.11
STATIONARY	1.25 ±0.30	1.09 ±0.26	1.40 ±0.28	0.95 ±0.23	1.08 ±0.24	1.27 ±0.33
SLIDE STOP RIGHT	2.09 ±0.21	1.49 ±0.26	2.06 ±0.24	1.56 ±0.22	1.81 ±0.23	1.81 ±0.26
SLIDE STOP LEFT	1.05 ±0.19	1.63 ±0.43	1.58 ±0.32	1.06 ±0.31	1.20 ±0.29	1.44 ±0.35
TACKLING	4.46 ±0.39	4.10 ±0.41	4.01 ±0.39	4.57 ±0.40	4.55 ±0.37	4.04 ±0.42
PASSING	1.63 ±0.32	2.29 ±0.61	2.17 ±0.44	1.71 ±0.50	1.91 ±0.49	1.97 ±0.41
COLLECTING LOOSE BALL	0.61 ±0.11	0.51 ±0.05	0.66 ±0.05	0.48 ±0.11	0.63 ±0.11	0.51 ±0.06
RECEIVING A PASS	1.34 ±0.15	1.27 ±0.15	1.35 ±0.15	1.27 ±0.15	1.43 ±0.13	1.19 ±0.16
DRIBBLING	0.47 ±0.10	0.15 ±0.04	0.32 ±0.11	0.31 ±0.07	0.25 ±0.06	0.39 ±0.11
SHOT - FOREHAND FLICK	0.19 ±0.04	0.21 ±0.05	0.16 ±0.04	0.16 ±0.03	0.16 ±0.03	0.16 ±0.04
SHOT - BACKHAND FLICK	0.06 ±0.01	0.12 ±0.11	0.09 ±0.05	0.05 ±0.02	0.12 ±0.05	0.03 ±0.01
SHOT - FOREHAND SLAP	0.18 ±0.04	0.28 ±0.07	0.24 ±0.05	0.22 ±0.06	0.30 ±0.07	0.17 ±0.04
SHOT - BACKHAND SLAP	0.12 ±0.04	0.12 ±0.03	0.16 ±0.05	0.09 ±0.02	0.07 ±0.02	0.16 ±0.04
TRAVELLING WITH BALL	4.83 ±0.47	3.83 ±0.63	3.93 ±0.48	4.78 ±0.63	4.10 ±0.61	4.62 ±0.50

Note: Shading represents significant differences, where $p \leq 0.05$.

Table 4.5b: The effect of position, half, and score on the frequency of roller hockey actions performed in each half.

ROLLER HOCKEY ACTIONS	POSITION		HALF		SCORE	
	Forwards Mean ±S.E	Defenders Mean ±S.E	First Mean ±S.E	Second Mean ±S.E	Winners Mean ±S.E	Losers Mean ±S.E
ROLLING	183.35 ±10.61	161.13 ±11.47	185.88 ±11.20	160.00 ±40.56	175.81 ±9.34	170.06 ±13.07
PUSHING	116.53 ±3.45	104.07 ±8.24	115.50 ±6.15	105.88 ±5.92	116.50 ±6.65	104.88 ±5.41
SPRINTING	53.35 ±10.58	41.40 ±8.07	64.06 ±9.55	31.44 ±6.09	41.56 ±6.89	53.94 ±11.67
FALLING	2.53 ±0.56	2.13 ±0.50	1.44 ±0.53	3.25 ±0.54	3.19 ±0.60	1.50 ±0.35
STATIONARY	6.35 ±1.15	7.13 ±1.40	8.13 ±1.25	5.31 ±0.88	5.75 ±0.88	7.59 ±1.53
SLIDE STOP RIGHT	35.29 ±3.43	21.80 ±3.49	33.38 ±3.81	24.56 ±3.59	31.19 ±3.71	26.75 ±3.94
SLIDE STOP LEFT	16.06 ±3.07	21.27 ±4.62	23.31 ±3.83	13.69 ±2.79	16.75 ±3.67	20.25 ±4.05
TACKLING	52.76 ±1.79	43.20 ±2.42	46.69 ±2.19	49.88 ±2.58	50.81 ±2.35	45.75 ±2.33
PASSING	34.47 ±3.00	33.67 ±3.59	36.81 ±3.09	31.38 ±3.32	36.81 ±2.89	31.38 ±3.50
COLLECTING LOOSE BALL	10.47 ±1.00	9.53 ±0.83	11.56 ±0.80	8.50 ±0.91	9.85 ±1.03	10.31 ±0.84
RECEIVING A PASS	35.53 ±2.95	30.53 ±3.41	32.38 ±3.29	34.00 ±3.16	35.88 ±2.51	30.50 ±3.69
DRIBBLING	4.24 ±1.06	2.27 ±0.59	2.94 ±0.65	3.69 ±1.13	3.75 ±1.16	2.88 ±0.56
SHOT - FOREHAND FLICK	4.00 ±0.44	2.58 ±0.51	2.85 ±0.37	3.86 ±0.57	3.40 ±0.51	3.33 ±0.50
SHOT - BACKHAND FLICK	1.67 ±0.20	1.00 ±0	1.67 ±0.33	1.57 ±0.20	1.75 ±0.25	1.56 ±0.24
SHOT - FOREHAND SLAP	2.83 ±0.69	3.56 ±1.03	4.18 ±0.99	2.86 ±0.70	5.00 ±1.36	2.91 ±0.76
SHOT - BACKHAND SLAP	2.93 ±0.44	2.67 ±0.61	2.56 ±0.58	3.09 ±0.44	2.71 ±0.64	2.92 ±0.43
TRAVELLING WITH BALL	45.47 ±5.25	42.13 ±8.51	41.06 ±5.90	46.75 ±7.68	39.25 ±5.23	48.56 ±8.04

Note: Shading represents significant differences, where $p \leq 0.05$.

Table 4.5c: The effect of position, half, and score on the mean duration (in seconds) of roller hockey activities in each half.

ROLLERHOCKEY ACTIONS	POSITION		HALF		SCORE	
	Forwards Mean ±S.E	Defenders Mean ±S.E	First Mean ±S.E	Second Mean ±S.E	Winners Mean ±S.E	Losers Mean ±S.E
ROLLING	7.24 ±0.39	9.27 ±1.04	7.06 ±0.78	9.33 ±0.87	7.92 ±0.53	8.47 ±0.11
PUSHING	2.36 ±0.12	2.42 ±0.12	2.41 ±0.12	1.37 ±0.11	2.34 ±0.14	2.44 ±0.11
SPRINTING	1.71 ±0.13	1.66 ±0.15	1.71 ±0.14	1.66 ±0.11	1.69 ±0.16	1.68 ±0.11
FALLING	2.79 ±0.76	1.91 ±0.51	2.03 ±0.66	2.73 ±0.37	1.93 ±0.32	2.83 ±0.88
STATIONARY	3.29 ±0.36	2.62 ±0.54	3.14 ±0.45	2.80 ±0.35	3.18 ±0.50	2.76 ±0.40
SLIDE STOP RIGHT	1.10 ±0.04	1.56 ±0.43	1.16 ±0.29	1.47 ±0.40	1.12 ±0.11	1.51 ±0.39
SLIDE STOP LEFT	1.34 ±0.22	1.74 ±0.57	1.53 ±0.41	1.53 ±0.42	1.57 ±0.41	1.49 ±0.42
TACKLING	1.55 ±1.07	1.75 ±0.17	1.56 ±0.11	1.72 ±0.16	1.68 ±0.15	1.60 ±0.13
PASSING	0.83 ±0.13	1.29 ±0.33	1.11 ±0.22	0.99 ±0.27	1.01 ±0.28	1.08 ±0.21
COLLECTING LOOSE BALL	1.24 ±0.36	1.06 ±0.12	1.09 ±0.08	1.22 ±0.39	1.39 ±0.38	0.92 ±0.11
RECEIVING A PASS	0.68 ±0.06	0.80 ±0.08	0.80 ±0.07	0.67 ±0.07	0.75 ±0.06	0.72 ±0.08
DRIBBLING	2.08 ±0.28	0.93 ±0.20	1.59 ±0.32	1.49 ±0.26	1.03 ±0.20	2.05 ±0.31
SHOT - FOREHAND FLICK	0.93 ±0.15	0.96 ±0.14	1.00 ±0.18	0.89 ±0.10	0.86 ±0.09	1.04 ±0.19
SHOT - BACKHAND FLICK	0.58 ±0.10	0.18 ±0.10	0.53 ±0.14	0.49 ±0.13	0.60 ±0.17	0.46 ±0.11
SHOT - FOREHAND SLAP	1.28 ±0.26	1.24 ±0.25	1.31 ±0.30	1.22 ±0.22	1.44 ±0.29	1.10 ±0.22
SHOT - BACKHAND SLAP	0.93 ±0.13	1.06 ±0.16	1.15 ±0.15	0.77 ±0.10	0.78 ±0.12	1.08 ±0.13
TRAVELLING WITH BALL	2.04 ±0.10	2.54 ±0.71	1.87 ±0.09	2.68 ±0.65	1.89 ±0.10	2.66 ±0.65

Note: Shading represents significant differences, where $p \leq 0.05$.

The effects of position, half and score on the intensity of activity in a match were also analysed (tables 4.6a, and 4.6b)

Table 4.6a: The effect of position, half, and score on the percentage of time in each half spent performing high and low intensity activities.

INTENSITY	POSITION		HALF		SCORE	
	Forwards mean±S.E	Defenders mean±S.E.	First mean±S.E	Second mean±S.E	Winners mean±S.E	Losers mean±S.E
HIGH	24.67 ±3.07	20.38 ±2.22	24.37 ±2.12	20.36 ±1.71	20.60 ±1.37	24.13 ±2.38
LOW	74.53 ±8.91	82.53 ±2.22	74.90 ±2.14	82.84 ±3.19	78.34 ±1.49	79.40 ±3.92

Note: Shading represents significant differences, where $p \leq 0.05$.

Table 4.6b: The effect of position, half, and score on the mean duration (in seconds) of high and low intensity activities in each half.

INTENSITY	POSITION		HALF		SCORE	
	Forwards mean±S.E	Defenders mean±S.E	First mean±.S.E	Second mean±S.E	Winners mean±S.E	Losers mean±S.E
HIGH	1.57 ±0.14	1.44 ±0.09	1.58 ±0.15	1.40 ±0.05	1.40 ±0.09	1.58 ±0.13
LOW	6.52 ±0.34	7.77 ±0.85	5.99 ±0.37	8.31 ±0.68	6.93 ±0.40	7.38 ±0.80

Note: Shading represents significant differences, where $p \leq 0.05$.

Finally the effect of position, half and score on the direction of movement was investigated (table 4.7).

Table 4.7: The effect of position, half, and score effect on the percentage of each half spent travelling in different directions.

DIRECTION	POSITION		HALF		SCORE	
	Forwards mean±S.E	Defenders mean±S.E	First mean±S.E	Second mean±S.E	Winners mean±S.E	Losers mean±S.E
FORWARDS	70.93 ±1.96	68.68 ±4.63	72.01 ±1.38	67.74 ±2.20	66.17 ±4.49	64.97 ±2.29
BACKWARDS	6.31 ±0.50	8.13 ±1.10	7.79 ±0.79	6.54 ±0.77	7.29 ±0.90	6.36 ±0.77
STATIONARY	1.21 ±0.37	1.18 ±0.28	1.51 ±0.40	0.89 ±0.20	0.92 ±0.23	1.41 ±0.40
FORWARDS + BACKWARDS	8.50 ±1.06	11.65 ±2.24	7.53 ±0.97	12.42 ±2.06	10.27 ±1.35	9.19 ±1.90

Note: Shading represents significant differences, where $p \leq 0.05$.

This study is the first of its kind on English roller hockey therefore analysis of the data in tables 4.5a to 4.7 focused on statistical differences within the position played, the match half and the match score; rather than analysing statistical differences across these three variables. Statistical analysis using multiple one-way analysis of variance tests, revealed that the position played, the match half and the match score, influenced the time and motion of roller hockey match play in various ways. Whilst it is acknowledged that these variables may interact, it is hoped that future research may go on to study these interactions using three-way analysis of variance tests.

Positional Effect

The effect of a roller hockey player's position on the actions performed in match play is shown in table's 4.5a, 4.5b, and 4.5c. Forwards performed a significantly higher percentage of dribbling (table 4.5a, $F_{(1, 30)} = 8.01$, $p = 0.008$) in a match, with significantly longer mean durations (table 4.5c, $F_{(1, 30)} = 10.64$, $p = 0.003$). Table 4.5b shows forwards made a significantly higher frequency of tackles, forehand flick shots, backhand flick shots, and slide stops right ($F_{(1, 30)} = 10.4$, $p = 0.003$, $F_{(1, 30)} = 4.5$, $p = 0.042$, $F_{(1, 30)} = 9.86$, $p = 0.004$, and $F_{(1, 30)} = 7.56$, $p = 0.01$, respectively), but table 4.5a shows that none of these resulted in an increase in the percentage of time spent performing these specific actions. Table 4.5c shows forwards displayed a significantly longer mean duration for backhand flick shots ($F_{(1, 30)} = 7.94$, $p = 0.009$). Table 4.6a, 4.6b and 4.7 show that a roller hockey player's position had no effect on the intensity of activity or the direction of movement in a match.

Half Effect

The difference in match play activity between the first and the second half is shown in table 4.5a, 4.5b, and 4.5c. Table 4.5a shows a significantly higher percentage of sprinting in the first half ($F_{(1, 30)} = 10.79$, $p = 0.003$) and rolling in the second half ($F_{(1, 30)} = 3.98$, $p = 0.055$). Sprinting occurred significantly more frequently in the first half (table 4.5b, $F_{(1, 30)} = 8.29$, $p = 0.007$). In the first half table 4.5b shows significantly higher frequencies in the first half of collecting loose balls ($F_{(1, 30)} = 6.38$, $p = 0.017$) and slide stopping left ($F_{(1, 30)} = 4.21$, $p = 0.051$), and higher frequencies of falling in the second half ($F_{(1, 30)} = 5.92$, $p = 0.023$), however this had no effect on the overall percentage of time spent performing each specific action (table 4.5a). Table 4.5c shows significantly longer mean durations for backhand slap shots ($F_{(1, 30)} = 4.44$, $p = 0.044$), and pushing ($F_{(1, 30)} = 40.82$, $p = 0.00001$) in the first half, but again these results had no effect on the overall percentage of match time spent performing backhand slap shots and pushing (table 4.5a). The difference in the intensity of activity between the first and the second half is shown in table 4.6a, and 4.6b. Table 4.6a shows a significantly higher percentage of the second half was spent at low intensity ($F_{(1, 30)}$ = 4.27, p = 0.048), and low intensity activities displayed significantly longer mean durations in the second half (table 4.6b, $F_{(1, 30)}$ = 8.98, p = 0.005). The difference in the direction of movement between the first and the second half is shown in table 4.7. A significantly greater percentage of the second half was spent travelling forwards + backwards ($F_{(1, 30)}$ = 4.61, p = 0.04).

Score Effect

The effect of score on the time and motion characteristics of match play is shown in table 4.5a, 4.5b, and 4.5c, the only significant difference between winners and losers occurred in shooting, where losers spent a significantly greater percentage of match play performing backhand slap shots ($F_{(1, 30)}$ = 4.05, p = 0.053). Table 4.5b shows a higher frequency of falls by winners ($F_{(1, 30)}$ = 5.92, p = 0.021), and table 4.5c shows losers had a significantly higher mean duration for dribbling ($F_{(1, 30)}$ = 7.64, p = 0.01). Both intensity and direction showed no significant score effects (tables 4.6a, 4.6b, and 4.7).

DISCUSSION

In accordance with the original aims, this study established the characteristics of roller hockey match play and analysed the effect of playing position, match half, and match score on the match play characteristics. Firstly considering the overall activity during competitive roller hockey match play, the results showed that roller hockey is a fast, dynamic sport, involving many different skating and hockey movements performed in quick succession. The results also demonstrated that rolling was the most common skating activity (71% of match time), followed by pushing (14% of match time), and sprinting (4% of match time) (table 4.0). Further analysis of the video recordings revealed that sprinting lasted typically for only 4 or 5 strides, before the player went into pushing or rolling.

During roller hockey match play, travelling with the ball and tackling were the most frequently performed hockey actions (see table 4.1). Blanco *et al.* (1996b) reported that dribbling and passing were the most frequent skills in Spanish roller hockey. The findings of this current investigation showed that dribbling occurred infrequently and accounted for only 0.3% of match time and passing accounted for 1.94% of match time. These discrepancies between results for English and Spanish matches may be explained because travelling with the ball and dribbling were defined in this current investigation as two separate movements (one passive and one challenging, respectively). Blanco *et al.* (1996b) may not have separated these categories, but the report does not make this clear. In the current study an amalgamation of these two categories (travelling with the ball and dribbling) would make this the most frequent hockey action, in accordance with Blanco *et al.* (1996b). The results of the current investigation also showed a low frequency of dribbling and higher frequencies of passing and stopping. This combination may indicate a certain style of play, more team orientated than individual, with more passing. Blanco *et al.* (1996b) stated that dribbling was as frequent as passing, which may suggest that the Spanish style of play is different to the English, a more individual game, and hence higher frequencies of dribbling.

The most common shot was the forehand flick shot (table 4.2). The quickest shot was the backhand flick shot, and the shot with the longest duration was the forehand slap shot. This was an interesting result as anecdotal evidence from English roller hockey training sessions would suggest that the most practised shot is probably the forehand slap shot (J. Kingman, personal observation). This shot is probably the fastest through the air and the most powerful shot, but the results of this study showed that it took the longest time to set up (table 4.2), therefore making it the easiest shot to intercept. Perhaps more training time should be devoted to the shots that are executed more quickly.

High intensity activity consisted of sprinting, pushing, falling, slide stopping, tackling, passing, dribbling, receiving a pass, and shooting, while low intensity activities were rolling, pushing, falling, stationary, tackling, passing, collecting loose ball, receiving a pass, and travelling with the ball. The ratio of high intensity to low intensity activity was 22:77 (table 4.3). Docherty *et al.* (1988) reported that 15% of a Rugby Union match was spent at high intensity and 85% at low intensity. In soccer, Mayhew and Wenger (1985) reported 12% of match play was spent in activities that were primarily anaerobic in nature (high intensity) and 88% primarily aerobic (low intensity). In women's field hockey, Lothian and Farrally (1994) reported similar findings to the current investigation with regard to intensity, 17.5 to 29.2% spent at low intensities and 71.8 to 83.6%, spent at high intensities. Despite the similarities between the intensity of play for roller hockey and field hockey, differences still exist between the physical demands. A field hockey player spent only 3.6% of the match in contact with the ball (Lothian and Farrally 1994), while in this study players spent 13% of roller hockey match play in contact with the ball. In this current investigation the intensity of each action was determined individually, whereas Lothian and Farrally (1994) pre-determined the intensity of the actions observed in field hockey, and described jogging, cruising, sprinting, and hockey related activity (dribbling, passing, stopping, tackling), as high intensity activities.

The identification of ball contact time provides the coach with valuable information regarding players' match play activity. Blanco *et al.* (1996b) reported that skating with the ball during roller hockey placed additional physiological demands on the body, compared to skating without the ball. On the other hand Ali and Farrally (1991) stated that the movements with the ball in soccer were sufficiently similar to those without the ball to make the 'ball effect' an insignificant part of the players' movements during the game. Reilly and Thomas (1976), Lothian and Farrally (1994) and Docherty *et al.* (1988) made no differentiation between the actions on the ball and instead classed all ball play activities together in one category.

This current investigation indicated that a player spent an average of 13% of a roller hockey match in contact with the ball. Treadwell (1988) reported that soccer players and Rugby Union three-quarter players spent an average of 1.5% and 1.9% of a match in contact with the ball. Reilly and Thomas (1976) reported an average of 1.7% of the distance covered during a soccer match was in possession of the ball.

The current study found that during roller hockey match play a relatively low percentage of time was spent stationary (table 4.2; 1.3% of match time) in comparison with Docherty *et al.* (1988) who reported 38% of a Rugby Union match was spent standing, and Ali and Farrally (1991) who reported 7% of a soccer match was spent stationary. These differences are probably due to the fact that roller hockey players are on wheels that roll with little assistance. Consequently a higher percentage of match play was spent rolling. The proportion of match play spent travelling forwards (70%) and backwards (7%) gives an indication of the levels of replication necessary in a training environment.

In a practical context the results of the first section of the analysis highlight the importance of quick and precise ball contact (mean duration 1.2 seconds), and the relative importance of training techniques in passing, and stopping the ball, over dribbling training. Additionally players may benefit from practising the quicker shots to execute, rather than the forehand slap shot that displayed the longest execution time.

This chapter will now move on to discuss the effect of position, half and score on the match play characteristics of roller hockey players. In roller hockey the similarity of the demands placed on forwards and defenders is contentious. In the results of this investigation the position a player occupied for a match only affected the percentage of time spent dribbling, and dribbling accounted for only 0.3% of a match. The intensity and the direction of movement were unaffected by playing position. Aguado (1991) advocated the need for a specialisation of skills in top-level roller hockey; however the findings of Aguado's (1991) study showed few differences in the time and motion activities between positions. Vazquez (1991) assessed the physical condition of roller hockey forwards and defenders using two on-rink tests (game simulation and the maximal and progressive shuttle skate test) and found no significant differences between the two playing positions. The findings of the current investigation generally support the similarities between the demands placed on forwards and defenders, leading to the recommendation that all players should be trained together, in all aspects of roller hockey, including fitness.

The results of this investigation also demonstrated that match score had a negligible effect on the time and motion activity during competitive roller hockey match play. Lothian and Farrally (1994) also reported no score effect in women's field hockey. There may be a number of explanations for this result in the current investigation. It may be possible, that players were unaware of the score, or that roller hockey at this level is a very tactical game with many set plays, which are dictated by the coach, or finally that the teams analysed in this investigation were evenly matched (however neither match resulted in a draw). Therefore in order to substantiate this result, further research into the effect of score on roller hockey players' match play characteristics needs to be undertaken with a greater sample of matches than the current investigation.

In comparison with the effect of position and score on match play characteristics, the greatest difference in players' activity was between the first and the second half. Match half displayed a significant effect on the percentage of a match spent rolling and sprinting; these two actions combined accounted for a mean of 75% of a match. Anecdotal evidence would suggest that sprinting is the most intense activity in roller hockey match play. The results of this study showed a significantly smaller percentage of sprinting in the second half and a significant increase in rolling, which suggests that fatigue may be occurring. This idea is supported by an increase in low intensity activity in the second half. These findings stress the importance of stamina since a reduction in sprinting in the second half and an increase in rolling opens the play to exploitation by fitter opposition.

Research in soccer and women's field hockey reported similar findings, with a significant increase in the time spent in low intensity activity during the second half (Ali and Farrally, 1991; and Lothian and Farrally, 1994 respectively). Reilly and Thomas

(1976) attributed a decrease in the distance covered in the second half to the existence of a 'fatigue' effect. They also suggested that the usual reduction of the uncertainty of the result as the match progresses effects a change in work-rate.

The possibility of a fatigue effect during the second half in roller hockey may have implications for training. It is suggested that the training of skills should be conducted around fitness training, encouraging the players to perform high intensity activities when they are already tired, in order to simulate the fatigue of the second half. Skating ability should also be monitored when players are fatigued to minimise the frequency of falling.

Analysis of all the movements, of all the players, in a match produces a large amount of data (as found in this investigation), leading some investigators to narrow their population by concentrating on individual players or positions (Montgomery and Vartzbedian, 1979; Mayhew and Wenger, 1985; Docherty *et al.,* 1988). In ice hockey Lafontaine (1998) analysed only skating skills, excluding the influence of hockey skills. In soccer, Ali and Farrally (1991) concentrated on specific movements, and Andrews (1985) in field hockey, only analysed activity in certain parts of the pitch. Narrowing the field of analysis means choosing an aspect of play to analyse, and this invariably means missing crucial match play activity. Narrowing the field of analysis also presents the problem of selecting the critical parameters to analyse. Match analysis is an effective means of gathering quantitative data, but only if it provides an unbiased collection of all match play activity.

This current investigation is the first of its kind in England, and should be viewed as a preliminary analysis into the activities of Premier League roller hockey match play. In order to carry out a thorough investigation of all the parameters involved in roller hockey match play, it was decided to limit the number of matches analysed, due to the large amount of data acquired from any match analysis.

The limitations of this investigation must be considered when drawing conclusions from these data. Although a large amount of data was collected and analysed, these data only represented the activity in 2 matches, which were analysed by an international roller hockey player following reliability assessment. Future research in this area may benefit from repetitive analysis of a larger number of matches by several trained data collectors, in order that the results of this preliminary investigation may be validated and consequently generalised to roller hockey match play of a similar standard, in this country.

CONCLUSION

In conclusion, this study aimed to analyse the time and motion characteristics of all the actions observed during roller hockey match play. The results established 17 different actions and provided the percentage of the match spent performing each of these actions, their total time, their frequency and their mean duration. Also analysed were the intensity with which each of these actions was performed and the direction of motion during each of these actions.

This information provided comprehensive data on the time and motion characteristics of roller hockey players during 2 competitive Premier League roller hockey matches. The relatively large amount of high intensity activity and the large number of actions that were performed in quick succession indicated that roller hockey is a fast, dynamic sport. Rolling accounted for an average of 71% of match time for each position, while the most common hockey actions were travelling with the ball and tackling. Shooting accounted for an average of only 0.4% of match time, with the forehand slap shot displaying the longest mean duration (1.18 s). Each position spent an average of 22% of match time performing activities classed as high intensity, whilst 70% of match time was spent travelling forwards and only 7% travelling backwards.

This investigation also analysed the effect of playing position, match half, and match score on match play characteristics. The findings showed minor positional effects, supporting the previous literature and also supporting anecdotal evidence that differences among the playing positions in roller hockey do not exist. Match score had a negligible effect on match play activity, whilst the greatest difference in match play characteristics was observed between the first and the second half. Due to an increase from the first to the second half in the percentage of time spent rolling and the percentage of time spent at low intensity activity, and a decrease in sprinting time, it was suggested that fatigue in the second half should be an important training consideration.

Although certain implications have been made for roller hockey training from the results of this study, the limitations of these findings should be recognised, firstly due to the small number of matches analysed and secondly the results themselves are likely to reflect the pre-match training that the teams in this study had experienced. To maximise the benefits of match analysis it may be worth considering routine monitoring of match play so that the efficacy and suitability of training can be optimised.

To prepare players effectively for competition it is important to reproduce the appropriate intensity of competitive play during training; therefore it is crucial to gain accurate information on the intensity of competitive match play. Future research may also benefit from a more automated system of data collection, due to the time consumed during manual notation and the human error factor. Analysis of the distance travelled may also provide additional information on the demands of roller hockey match play.

Finally, this was the first study of its kind in England and its value should not be underestimated. This study should be viewed as a preliminary analysis into the activities of roller hockey match play. Research on muscular activity during roller hockey needs to be based on a comprehensive knowledge of match play characteristics and therefore this study will also form the basis of the following research in this thesis.

CHAPTER 5

HEART RATE ANALYSIS DURING ROLLER HOCKEY TRAINING AND COMPETITION.

INTRODUCTION.

The exercise intensity of roller hockey match play was measured subjectively during the previous match analysis investigation. Oxygen consumption during performance in competitive sport provides a more objective indication of the physiological strain incurred in the organism, but an inherent shortcoming of indirect calorimetry is the additional effect that carrying such measuring devices has on the performance being monitored. However, the physiological strain on an individual can be indicated by the heart rate (Reilly and Thomas, 1976) as there is a linear relationship between exercise intensity and heart rate at sub-maximal levels of activity.

Heart rate has been used to assess the demands of physical activity for many years. Even though many factors influence heart rate, such as environmental conditions and psychological state, "the heart rate is one of the simplest and most informative of the cardiovascular parameters.... heart rate reflects the amount of work the heart must do to meet the increased demands of the body when engaged in activity" (Wilmore and Costill, 1994).

Thus, analysing heart rate during competitive roller hockey matches would provide a sufficiently objective measure of the physiological strain placed on roller hockey players in a match situation. The monitoring of heart rate values during roller hockey has not been undertaken in this country. This information would enable the physiological strain of English roller hockey to be compared with data already reported in other international articles. It would also enable the strain of roller hockey match play to be compared with other sports.

Understanding the physiological strain of competitive match play has valuable implications for training. Training needs to be more physically demanding than competitive play to produce further training adaptations and consequently improve performance. This is known as the "overload effect" (Rasch, 1989). Consequently monitoring the heart rate during competition and training would allow appropriate training intensities to be set for individual players.

When monitoring the heart rate of subjects in a dynamic situation such as a roller hockey match, it is also useful to understand the subjects' heart rate response to maximal exercise. The subjects' maximum heart rates then act as a reference value upon which their heart rate during dynamic activities (such as competitive match play and training) can be compared. Rodriguez (1991), Rodriguez *et al.* (1991) and Blanco *et al.* (1995) analysed roller hockey players' performance during a maximal and progressive shuttle skate test. They concluded that this test induced a maximum physiological strain (indicated by maximum heart rate values) and they considered the test highly specific to roller hockey.

Therefore the aims of the second discrete study within this thesis are, firstly to record physiological activity as indicated by heart rate, during competitive English roller hockey match play; secondly to analyse and compare heart rates during competitive match play and typical roller hockey training sessions; and thirdly to evaluate top English roller hockey players performance and heart rate values during the maximum progressive shuttle skate test used by Rodriguez (1991), Rodriguez *et al.*(1991) and Blanco *et al.* (1995). Oxygen consumption values will also be calculated during this skate test using the equation proposed by Blanco *et al.* (1995) and the results will then be compared between reports.

REVIEW OF LITERATURE

Some research has been identified which recorded the heart rates of Spanish roller hockey players during match play. Blanco *et al.* (1994) analysed the heart rates of top class (Honour Division) Spanish roller hockey players during training sessions and competitive matches, reporting similar heart rate values during training matches and competitive matches. In order to assess heart rates during other types of training they also divided the training sessions into categories of activity. These categories were warming up, technical exercises (equivalent to tactics training), shooting, and match play.

The maximum heart rates of roller hockey players were established by Rodriguez (1991) and Rodriguez *et al.* (1991) using a maximum progressive test on roller skates based on Leger and Lambert's (1982) maximum progressive shuttle run test. This test has since been used by Vazquez (1991), Blanco *et al.* (1995) and Blanco *et al.* (1996). As well as providing maximum heart rate data, Rodriguez (1991) suggested that as the duration of the test is limited by the aerobic metabolism, this test could be used for the evaluation of maximum oxygen consumption of roller hockey players. Leger and Lambert (1982) and Leger *et al.* (1988) proposed an equation to calculate $\dot{V}O_2$ during the maximum progressive shuttle run test. Rodriguez (1991) assessed the validity of this equation at predicting $\dot{V}O_{2max}$ related to body weight during the skate test. The results showed a low correlation ($r = 0.58$) between the calculated $\dot{V}O_{2max}$ values during the maximum skate test and $\dot{V}O_{2max}$ values obtained during treadmill running. Rodriguez *et al.* (1991) concluded that this lower correlation was due to the difference between running and skating.

In a later study, Blanco *et al.* (1995) used a portable gas analyser to measure $\dot{V}O_2$ levels directly during the maximum progressive shuttle skate test. Their findings showed that the equation proposed by Leger and Lambert (1982) led to an underestimation of $\dot{V}O_2$ during the maximum test on roller skates. This underestimation was attributed to differences in the mechanical performance between running and skating and also due to the changing direction (accelerating and braking) when carrying out the maximum test on roller skates, which is not seen in continuous treadmill running. Based on these results, Blanco *et al.* (1995) proposed an equation using heart rate data to calculate $\dot{V}O_2$ during each level of the skate test when a portable gas analyser is not available:

$$\dot{V}O_2\ (ml/kg/min) = [1.326 * \text{Number of level}] + [0.167 * \text{HR level maximum}] + 0.767$$

They concluded that the equation demonstrated good reliability (r=0.918).

METHODS

The subjects were the 8 outfield players of the England Men's 1998 roller hockey team (mean ± standard deviation; age 25.5 years ± 2.62 years, mass 77.8 kg ± 7.1 kg). All the players were free of injury and consented to participate in this study. The collection of data took place over three separate sessions, with three weeks between each session. Players' heart rates were recorded using Polar Vantage Night Vision heart rate monitors, which consisted of a chest band holding conductive rubber electrodes, a transmitter and a receiver unit. The transmitters and receiver units were matched and their functionality checked prior to each recording session. The position of the chest band was optimal for signal detection and in some cases the chest band was taped to the chest to preserve data collection during sweating and potential slippage of the band.

Session 1: Heart rate analysis during competitive match play.

Two stationary Panasonic SVHS AGDP800E video cameras with stationary fields of view recorded the 8 players simultaneously during three competitive matches. The matches were cup matches of Premier league standard (top English league) and they were 20 minutes each half (running clock).

Each player wore a Polar Vantage Night Vision heart rate monitor with a receiver unit, which recorded his heart rate every 5 seconds during each match. This receiver unit was attached to the player's back to minimise the risk of injury and to prevent the players from obtaining visual information about their heart rates.

The heart rate monitors and the video cameras were synchronised for subsequent analysis using a verbal cue. The heart rate data were downloaded onto a Viglen Genie 45X25 Personal Computer using Polar Heart Rate Analysis Software version 5.04.02. Each player's heart rate data were then matched to the video recording of his activity during each match.

Session 2: Heart rate analysis during the maximum test.

The 8 players completed the maximum and progressive shuttle run test (The National Coaching Foundation; Brewer *et al.*, 1988) on roller skates, to establish each player's maximum heart rate. The test was carried out in a covered sports hall regularly used as a roller hockey rink, with a clean and dry wooden floor. Markers were placed 20-m apart indicating the turning line. The objective of the test was to skate 20 m shuttles for as long as possible, whilst keeping rhythm with the audio signal emitted from a tape recorder. These signals coincided with the target times to skate the distance of 20 m. The subjects then executed a slide stop before accelerating in the opposite direction. Slide stops were performed on alternate sides. The test began at a speed corresponding to 8 km/h, increasing by 0.5 km/h at the end of each one-minute level.

Subjects used their own conventional roller hockey skates and wore full roller hockey kit; they did not carry their sticks. Again subjects wore a Polar Vantage Night Vision heart rate monitor, with a receiver unit attached to their back, which recorded heart rate every 5 seconds. Following a brief warm up, subjects performed the maximum test in groups of four. The duration of the test for each player was recorded to the nearest second; each level was one minute in duration and indicated the maximum level reached. The heart rate data were downloaded using the same Polar Heart Rate Analysis Software. These data were used to calculate the subject's $\dot{V}O_2$ over the course of the test, using the equation proposed by Blanco *et al.* (1995).

Session 3: Heart rate analysis during roller hockey training sessions.

Five of the original eight subject completed session 3. Data collection sessions took place individually and involved recording players' activity during their typical 2-hour Premier League roller hockey training session. Each players' activity was video recorded continually using a Panasonic SVHS AGDP800E video camera and players heart rate was also monitored every 5 seconds throughout the training session, using similar Polar Vantage Night Vision heart rate monitors with receiver units attached to the back.

The heart rate monitors and the video cameras were again synchronised for subsequent analysis using a verbal cue. The heart rate data were later downloaded again using the

Polar Heart Rate Analysis Software. Training sessions were then analysed and the players' heart rate data were matched to their activity during the training session.

The training session was divided into activity categories similar to those reported by Blanco *et al.* (1994), and mean heart rates were calculated for each category. Comparisons were then made between the intensity of training matches and the intensity of competitive matches.

RESULTS

Session 1: Heart rate analysis during competitive match play.

The individual heart rate profiles for each subject during each match are presented in Appendix 1. An example of one subject's heart rate profile is presented in figure 5.0.

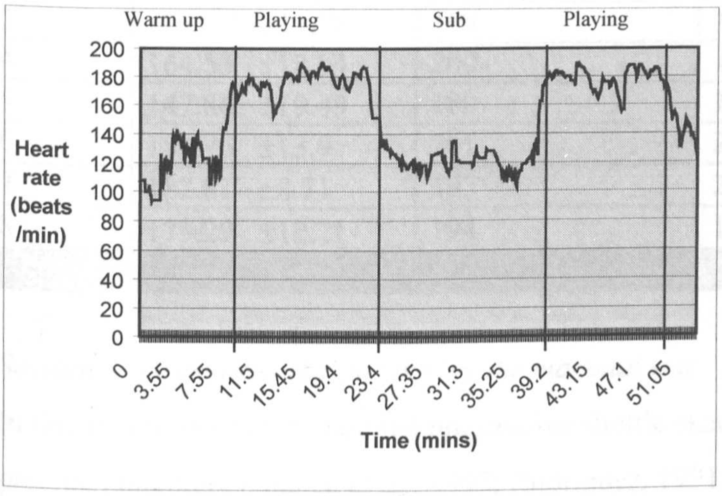


Figure 5.0: Heart rate profile of one subject during a competitive roller hockey match.

Table 5.0 shows the mean heart rates for each player during actual playing time in the competitive matches (excluding substitution). Table 5.0 also includes the maximum heart rates obtained during the maximal test; it is interesting to compare the highest heart rates obtained during competitive match play with those achieved during the maximal test. A paired sample t-test revealed that there was no significant difference (at $p<0.05$) in the heart rates obtained during competitive match play and those recorded during the maximal test.

Table 5.0: Mean (± S.D.) and maximum heart rates (beats/min.) for 8 subjects during 3 competitive matches and during the maximal skate test.

Subjects	Mean heart rate during competitive match play (n=3)	Peak heart rate during competitive matches	Max. heart rate (obtained during maximal skate test)
1	164.52 ±13.35	190	205
2	178.35 ±8.31	191	197
3	177.07 ±11.76	194	194
4	164.53 ±18.04	200	197
5	147.86 ±19.49	180	192
6	187.76 ±13.9	201	200
7	182.81 ±8.71	197	203
8	175.29 ±12.21	194	190
Mean	172.27 ±12.74	193.38 ±6.67	197.25 ±5.23

Session 2: Heart rate analysis during the maximal test.

In this investigation the maximal progressive shuttle skate test used a similar protocol to previous literature (Blanco *et al.*, 1995; Rodriguez, 1991; Vazquez, 1991), therefore the mean values for the duration of the test and the maximum heart rate achieved can be compared across studies (see table 5.1). Unfortunately Vazquez (1991) did not report maximum heart rate values during the maximal test.

Table 5.1: Mean duration and mean maximum heart rate values for the maximal progressive shuttle test on skates (± standard deviation).

	Mean duration (min/secs)	Mean maximal heart rate (beats/min)
Current study	14.49 ±0.36	197.25 ±5.23
Blanco *et al.* (1995): 1st division Spanish team	12.78 ±0.69	197.73 ±6.98
Rodriguez (1991): Spanish Olympic team	14.24 ±1.36	194.77 ±4.26
Rodriguez (1991) Spanish national team (World Champions).	14.61 ±0.61	195.2 ±5.11
Vazquez (1991): Global average	14.35	
Vazquez (1991): Attacking players	14.64	
Vazquez (1991): Defending players	14.07	
Vazquez (1991): Olympic team 1989	14.20	
Vazquez (1991): Olympic team 1990	14.35	

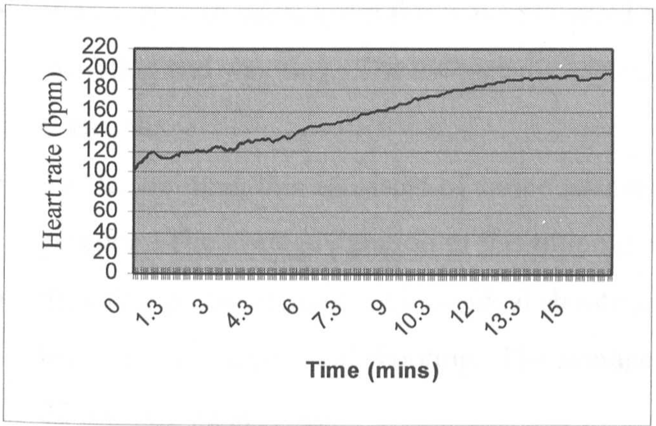


Figure 5.1: Profile of mean heart rate (n=8) during the maximal progressive test on skates.

Using the equation proposed by Blanco *et al.* (1995), the $\dot{V}O_2$ values were calculated for each player individually; overall mean values were also calculated (figure 5.2). The calculated mean maximum oxygen uptake for all players ($\dot{V}O_{2max}$) was 53.99 ml/kg/min with a standard deviation of 1.21 ml/kg/min.

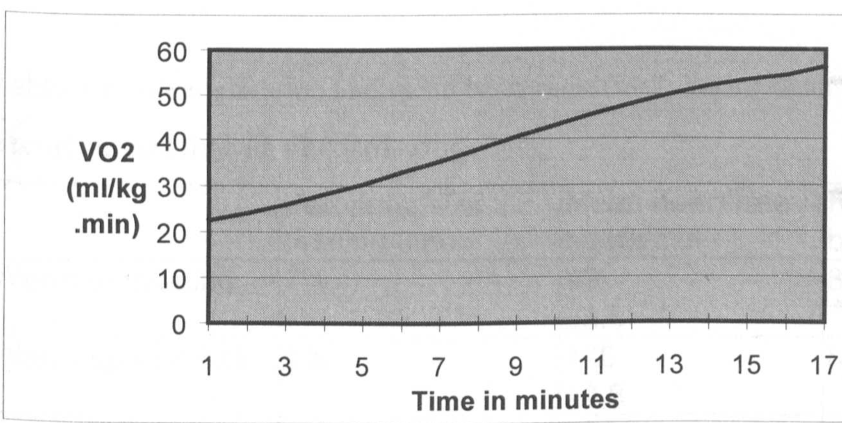


Figure 5.2: Profile of mean calculated oxygen consumption for all players (n=8) during the maximal test on skates based on the equation of Blanco *et al.* (1995).

Session 3: Heart rate analysis during roller hockey training.

Training sessions consisted of six categories of activity;

- Warm up skating and stretching; the warm up was performed individually by each player at the start of the session (always low intensity) and involved skating forwards and backwards around the pitch at a self-selected pace, performing stretches whilst on the move, without a ball. The average duration of this training activity was 8 minutes 14 seconds.

- Warm up with balls; again this was performed individually and involved mainly dribbling and shooting. The average duration of this training activity was 7 minutes 6 seconds.
- Tactics training; this consisted of unopposed attacking and defending formation practice. The average duration of this training activity was 3 minutes 28 seconds.
- Shooting practice; involved individual shooting at the goalkeeper, and passing between two players and shooting. The average duration of this training activity was 22 minutes 11 seconds.
- Training matches; these varied in length and fouls were rarely committed or penalised. Training matches always consisted of four players on each team plus a goalkeeper. The average duration of this training activity was 37 minutes 21 seconds.
- Rest time; this consisted of 'off rink' breaks, 'on rink' breaks, team talks, demonstrations, and waiting in queues. The average duration of this training activity was 41 minutes 41 seconds.

Table 5.2: Mean duration and mean heart rates (n=5) during each training activity excluding rest time (± standard error).

	Percentage of training time	Mean heart rate beats/min	Range of heart rate beats/min
Warm up skating	7%	99 ±3.5	80 - 127
Warm up with ball	6%	126 ±2.8	81 - 147
Tactics training	3%	121 ±27.8	82 - 182
Shooting practice	18%	136 ±4.2	82 - 176
Training matches	31%	166 ±4	84 - 195
Rest time	35%	121 ±31.3	69 - 195
TOTAL	100%	128 ±20.4	69 - 195

Table 5.3: Comparison of mean heart rates (beats/min) during training matches and competitive matches (± standard error).

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Overall heart rate range	Mean totals
Training matches	165.79 ±0.91	160.38 ±0.93	155.37 ±0.73	173.55 ±1.01	176.93 ±0:63	84 - 195	166.4 ±4
Competitive matches	164.52 ±0.58	178.35 ±0.3	177.2 ±0.3	177.07 ±0.6	182.99 ±0.28	94 - 202	176.02 ±3.07

Note: Shading represents significant differences, where $p \leq 0.05$

The results in table 5.3 reveal that all subjects except subject 1, showed a higher mean heart rate during competitive matches than during training matches. Subject 1 on the other hand showed a higher heart rate during training matches. To test the statistical significant of these results Wilcoxon's Matched-Pairs Signed-Ranks test was used, due to the lack of normality in the data. The results revealed that all differences were significant at $p<0.05$. Subject 1: $z = -2.6$, $p = 0.01$; subject 2: $z = -14.5$, $p < 0.00001$; subject 3: $z = -15.3$, $p < 0.00001$; subject 4: $z = -2.7$, $p = 0.007$; and subject 5: $z = -10.9$, $p < 0.00001$. Overall the mean heart rate was significantly higher during competitive matches than training matches, where $z = -15.6$, $p < 0.00001$.

DISCUSSION

Roller hockey match play was described by Dal Monte (1983; cited in Rodriguez *et al.*, 1991) as an alternating aerobic-anaerobic sport, where changing demands are made on the three energy production systems. Physiological activity is characterised by periods of low intensity activity that allow for recovery from periods of high intensity activity. Blanco *et al.* (1993) reported a work to rest ratio of 1:1.05.

Heart rate analysis during competitive roller hockey match play.

The first aim of this study was to analyse physiological activity during competitive English roller hockey match play (indicated by heart rate). Figure 5.0 represents a typical heart rate trace during a roller hockey match from the current population; the heart rate fluctuated with the varying demands of match play, but remained approximately in the range of 170 – 190 beats/min for most of the actual playing time. This suggests that competitive roller hockey match play places a reasonably high level of physiological demand on the players. The heart rate profiles during competitive matches for all the players showed that once the heart rate had risen to match levels, it remained in this range and hardly ever fell below 160 beats/min (see Appendix 1). This suggests, contrary to Dal Monte (1983), that the periods of low intensity activity during the match did not allow for complete recovery from the higher intensity activity. For nearly all the subjects the heart rate was elevated considerably before playing and during substitution, even though the subjects did not warm up before any competitive matches during this investigation.

Players can be substituted and brought back on to the pitch during roller hockey match play as often as required (this is known as rolling substitution). However, players are frequently required to play a whole match without being substituted. For English Premier league matches chapter 4 reported a mean duration of 61 minutes; Blanco *et al.* (1993) reported a mean duration of 82 minutes for top Spanish matches. The high, fluctuating heart rate values, sustained over a reasonably long period of time support the statement from Dal Monte (1983) that roller hockey match play requires considerable anaerobic and aerobic capacities.

The mean heart rates during competitive matches varied considerably between players (table 5.0). The work done by a player during a match is situation-dependant, making it difficult to compare the heart rates of different players. Only the coach can assess through subjective observation of play whether a player is performing to his full potential.

The overall mean heart rate obtained during the three competitive matches (excluding substitution, half time, time outs, or the warm up periods) was relatively high at 172 beats/min (table 5.0). Blanco *et al.* (1994) reported a lower mean heart rate (158 beats/min) during competitive Spanish roller hockey matches. This may be explained by the greater amount of stoppage time during Spanish roller hockey. Blanco *et al.* (1993) reported unlawful stoppages accounted for 37% of a match, as opposed to 18% in English Premier League roller hockey (chapter 4, the match analysis). Increased stoppage time would give the Spanish players longer to recover from the high intensity activity during match play, thereby explaining the lower heart rate values. Care should be taken when analysing mean heart rate values due to the diversity of roller hockey activity that cannot be accounted for in a mean value. It is suggested that mean heart rate values should always be accompanied by a graph displaying heart rate activity.

The maximum heart rates achieved during competitive match play indicate the demanding nature of the matches (table 5.0). It is interesting to note that during competitive matches three players reached higher heart rate values than during the maximal and progressive shuttle skate test. Limited conclusions can be drawn from this finding as the heart rate analysis during competitive match play took place six weeks before the maximum progressive shuttle skate test. During this time the players of the England team were required to increase their home training and may have become fitter, thus slightly reducing their maximum heart rate levels. Overall, however, the maximum heart rates during competitive matches and during the maximum test were not significantly different.

Heart rate analysis during roller hockey training.

The second aim of this study was to analyse and compare heart rates during competitive match play and typical roller hockey training sessions. The training sessions were divided into activity categories, and a large proportion of the roller hockey training sessions were spent in match play. The training activities observed in this investigation were similar to those reported in Spanish training sessions (Blanco *et al.*, 1994). One observation of good practice was the variation in the order of training activities. The coach would often play a training match straight after the warm up, which would then be followed by skills training. This was one of the recommendations made following the match analysis in chapter 4, that skills should be practised when players were fatigued in an attempt to improve match performance in the second half.

The highest mean heart rates during a training session were observed during the training matches (table 5.2). The heart rates remained fairly low during the warm up and increased with the introduction of a ball. This observation is supported by Blanco *et al.* (1996) who found that skating with the ball significantly increased the physiological demands to a roller hockey player, indicated by elevated heart rate, $\dot{V}O_2$, ventilation, and perceived exertion, compared to skating without the ball. Excluding training matches the average heart rate remained fairly low during all other training exercises, suggesting a reliance on aerobic energy systems. As previously mentioned, mean heart rate values should be analysed with caution, as they may not give a true reflection of changes in activity. For example, during shooting training a high intensity activity was followed by waiting stationary in a queue for another turn, a mean heart rate value does not reflect this range of high and low intensity activity.

Table 5.2 also showed that on average 35% of the training sessions was taken up by rest time. Although the rest periods took up a considerable amount of the training session, it must be remembered that rest time included opportunities for coaching, demonstrations, team talks, and waiting in queues, and therefore was an essential part of any training session. The small percentage of the training session spent practising tactical manoeuvres (3%) could be attributed to the fact that tactical manoeuvres were usually discussed during the team talks and then practised in the training matches. Players were of a high enough standard to know the coach's tactics and put them straight into a match situation.

The range of heart rates during tactics training (table 5.2) is likely to reflect not only the kind of activities involved, but also how familiar the players were with these activities, and the effort that the players exerted during this training activity. The baseline heart rate level for all the categories in table 5.2 is approximately 82 beats/min, suggesting that during the training sessions the rest periods gave the players adequate time to recover from the high intensity activities. Lower overall heart rates during the training sessions (128 ± 20 beats/min) suggested a reliance on aerobic energy; however, high (near maximal) heart rate values during competitive matches suggested that anaerobic energy was also very important. In comparison with training matches, four of the five players displayed significantly higher mean heart rates during competitive matches (table 5.3). Overall the mean heart rate observed during training matches (166 ± 4 beats/min) was significantly lower than that observed during competitive match play (176 ± 3.1 beats/min). To improve the physical condition of roller hockey players in preparation for competitive match play the training sessions need to match, and even exceed, the physical demands of competitive play. Rasch (1989) referred to the "overload principle" when training for competition and stated, " low-level demands, to which the body has already adapted, are not sufficient to induce a further training adaptation". Rasch (1989) suggested increasing the training load, either by increasing training volume i.e. training for longer or increasing training intensity i.e. training harder. The results of this study suggest that these subjects may benefit from an increase in training intensity. When comparing the heart rate during two different situations it must be recognised that a number of factors may have influenced the heart rate in the competitive matches more than during training, such as anxiety, the strength of opposition, the importance of the result, and so on.

Very few measurement errors were encountered during this section of the analysis. The heart rate monitor and the video recording system were synchronised using an audible cue as the heart rate monitors were started, and as a result of this any timing errors incurred were considered negligible (± 0.5 s).

Heart rate analysis during the maximum test.

The third aim of this study was to evaluate top English roller hockey players' performance and heart rates during the progressive maximum shuttle skate test used by Rodriguez (1991) and Blanco *et al.* (1995). It also included calculating $\dot{V}O_2$ values during this skate test using the equation proposed by Blanco *et al.* (1995) and comparing results with top Spanish players. A comparison of the results of the maximum skate test with other studies (table 5.1) showed similar mean maximal heart rates across investigations. The mean duration for the current test was similar to that reported by Rodriguez (1991) for both the Spanish National team and the Spanish Olympic team. The results of this comparison however, showed that the English roller hockey players completed more levels of the maximum test than the first division Spanish team (Blanco *et al.*, 1995). However, Blanco *et al.* (1995) acknowledged the low results of their study and attributed this to lower levels of fitness; but other factors, such as inadequate motivation, may also have contributed to the results.

It should also be noted that the overall results of a progressive maximum shuttle skate test may be influenced by the inclusion of the goalkeepers. The level of aerobic capacity required for a goalkeeper is lower than that required for an outfield player (Blanco *et al.*, 1994). It is also suggested that, in most instances, the skating ability of the goalkeepers may not be as good as the outfield players, suggesting that the test may not properly determine their full aerobic potential due to limitation of muscular demand. Therefore goalkeepers were excluded from this study, although the study by Rodriguez (1991) and Blanco *et al.* (1995) included the results obtained from goalkeepers.

Figure 5.1 shows the mean heart rate during the maximum test rising sharply at the beginning, then rising steadily until reaching a plateau just before the end of the test. Blanco *et al.* (1995) reported a similar pattern of heart rate activity during the maximum test. Table 5.0 indicated no significant difference between mean maximum heart rate values during the maximum test and during competitive match play, suggesting that the maximum progressive shuttle skate test was indeed maximal, as reported by Rodriguez *et al.* (1991), Blanco *et al.* (1995) and Blanco *et al.* (1996). As the test was performed on skates and on a roller hockey rink, "requiring the succession of the following phases; acceleration on studs (sprinting), acceleration with propulsive sliding (pushing), deceleration, braking and changing of direction" (Rodriguez *et al.*, 1991), the test was considered highly specific to roller hockey match play.

The results of this maximum test were used to calculate the $\dot{V}O_2$ values of the 8 England roller hockey players using the equation proposed by Blanco *et al.* (1995). The mean calculated $\dot{V}O_{2max}$ in this investigation was 53.99 ml/kg/min (S.D. 1.21). Blanco *et al.* (1995) reported a mean $\dot{V}O_{2max}$ of 50.46 ml/kg/min (S.D. 4.36) for first division Spanish players. The lower $\dot{V}O_{2max}$ values for the Spanish players are consistent with the lower overall test duration reported. Blanco *et al.* (1995) also used a portable gas analyser, and reported a steady rise in $\dot{V}O_2$ over the course of the test, with a plateau just before exhaustion. A plateau is classed as the most widely accepted criterion to establish whether $\dot{V}O_{2max}$ has been reached (Davis, 1995). During the current study, the mean calculated $\dot{V}O_2$ for top class English roller hockey player, displayed a steady rise over the course of the test (figure 5.2), showing no plateau towards the end. Whether or not a plateau signifies $\dot{V}O_{2max}$ is a contentious issue and one that is beyond the scope of this report. Davis (1995) having reviewed the issue concluded that typically less than 50% of subjects actually demonstrated a plateau during $\dot{V}O_{2max}$ tests. For roller hockey match play Rodriguez *et al.* (1991) reported a mean $\dot{V}O_{2max}$ value of 56.2 ml/kg/min ± 5.7 (with a range of 50 – 62 ml/kg/min). Rodriguez *et al.* (1991) concluded that roller hockey had a high $\dot{V}O_2$ demand, compared to other team sports; unfortunately the origins of the $\dot{V}O_{2max}$ values from other team sports were not reported.

Again few errors were encountered in this section of the analysis, and the heart rate analysis showed almost total data acquisition, partially because much care was taken at the time of recording. The Polar Vantage Night Vision heart rate monitors were in their factory calibrated condition. The subjects were considered highly motivated and the environmental conditions were satisfactory (a clean and dry floor). Before valid conclusions can be drawn from the $\dot{V}O_2$ values reported in the current investigation more research is required using a portable gas analyser to test the reliability of the equation proposed by Blanco *et al.* (1995) for predicting $\dot{V}O_2$ values during this maximum skate test. It should be recognised that this study used a limited number of subjects; therefore further research is required in this area to substantiate the results of this study.

CONCLUSION

Despite the dynamic, aggressive nature of roller hockey match play and the excessive sweating experienced by some players, the system used to monitor heart rate during training sessions and competitive match play was highly successful, producing almost total data acquisition. The first aim of this study was to analyse physiological activity during competitive English roller hockey match play, the results displayed a reasonably high level of physiological activity. Heart rates were maintained at a high level throughout competitive matches, suggesting that the periods of low intensity activity did not allow for full recovery from the periods of high intensity activity. High, fluctuating heart rates sustained over a relatively long period of time, suggested that roller hockey match play demands high anaerobic and aerobic capacities. Differences in mean heart rate values during competitive English and Spanish roller hockey matches may have been due to fundamental differences in the characteristics of English and Spanish match play (there was a substantial increase in stoppage time during Spanish roller hockey match play, allowing players more recovery time).

The second aim of this study was to analyse and compare heart rates during competitive match play and typical roller hockey training sessions. Overall, lower heart rates were reported during roller hockey training matches when compared to competitive matches. There may be many reasons for this, but players should be encouraged to work harder during training matches to improve their physical condition for competitive match play. Training matches should resemble as closely as possible the real situation; players should be overloaded during training matches so that performance during competitive matches can be maintained for longer periods of time. One recommendation for this would be to increase the length of training matches to exceed that of competitive matches. Due to limited funding for rink hire and to general limited facilities, this is not always possible.

The third aim of this study was to evaluate top English roller hockey players performance and heart rate values during the progressive maximum shuttle skate test used by Rodriguez (1991) and Blanco *et al.* (1995). The current population displayed similar heart rates to Rodriguez (1991) and Blanco *et al.* (1995) during the maximum test. The maximum test was considered an easy to use, roller hockey specific, physiological performance test and would be recommend for routine physical performance monitoring. To determine the reliability of the equation proposed by Blanco *et al.* (1995) to calculate $\dot{V}O_2$ during this maximum test, it is necessary for more research in which $\dot{V}O_2$ is assessed using a portable gas analyser during performance of the maximum test by roller hockey players on roller skates.

CHAPTER 6

KINESIOLOGICAL ANALYSIS OF ROLLER HOCKEY MATCH PLAY ACTIONS.

INTRODUCTION

The match analysis study (chapter 4) divided the actions performed by an outfield roller hockey player during competitive match play into two categories, i.e. skating activities and hockey activities. Each category was further subdivided into individual actions, incorporating all the major activities performed by a player during match play. The next stage in developing a deeper understanding of the biomechanical and physiological demands of the sport entails a detailed analysis of major muscle activity. Electromyography is the preferred method for providing valuable information on the electrical activity of muscles. However, O'Connell and Gardner (1963) stated that 'before interpretation of the EMG is attempted there should be a thorough kinesiological analysis of all movements involved in the study' (p 180-181). Therefore before conducting an EMG study to assess muscular activity during roller hockey, a kinesiological analysis is necessary on all the actions performed by a roller hockey player during match play.

Kelley (1971) defined kinesiology as "the study of motion which is characterized by the movements of human beings and those other objects which are influenced directly by human motivation". Rasch (1989) stated that joint and muscular analyses, although extremely simple, are fundamental in the qualitative analysis of movement, and that analysis of this kind will precede more complex analyses. He also divided the joint and muscular analysis into three steps. Firstly, describing the movement and, where appropriate, dividing it into important segments, or phases; secondly, subjecting each phase to the joint and muscular analysis; and thirdly, subjecting the analysed data to the selected criteria.

No previous research has been located on roller hockey in this area. Therefore this investigation will not only form the base for the proceeding EMG investigation, but it will also provide valuable and unique descriptions and definitions of the movement phases, the joint actions and the muscular activity, involved in each roller hockey action.

This kinesiological investigation took the form of a single subject case study in which various roller hockey actions were performed in isolation, outside a match setting. This approach was adopted because it was necessary to establish a theoretical base of the major joint actions and the muscles involved in each roller hockey movement. The kinesiological demands when combined with an understanding of roller hockey match play (the match analysis data, chapter 4) will allow a rational selection of the important muscles in roller hockey match play. The electromyography analysis will then focus on these muscles.

Therefore the aims of this kinesiological investigation are twofold. The first aim is to observe key skating and hockey actions, break these actions down into movement phases and joint actions, and use these observations to select subjectively the muscle groups involved in each of these roller hockey actions. The second aim is to establish a theoretical hierarchy of these muscle groups which are central to roller hockey match play, using the information from the match analysis on the percentage of a match spent performing each action.

METHODS

The subject (J. Kingman) was a female international roller hockey player with 14 years roller hockey experience (age: 23 years, height: 1.7 m, mass: 65 kg). This investigation was undertaken in a sports hall with a wooden floor similar to the surface of a roller hockey pitch. The subject used her own roller hockey equipment, and wore tight clothing with body markers positioned on the shoulders, elbows, wrists, hips, knees, ankles, toes of the skates, and the bottom and top of the stick.

Chapter 4 defined all the actions performed during roller hockey match play, those chosen for analysis in this current study were the skating actions; rolling, pushing, sprinting, and slide stopping, and the hockey actions; passing, receiving a pass, and shooting. The shooting analysis consisted of slap and flick shots on the forehand and backhand sides, and were performed with the subject standing still and then skating. The subject performed each action individually and outside a match situation. Some of the actions defined in chapter 4 are situation-dependant and the muscular activity varies considerably between performances. These actions are dribbling, tackling, travelling with the ball, falling, stationary, collecting loose ball, and backwards skating. Analysis of typical joint and muscle activity during these actions was considered unjustified due to the performance variability and therefore these situation-dependant actions were excluded from the analysis.

Six trials of each action were recorded using two stationary Panasonic SVHS AGDP800E cameras with fixed fields of view. One camera was positioned perpendicular to the direction of motion at a distance of 5.5 m, and the other (used only for reference) at 45 degrees to the direction of motion at a distance of 7 m. Both cameras were at a height of 1.5 m above the ground. Floor markings of 0.2 m intervals were used to establish distances. The narration microphone was used to indicate trial number and success. All the data were collected during one session lasting approximately 3 hours. The subject rested between trials to minimise any fatigue effect.

Data analysis.

Each trial was analysed individually, field-by-field (25 fields per second), using a television monitor and a VHS video player. The camera field of view was static, consequently the subject travelled across the screen from one side to the other. Analysis of each trial began by establishing a number of descriptive phases; the joint actions during each of these phases and the major muscles involved in the performance of each joint actions were then recorded manually by the experimenter during every other field (0.08 s). The six trials within each roller hockey action were then compared and an overall pattern established.

Using the three-dimension body markers, visual images were obtained manually every 0.08 s from the television screen by tracing the body markers onto clear acetate film. The visual images were used for illustrative purposes, to support the descriptive reviews of each phase.

Analysis of every field (0.04 s) provided information on the timing of each phase of each action. Each phase was considered as a percentage of the total action time, enabling comparisons to be made between skating actions and between hockey actions. Finally the floor markings enabled approximate horizontal ball velocity during shooting to be calculated.

RESULTS

The results of this investigation are divided into two sections, a qualitative analysis and a quantitative analysis. The qualitative analysis section provides detailed descriptions of the movement phases and joint actions during each roller hockey action using the joint motion terminology from Rasch (1989). The quantitative analysis provides quantifiable data on the timing of the movement phases, and ball velocity data during each action.

Qualitative analysis.

This section of the results provides detailed descriptions of the movement phases and joint actions involved in each individual roller hockey action. During each joint action a large number of active muscles were identified and many of these joint actions were repeated several times in the same action. Therefore to list all the active muscles in this qualitative results section would disrupt the flow of the movement descriptions. Consequently the muscles involved in each joint action are presented in Appendix 2.

This section begins by analysing the skating actions identified in chapter 4. Rolling was defined as an eight-wheel glide in either a forwards or backwards direction. Rolling included cruising, which was defined in ice hockey as one or two forward utility strides with minimal effort, used to maintain speed or to adjust position on the rink with almost no forward lean (Marino, 1977). In roller hockey, cruising included the gentle application of the toe stop when going backwards.

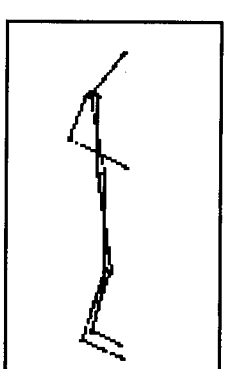


Figure 6.0: Diagram illustrating rolling.

Rolling is a very common movement in roller hockey and can take place at any speed, forwards or backward. The feet remained slightly apart with the knees slightly flexed. The muscular activity of this action was minimal.

Sprinting is defined as running on the skates, pushing off the toe stops.

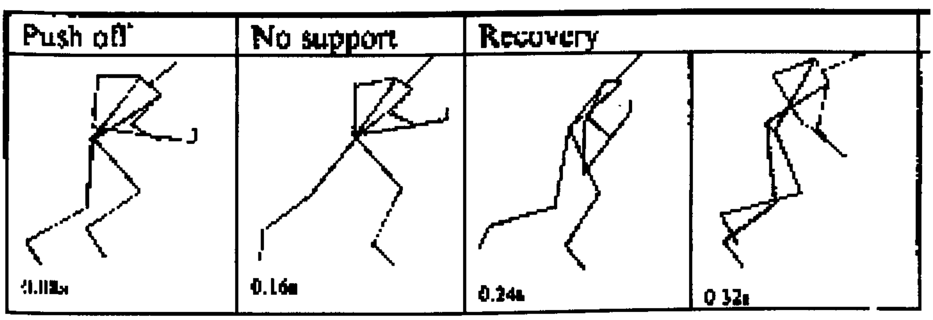


Figure 6.1: Diagram illustrating sprinting.

The extension phase of sprinting (figure 6.1: push-off) began as the recovery leg was brought underneath the body, flexing at the hip, knee and ankle to avoid contact with the floor. The hips remained square to the direction of motion (in the transverse plane), but the shoulders began to rotate in the opposite direction, away from the push-off leg (causing trunk rotation). As the shoulders rotated the arms followed, the extension side arm adducted and the other abducted, drawing the stick across the body. Both forearms were flexed. The push-off leg extended at the hip, knee, and ankle. During this extension phase the whole body was at an angle of approximately 65° to the horizontal. The extension phase ended as the push-off leg reached full extension at the hip, knee and ankle, plantar flexion gave the final thrust to the push-off leg causing the subject to lift off the floor.

During the 'no support' phase (figure 6.1) the trunk remained in a similar position as in the previous phase, but the push-off leg passively flexed at the hip, knee and ankle (still off the floor). The recovery leg also remained off the floor, but started to extend at the hip, knee, and ankle ready for planting.

During the recovery phase (figure 6.1) the shoulders and hips returned to a more square position in the transverse plane. The recovery leg was planted, landing on its toe stop.

This leg then pivoted about the toe stop and a stationary point on the floor, becoming the push-off leg. The other leg flexed at the hip, and knee, and the ankle dorsiflexed to avoid contact with the floor for as long as possible; this leg was now the recovery leg. See Appendix 2 for the muscular activity in each joint action during sprinting.

Pushing is defined as both a forward and backward propulsive movement. Marino and Weese (1979) described pushing in ice hockey, as bi-phasic, with each stride consisting of alternate periods of single support (the gliding/recovery period) and 'double support' (the propulsive period).

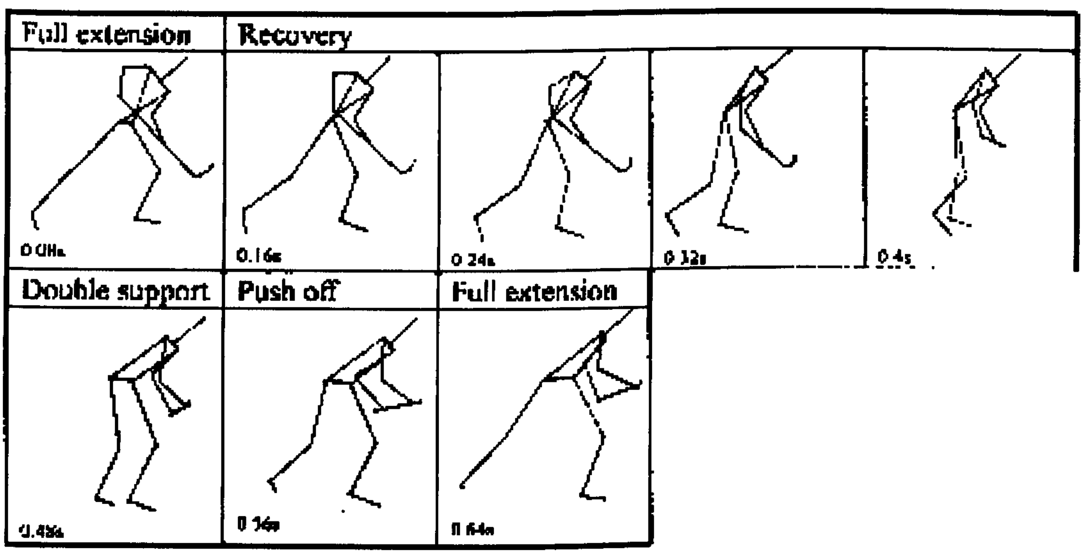


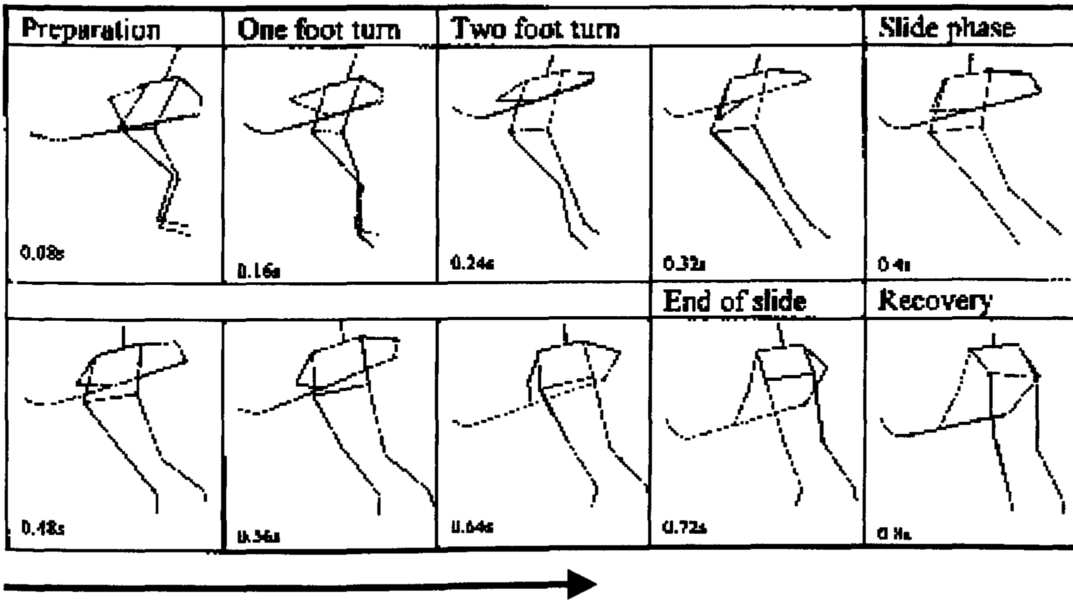
Figure 6.2: Diagram illustrating pushing.

During the extension phase (figure 6.2: push-off and full extension) there was an increase (compared to the rest of the movement) in trunk flexion and shoulder rotation towards the supporting leg, in the transverse plane. The hips rotated further in the opposite direction to the shoulders to drive the push-off leg; this caused trunk rotation. The supporting leg was flexed at the hip, knee, and ankle. During push-off the hip of the supporting leg remained behind the supporting foot which indicated that the body weight was not yet completely over the front foot. The push-off leg powerfully abducted, laterally rotated and extended at the hip, the knee was also powerfully extended, and the ankle plantar flexed; the push-off leg was then lifted from the floor. The plantar flexion seen in this action is unique to roller-skating; De Boer *et al.* (1987b) stressed the inhibition of plantar flexion during ice-skating. On full extension of the push-off leg there was also slight elevation and extension of the trunk at the supporting hip; this occurred as the push-off leg was rapidly extended or 'kicked' off the floor. Both elbows were flexed, with the supporting side elbow high.

During the recovery phase (figure 6.2) the push-off leg was flexed at the hip, knee, and ankle and passively rotated medially as it was adducted, ready to plant. This leg now became the recovery leg. The supporting leg extended slightly at the hip, knee, and ankle, and the trunk returned to a more erect position ready for the next leg extension. Both arms passively returned to their normal position in front of the body.

The 'double support' phase (figure 6.2) began as the recovery leg made contact with the floor; body weight was then immediately transferred on to this leg and it became the supporting leg. The shoulders now rotated towards this supporting leg while the hips rotated in the opposite direction, towards what was now the push-off leg (again causing trunk rotation). The push-off leg began to rotate laterally and abduct at the hip, whilst remaining flexed at the hip. The upper body showed an increase in trunk flexion. The push-off leg pushed perpendicular to the direction the subject was travelling, consequently it is suggested that there would be an increase in the activity of the adductor muscles of the supporting leg in order to maintain the intended direction of travel (forwards). This phase then leads into the next extension phase. The muscles involved in the joint actions established during pushing are listed in Appendix 2.

In chapter 4 slide stopping is defined as an action adopted by roller hockey players to stop in a fast and effective manner, whilst being ready to sprint in another direction. The action itself is similar to a snowplough stop in skiing, and can be performed on the left (with left side forward), or the right (with right side forward).



Direction of motion

Figure 6.3: Diagram illustrating a left slide stop.

The slide stop was initiated by the rotation of the trunk. During the preparation phase (figure 6.3) the trunk rotated towards the direction of the stop, whilst the feet and legs remained facing forward and rolling. The trunk also displayed slight flexion, and the legs were also flexed slightly at the hips, knees, and ankles. The rotation of the shoulders caused the left elbow (in this case) to rise and the right elbow to lower; forearm flexion increased slightly in both arms.

The ‘one-footed turn’ phase (figure 6.3) began as the trunk rotated further; this pronounced trunk rotation meant the feet could no longer maintain their forward motion. The right leg (in this case) started to rotate in the same direction as the trunk, flexing further at the hip and knee. The wheels were still rolling rather than sliding. The left leg remained rolling forwards, flexing further at the hip, knee and ankle. Both arms (and therefore the stick) were elevated for balance, this caused shoulder flexion.

During the ‘two-footed turn’ phase (figure 6.3) the trunk rotated further until it was almost perpendicular to the original direction of motion. This now caused both legs to rotate towards the direction of the stop. The inside leg (the right leg in this case) was flexed at the hip and knee and adducted so the ankle was everted. The outside leg (the left leg in this case) was gradually flexed at the hip causing more trunk flexion, but the knee and ankle were extended, the hip was also abducted, this caused the ankle to invert. Both skates were still rolling.

During the slide phase (figure 6.3) the hips were perpendicular to the original direction of motion and showed increased flexion; however, the shoulders continued to rotate. The arms remained in the raised position and extended at the elbows, in front of the body for balance. The inside leg (right leg) was at approximately 55° to the horizontal, adducted at the hip and inverted at the ankle. The left leg was at 48° to the horizontal, abducted and everted at the ankle. Both skates were now sliding in the original direction of motion. During the slide phase both legs extended at the knees as the subject pushed into the slide, causing the subject to slow down and eventually stop. Towards the end of the slide phase the arms were passively lowered, however the legs and feet continued to rotate past 90°; this meant that the inside foot (right foot) was laterally rotated and the outside foot (left foot) was medially rotated; an over-compensation.

During the recovery phase (figure 6.3) the feet continued to slide for slightly longer. The arms were passively lowered, whilst the subject started to return to a normal skating position. The legs were almost straight when the slide ceased. See Appendix 2 for the muscular activity of the slide stop.

This section now moves on to analyse the hockey actions identified in chapter 4. Firstly ,passing was considered situation-dependant; this is because in a match passes are made during many different situations. Therefore this investigation will analyse a stationary pass.

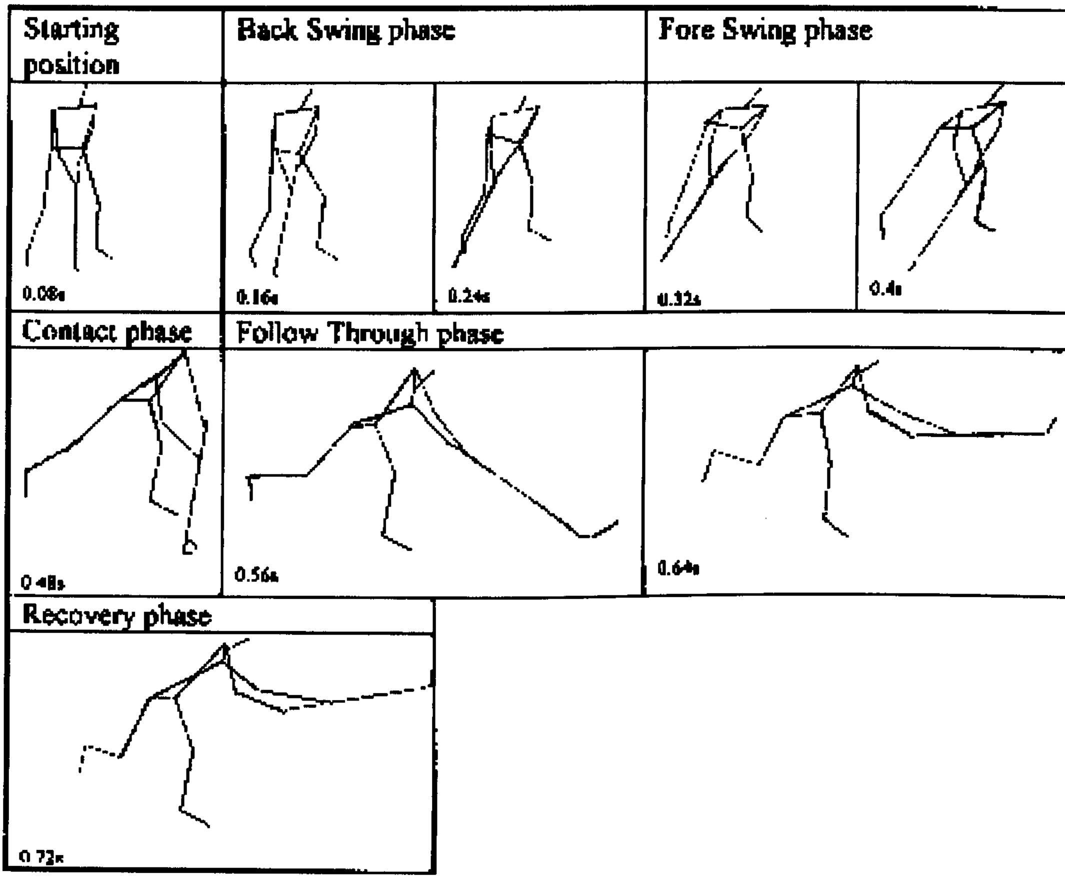


Figure 6.4: Diagram illustrating the stationary pass.

Initially the subject faced the ball, perpendicular to the direction of the pass (figure 6.4: starting position). The trunk was flexed slightly to allow the stick to touch the ground. The hips, knees and ankles were also slightly flexed. The feet were stationary and shoulder-width apart. The ball was placed ahead of the front leg.

During the back-swing phase (figure 6.4) the trunk flexed further and rotated away from the direction of the pass. The arm of the hand at the top of the stick (top arm) was abducted and the arm of the hand at the bottom of the stick (bottom arm) was adducted, drawing the stick across the body. The front leg rotated laterally to face the direction of the pass, flexing further at the knee and rolling forwards slightly to widen the foot base. The back leg abducted at the hip pushing the front foot forwards (during the fore-swing and the contact phase the extension of this back leg provided power for the pass). The back foot remained flat and everted, perpendicular to the direction of the pass.

The fore-swing phase (figure 6.4) began as the body weight was transferred on to the front foot. The trunk flexed further and the front shoulder was lowered bringing the top of the stick closer to the floor; the shoulders then rotated in the direction of the pass. The top arm was abducted and the bottom arm was adducted, sweeping the stick across the body and towards the ball. The back leg also extended at the hip, and the knee, but the foot remained in a flat position (everted) from which to push off; the extension of the back leg caused the front foot to roll further forwards.

During the contact phase of all passing and shooting in roller hockey and possibly in other hockey modalities, the hands perform an interesting manoeuvre. The position of the hands and the angle between the stick and the floor at the moment contact with the ball is lost is crucial to the trajectory of the resultant pass or shot. As already mentioned, during the fore-swing phase the top arm abducted at the shoulder pulling the top of the stick across the body, the bottom arm adducted at the shoulder, pushing the bottom of the stick across the front of the subject. During the contact phase this bottom arm continued to adduct and sweep the bottom of the stick across the body. However, the top arm reversed its direction of motion and adducted causing the top of the stick to be pushed away from the direction of the pass or shot, while the bottom of the stick was being pushed in the opposite direction. This adjustment in the motion of the top arm is dependant on the required outcome of the pass or shot. If the ball was required to maintain contact with the floor, at the moment contact was lost the stick had to be either vertical or at an acute angle with the floor; if the ball was to be lifted then the stick had to be at an obtuse angle to the floor. The trajectory of the ball was dictated by the distance between the top and the bottom hand in the transverse plane (consequently the angle of the stick to the floor). Therefore the stick acted as a lever with the bottom hand providing the force, the position of the top hand establishing the position of the fulcrum and the resistance or the load was the ball on the end of the stick. This manoeuvre was similar during forehand and backhand passing and shooting in roller hockey. For the purpose of this thesis, during further descriptive reviews of passing and shooting this manoeuvre will be known as the 'reversal of the hands'.

Also during the contact phase (figure 6.4) the shoulders continued to rotate. The back leg pushed against a fixed point on the floor, extending fully at the hip and knee. This caused the front foot and hence the whole body to roll forwards, and at contact this momentum was transferred to the ball. Due to its forceful extension, the back leg was then lifted slightly from the floor and rotated medially, behind the body. The front leg flexed further at the hip, knee and ankle as it supported the body weight.

After contact, during the follow-through phase (figure 6.4), the back leg rotated behind the body to counteract the rotation of the trunk; this was a manoeuvre seen during most passing and shooting actions in roller hockey to maintain balance. The arms and the stick continued to extend. The front foot remained in the same position, still rolling forwards slightly. The trunk elevated slightly as the supporting leg began to extend.

During the recovery phase (figure 6.4) the back leg continued to rotate further behind the body before passively flexing and returning to its normal skating position. The arms were passively flexed at the elbows and shoulders, and the trunk was elevated as the supporting leg returned to a normal skating position.

Having reviewed the stationary pass, the moving pass was similar in many respects. In the starting position for the stationary pass the subject stood perpendicular to the direction of the pass, however during the moving pass the subject performed the pass in the frontal plane. During the back-swing phase of the moving pass the trunk rotated away from the direction of the pass; this caused the legs to part, with one foot in front of the other, and the body weight was then transferred on to the front foot. The rest of the movement was similar to the stationary pass, but with both feet rolling forwards. See Appendix 2 for a list of the major muscles involved in the stationary pass.

In roller hockey the pass may also be performed on immediate receipt of the ball; this is known as a 'one-touch pass'. This 'one-touch pass' may again be performed whilst stationary or whilst skating. The stationary 'one-touch pass' is shown in figure 6.5.

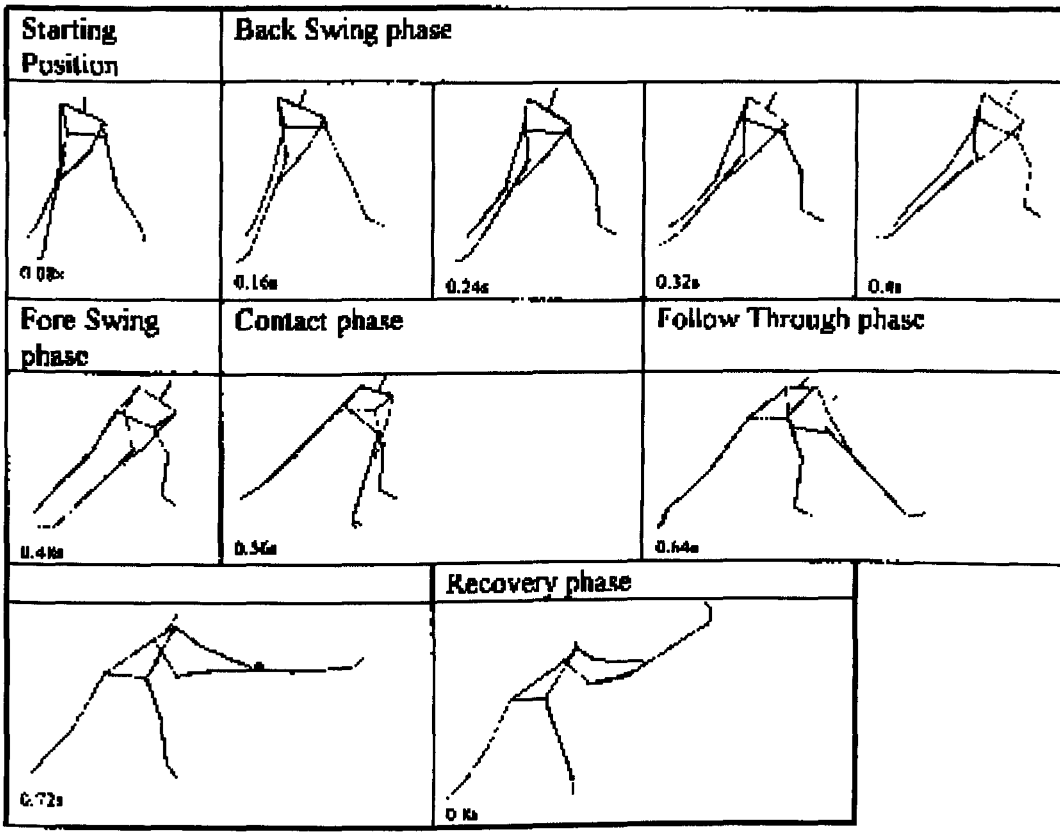


Figure 6.5: Diagram illustrating the stationary 'one-touch pass'.

In this example the ball was received in the frontal plane and passed immediately in the sagitial plane. The starting position for the stationary 'one-touch pass' (figure 6.5) was similar to the stationary pass; the subject faced the direction from which the ball was travelling, and perpendicular to the direction of the resultant pass. The stick was touching the floor, and the feet formed a slightly wider base than in the stationary pass.

The back-swing phase (figure 6.5) during the stationary 'one-touch pass' was slightly different to the stationary pass because the ball was not stationary in front of the subject; instead the subject had to time their fore-swing to contact the ball that was travelling towards them. The trunk flexed, while the shoulders rotated slightly away from the direction of the resultant pass. As the stick was drawn back in the back-swing the front shoulder was lowered considerably. While the shoulders rotated away from the direction of the pass, the hips remained square, causing slightly trunk rotation. During the back-swing the top arm adducted and the bottom arm abducted drawing the stick across the body. The front leg rotated laterally at the hip, so the foot was at an angle of approximately 45° to the direction of the incoming ball. The back leg extended at the knee and abducted at the hip, the ankle everted maintaining a flat foot position and causing the foot base to widen.

The fore-swing phase (figure 6.5) began as it did for the stationary pass, with the body weight being transferred over the front foot; the rotation of the shoulders towards the direction of the resultant pass initiated this transfer of weight. There was pronounced trunk flexion, as the front shoulder lowered even closer to the floor. The front leg remained in the same position and the back foot maintained a fixed position on the floor. The stick was now at an acute angle to the floor; to achieve this angle the top hand was in front of the bottom hand.

The extension of the back leg at the hip and knee and the rotation of the shoulders followed by the rotation of the hips provided the power for the pass. During the contact phase (figure 6.5) the body weight continued to be transferred over the front foot. The shoulders continued to rotate in the direction of the resultant pass. The stick remained in the same acute position as contact was made with the ball, the hands performed the reversal manoeuvre and contact with the ball was lost whilst the stick was still in an acute position. The resultant pass remained on the floor.

The follow-through phase (figure 6.5) was similar to that for the stationary pass as the shoulders and hips continued to rotate in the direction of the pass. The arms were flexed at the shoulders and extended at both elbows. The majority of the body weight was now on the front foot; the back leg provided support and balance as it rested on the floor.

During the recovery phase (figure 6.5) the front leg was extended (elevating the trunk) and passively rotated back to the normal skating position. The back leg was passively flexed at the knee and adducted. See Appendix 2 for the major muscles used during the 'one-touch pass'.

Again the 'one-touch pass' may also be performed whilst skating. This action produced similar phases, joint actions and muscular activity as the stationary 'one-touch pass'.

In chapter 4, receiving a pass was defined as stopping the ball and/or intercepting the ball.

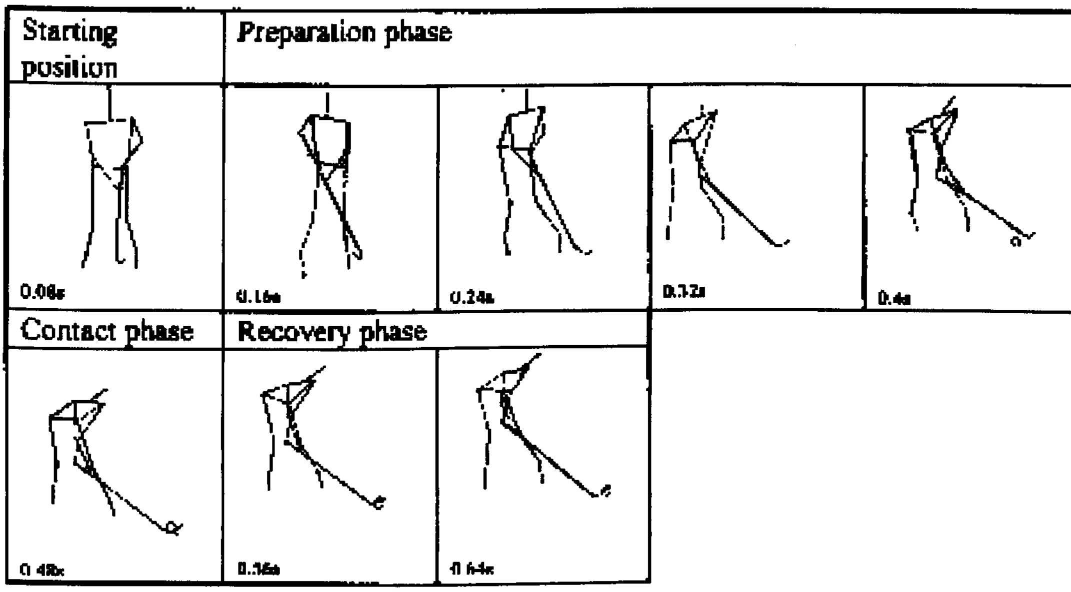


Figure 6.6: Diagram illustrating stationary receiving a pass.

During the starting position for receiving a pass (figure 6.6), the subject faced the direction of the pass. The trunk was flexed and both knees were also slightly flexed. The feet formed a base of shoulder-width, and the stick was held in the normal position (in front of the subject elevated from the floor) so that the player was ready to move the stick to either side to receive a forehand or a backhand pass.

During the preparation phase (figure 6.6) the shoulder on the side of the pass depressed and the trunk rotated slightly towards the side of the pass; the stick also moved to that side. The hips also rotated towards the side of the pass and the leg on the side of the pass dropped back; the ankle plantar flexed and the toe stop was planted. The top of the stick was pushed forwards, to establish an acute angle with the floor; to achieve this angle both arms adducted at the shoulders and extended at the elbows. Just before contact, the arms and hands adjusted the final position of the end of the stick to intercept the ball.

During the contact phase (figure 6.6) the force needed to stop the ball came from a movement of both arms, flexing at the shoulders, to absorb the force delivered by the ball at impact. Also the top hand pulled against the force of the ball and the bottom hand pushed, again using the stick as a lever. The stick was kept at an acute angle to the floor in order to 'trap' the ball; if the stick had been held at an obtuse angle the ball would have travelled up or over the stick. The subject maintained a constant body position as the impact of the ball was absorbed.

The length of the recovery phase (figure 6.6) was dependant on the success of the stop, providing an acute angle was maintained between the stick and the floor the stop was successful first time and the ball came to rest. Following the stop, the body returned to a normal skating position. See Appendix 2 for the major muscles involved during each phase of receiving a pass.

Shooting consisted of two standard roller hockey shots, the *slap shot* and the *flick shot.* The slap shot is similar to the snap shot or slap shot in ice hockey and consists of a back-swing, a fore-swing, contact, and follow-through. The flick shot is similar to a sweep shot in field hockey and the wrist shot in ice hockey. The ball starts behind the body and is dragged forward, contact is maintained until the stick, arms, and upper body are fully extended in the direction of the shot. The flick shot has no back-swing as such, the power comes from a build up of momentum as the ball is brought forwards. Both the flick shot and the slap shot may be performed on the forehand side or the backhand side, and whilst the player is stationary or skating. During a match many variations of these shots may occur; the wrist shot is a variation of the flick shot without dragging the ball forward; the power for this shot comes from a flicking motion of the wrist.

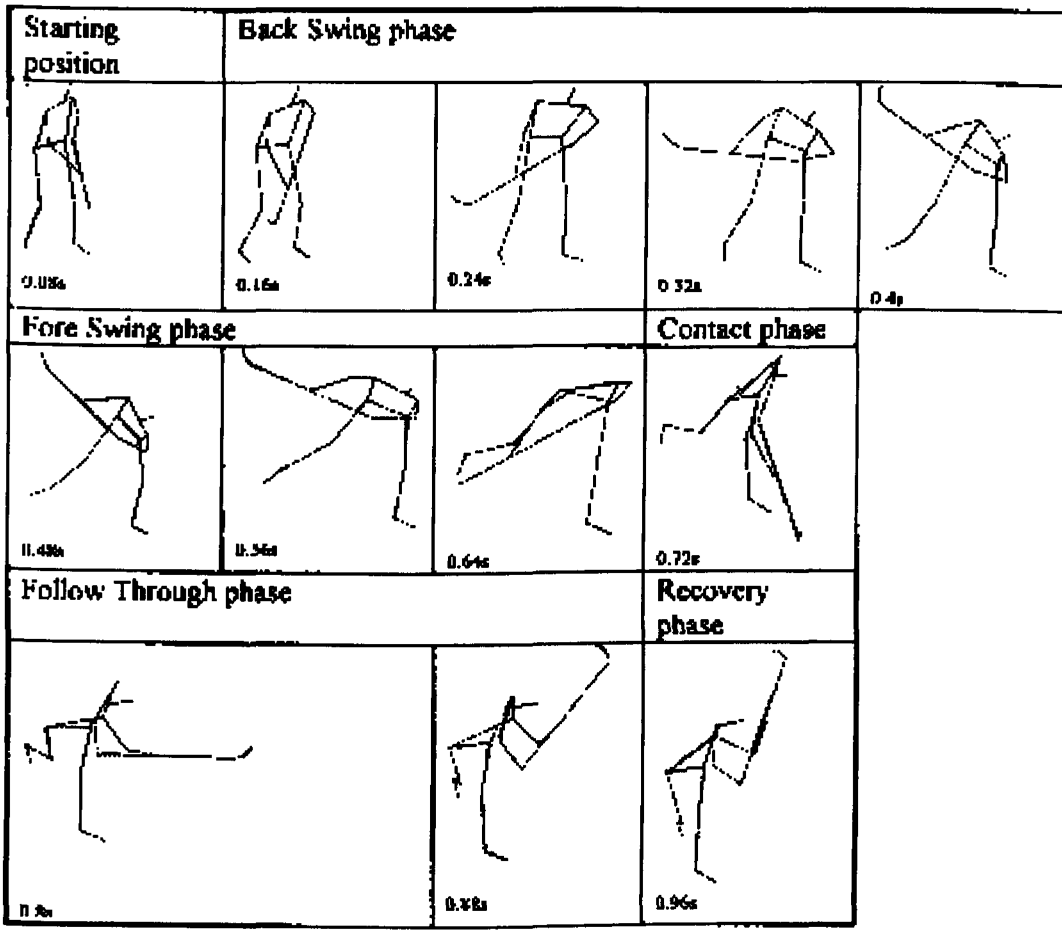


Figure 6.7: Diagram illustrating the stationary forehand slap shot.

Considering first the stationary forehand slap shot, the starting position for this shot (figure 6.7) was with the body facing the direction of the shot, slightly flexed at the hips with the feet shoulder-width apart. The ball was placed in front of the front foot. The bottom arm was adducted and the top arm was abducted; both arms were flexed at the elbows, thereby holding the stick in the normal position. The head faced the target.

During the back-swing phase (figure 6.7) the head now faced the ball and the shoulders rotated away from the direction of the shot, followed after a short delay by the hips. The arms were drawn across the body in the back-swing. The body weight was transferred on to the front leg and the back leg started to extend. The trunk flexed at the front hip until it was almost at a right angle to the leg. The front knee remained relatively extended. The back leg rotated laterally, extended at the hip and knee, and lifted off the floor.

The initial movement of the fore-swing phase (figure 6.7) involved the shoulders rotating towards the direction of the shot, followed by the arms and the stick. The top arm was abducted and the bottom arm was adducted in the fore-swing, with the bottom arm extended at the elbow, while the top arm remained flexed at the elbow. Then the hips rotated in the direction of the shot. To counteract the rotation of the trunk towards the ball and prevent over-rotation or loss of balance, the back leg rotated medially behind the subject. The front foot rolled forwards slightly and was now level with the ball. The head still faced towards the ball. The trunk flexed further at the front hip.

During the contact phase (figure 6.7) the shoulders and the hips continued to rotate. The trunk flexed further at the front hip, and this was followed by the reversal of the hands during contact. The back leg (still off the floor) was extended at the hip straight behind the body and flexed at the knee. The front leg retained its flexed position.

At the start of the follow-through phase (figure 6.7) the head remained facing towards the position that the ball had occupied before contact. Unusually the shoulders and the hips remained in the same position (square in the frontal plane) without following through. The arms followed through, flexing at the shoulders. The trunk actually flexed further at the front hip, while the back leg rotated further behind the body, flexing at the knee and ankle. Still the front leg remained in a flexed position.

During the recovery phase (figure 6.7) the head now faced towards the direction of the shot. The trunk started to extend to a more erect position at the front hip, while the arms and the back leg continued in the follow-through for slightly longer before relaxing and passively returning to a normal skating position.

During a roller hockey match the forehand slap shot is more likely to be performed whilst skating. The moving forehand slap shot consisted of similar phases, joint actions and muscular activity as the stationary shot with the exception of the position of the feet, which now face the direction of motion. See Appendix 2 for a list of the active muscles during both the stationary and the moving forehand slap shot.

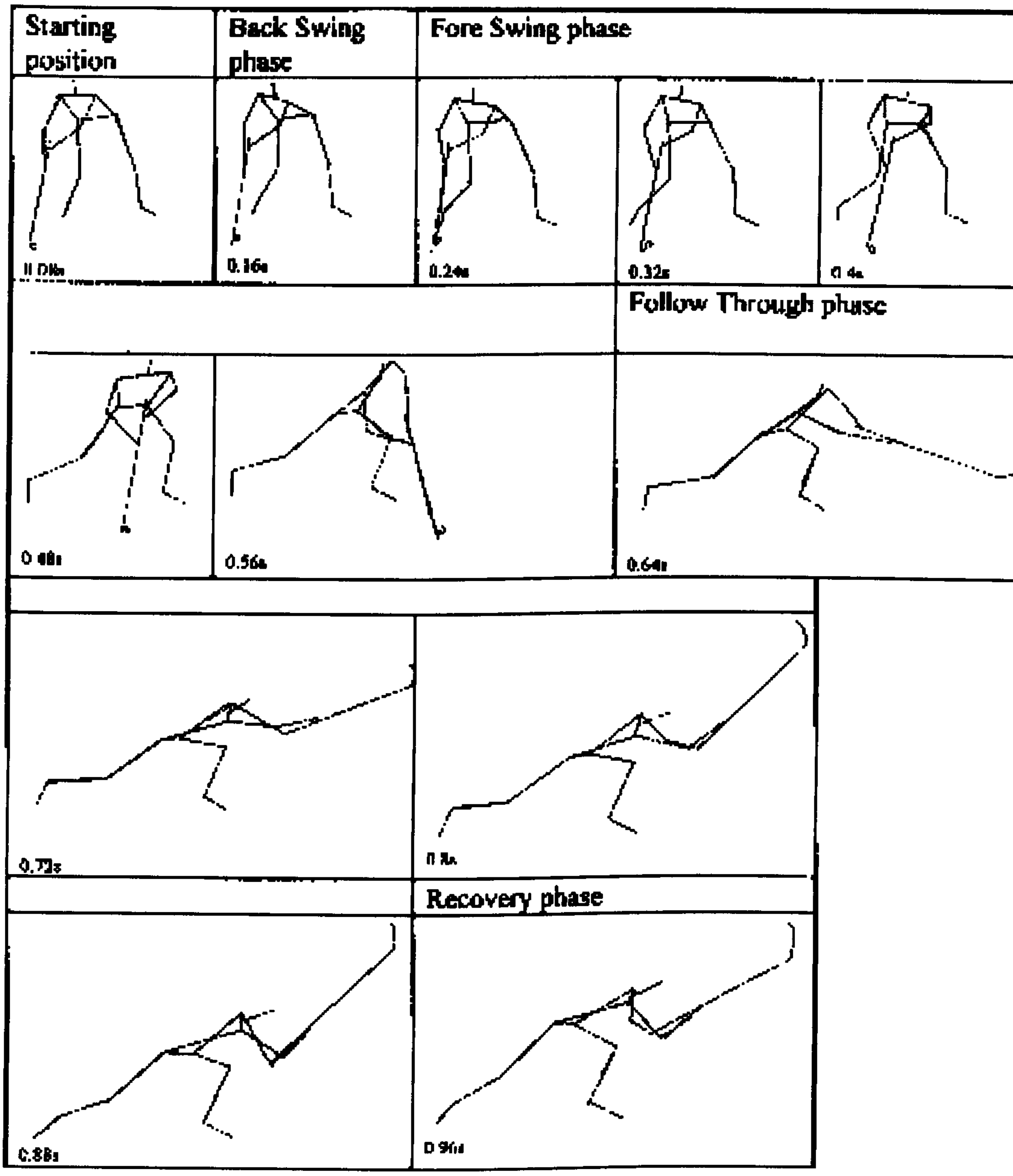


Figure 6.8: Diagram illustrating the stationary forehand flick shot.

The next shot to consider is the stationary forehand flick shot. The starting position for this shot (figure 6.8) was the feet shoulder-width apart and perpendicular to the direction of the shot. The head faced towards the target. The ball was behind the back leg and the trunk was rotated away from the direction of the shot to maintain the stick in a vertical position behind the ball. To achieve this, the bottom arm was adducted at the shoulder and both arms were extended at the elbows. The trunk was flexed and the knees and ankles were also slightly flexed.

During the flick shot there was some form of back-swing (figure 6.8). The shoulders and hips were rotated away from the direction of the shot, but the arms and stick remained in the starting position, in contact with the ball. The front leg was laterally rotated at the hip to face the direction of the shot, with the hip, knee and ankle flexed. The back leg was plantar flexed and remained stationary against a fixed point on the floor (this back foot remained the pivot as the foot base widens and the back leg extends later on in this action).

The fore-swing phase (figure 6.8) began as the body weight was transferred onto the front leg. The front leg flexed further at the hip, knee and ankle and rolled forward slightly, pushed by the extending, abducting back leg, which remained planted. The shoulders and hips began to rotate in the direction of the shot. The rotation of the shoulders was followed by the rotation of the arms and the stick. The stick remained in a vertical position, with the top arm abducted pulling the stick across the body and the bottom arm adducted pushing the stick across the body; reversal of the hands was seen just before loss of contact. Contact was lost on full extension of the bottom arm. The rotation of the hips caused the back leg to rotate medially. The head was now facing towards the ball. The power for this shot came from the sudden rotation of the shoulders and hips towards the direction of the shot and from the hyperextension of the back leg at the hip, and full knee and ankle extension about a fixed position.

During the follow-through phase (figure 6.8) the shoulders continued to rotate and the arms flexed at the shoulders. After loss of contact the hips did not rotate any further; they were prevented from doing so by the back leg, which was still fully extended behind the body. The trunk flexed further on the front leg. The front leg was flexed at the hip, knee and ankle, and rolled forward slightly.

During the recovery phase (figure 6.8) the arms relaxed at the shoulders, and the stick was passively retracted. The back leg also relaxed and the front leg began to extend, returning the body to a more erect position.

The forehand flick shot consisted of similar phases, joint actions and muscular activity when performed on the move. The starting position for the moving forehand flick shot was the same as the stationary forehand flick shot but with both feet facing and rolling forwards, and the ball was positioned slightly closer to the back foot. The rest of the actions were the same as the stationary forehand flick shot. Appendix 2 details the major muscles involved in each phase of the stationary and moving forehand flick shots.

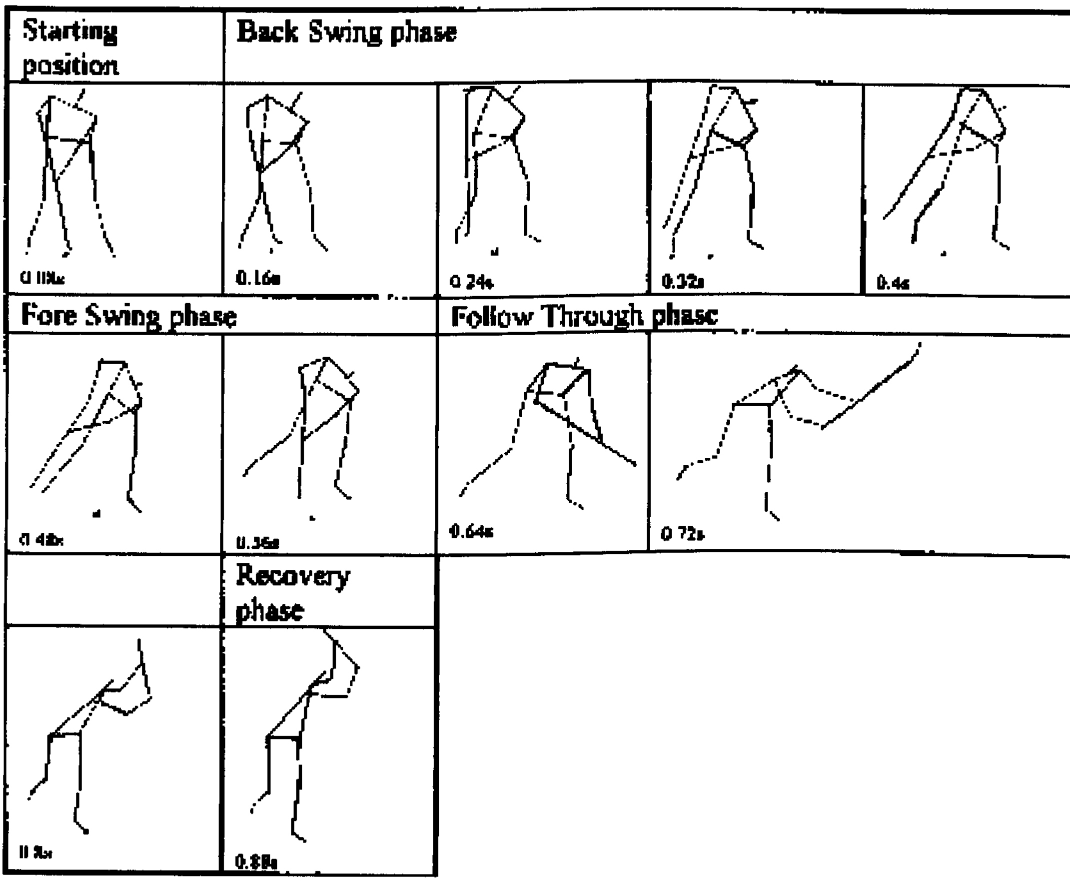


Figure 6.9: Diagram illustrating the stationary backhand slap shot.

The stationary backhand slap shot had a starting position (figure 6.9) where the body was perpendicular to the direction of the shot. The shoulders were slightly rotated away from the direction of the shot; this caused the front arm to adduct and extend at the elbow, while the back arm was abducted and flexed at the elbow. The trunk was flexed, as were both knees and ankles, so that the stick touched the floor. Both feet were parallel, shoulder-width apart, and the ball was stationary between them.

During the back-swing phase (figure 6.9) the trunk flexed further. The shoulders rotated further away from the direction of the shot, the front shoulder lowered so it was now closer tó the floor, while the back shoulder and elbow elevated; this caused the stick to rise in the back-swing. As the shoulders rotated, the body weight was gradually transferred on to the front foot. The hips remained relatively square in the frontal plane. The front leg rotated outwards at the hip and flexed at the knee and ankle. The back leg was flexed at the knee and ankle at first, but then extended as the body weight was transferred on to the front foot. At the top of the back-swing the hips started to rotate away from the direction of the shot, pivoting on the front leg. The back leg was then lifted off the floor, flexing at the knee and abducting at the hip. During the rotation of the hips, the shoulders remained fully rotated and in an almost vertical position in relation to the floor.

The fore-swing phase (figure 6.9) was initiated by the rotation of the shoulders towards the direction of the shot; this caused the arms and the stick to move towards the ball. The trunk flexed further and the body weight was now totally supported by the front foot. The hips remained fully rotated in the opposite direction to the shot. The back leg, which was still raised from the floor and flexed at the knee, swung forward with the rotation of the shoulders and the motion of the stick. Just before contact, the hips rotated towards the direction of the shot. On contact with the ball the hands reversed their actions, delivering direction to the shot.

During the follow-through phase (figure 6.9) the back leg rotated behind the body to prevent the over-rotation of the hips. The shoulders and trunk continued to rotate in the follow-through. The back leg increased its opposition to the rotation of the hips by kicking out behind the body (extending at the knee). The arms followed-through, flexing at the shoulders and extending at the elbows.

During the recovery phase (figure 6.9) the trunk extended to a more erect position. The shoulders continued to rotate, and the back leg continued to rotate behind the body, before relaxing and returning to their normal skating position.

In a match situation the backhand slap shot is more commonly performed whilst skating, and is almost identical to the stationary backhand slap shot except that the feet were facing the direction of motion. The muscular activity of the joint actions established for both the stationary and the moving backhand slap shot are presented in Appendix 2.

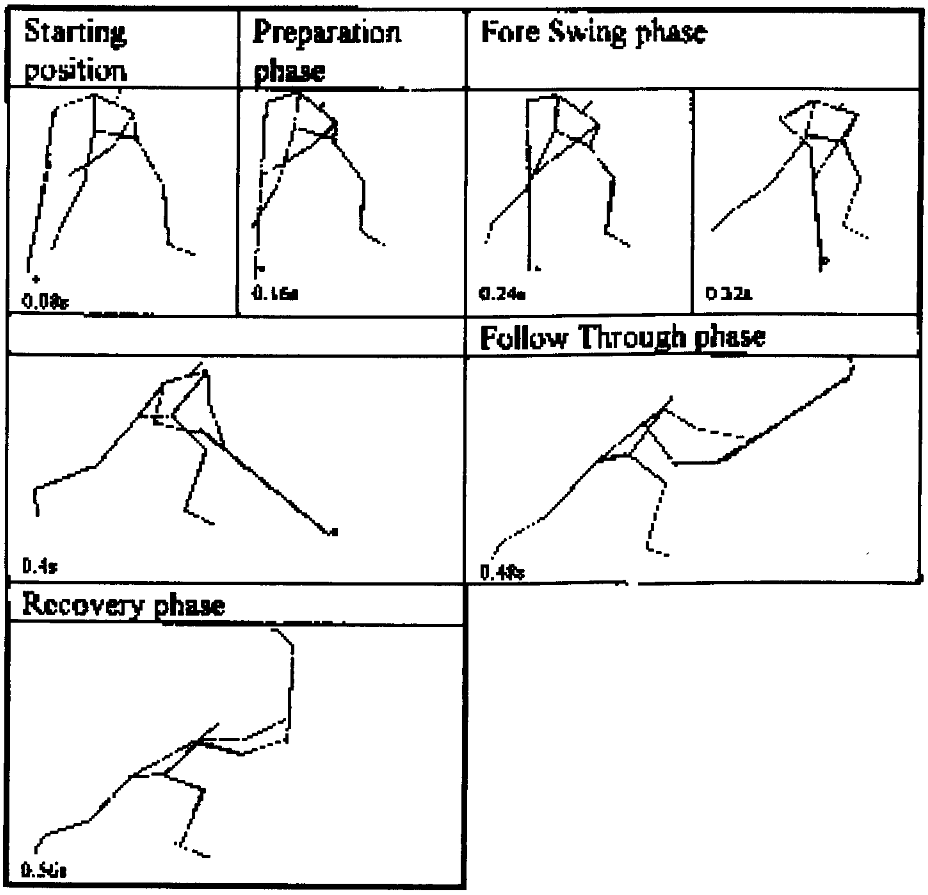


Figure 6.10: Diagram illustrating the stationary backhand flick shot.

The stationary backhand flick shot was similar to the stationary forehand flick shot. The starting position (figure 6.10) saw the ball and stick positioned behind the back foot, thus requiring the shoulders and the hips to rotate away from the direction of the shot. Both knees were flexed slightly and the feet formed a wide base, stationary and perpendicular to the direction of the shot.

During the fore-swing phase (figure 6.10) the ball gained momentum as it was brought forward; the stick remained vertical while the ball was behind the mid-line of the body. The front leg rotated laterally to face the direction of the shot; it flexed at the knee and rolled forward widening the foot base. The trunk flexed and the body weight was slowly transferred on to the front foot. The back leg extended and abducted causing inversion of the ankle. The bottom arm abducted across the body, extending at the elbow as the stick remained in a vertical position. The shoulders remained rotated in the opposite direction to the shot, until just before loss of contact.

The power for this shot came from the rapid rotation of the shoulders and the hips in the direction of the shot, and also from the powerful extension of the back leg at the hip, knee and ankle. The extension of the back leg almost caused it to lift from the floor. The hands reversed their action just before loss of contact.

During the follow-through phase (figure 6.10) the shoulders continued to rotate and the arms extend. The hips were prevented from over-rotating by the back leg, which extended further behind the body. The trunk flexed further, and the front leg also flexed further and rolled forwards.

During the recovery phase (figure 6.10) the hips rotated slightly further. The back leg relaxed at the hip, knee and ankle, and rested on the floor, before being adducted towards the body. The shoulders ceased rotating and began to return to a normal skating position. The arms flexed at the elbows and were brought in towards the body. The upper body started to extend to a more erect position.

The moving backhand flick shot was very similar to the stationary shot, except during the starting position both feet faced the direction of motion. The muscles involved in the stationary and the moving backhand flick shots are detailed in Appendix 2.

Quantitative analysis.

This section examines the information gained from the qualitative analysis regarding the timings involved in each phase of each action; this enables skating actions (table 6.0) and hockey actions to be compared (tables 6.1 and 6.2). Also included in this section are the ball velocity data obtained during shooting and passing (table 6.3).

Due to the varying lengths of the different roller hockey actions, the times in tables 6.0 – 6.2 are presented as percentages of the total action time. For skating actions the percentage of time spent performing each phase is absolute. The actual duration of each of these phases may be altered by changes in velocity, but the proportional divisions of each phase of the action (the percentage) should remain relatively constant and when amalgamated should make one complete stride. During hockey actions, however, the proportional timings of the preparation phase and the recovery phase may vary considerably. For example, it is suggested that a player may prepare for a shot much more quickly if pressured by an opponent and also may recover much more quickly if necessary. The percentages of the other movement phases during hockey actions should remain relatively constant. Therefore the data presented on the timing of the phasic activity during hockey actions (tables 6.1 and 6.2) concentrates on the phases involved in the execution of the shot or the pass, excluding the preparation and recovery phases. For comparison purposes, the total duration of each action is also presented in seconds to give an indication of the length of time taken to execute each action (excluding preparation and recovery phases).

Table 6.0: The phasic activity of each skating action.

ACTION	PHASES OF ONE STRIDE				DURATION (seconds)
PUSHING	**Extension** 20%	**Recovery** 60%	**'Double support'** 20%		0.6
SPRINTING	**Extension** 28.57%	**No support** 28.57%	**Recovery** 42.86%		0.32
SLIDE STOP	**Preparation** 21.74%	**Rotation** 17.39%	**Slide** 30.43%	**Stationary recovery** 30.43%	0.92

Table 6.1: The phasic activity during passing as a percentage of the total action.

ACTION	PHASES OF EXECUTION OF PASSES			DURATION (Seconds)
	Back-swing	Fore-swing	Follow-through	
One-touch Pass	0%	50%	50%	0.4
Stationary Pass	29.41%	35.29%	35.29%	0.68

Table 6.2: The phasic activity during shooting as percentages of the total action.

ACTION	PHASES OF EXECUTION OF SHOT			DURATION (Seconds)
	Back-swing	Fore-swing	Follow-through	
Stationary Backhand Slap Shot	29.41%	29.41%	41.18%	0.68
Stationary Backhand Flick Shot	0%	53.85%	46.15%	0.52
Moving Backhand Slap Shot	28.57%	21.43%	50%	0.56
Moving Backhand Flick Shot	0%	45.45%	54.55%	0.44
Stationary Forehand Slap Shot	40.91%	31.82%	27.27%	0.88
Stationary Forehand Flick Shot	0%	72.22%	27.78%	0.72
Moving Forehand Slap Shot	35.29%	35.29%	29.41%	0.68
Moving Forehand Flick Shot	0%	53.85%	46.15%	0.52

Table 6.3: Indicative horizontal ball velocity during shooting and passing (±0.2 m/s).

ACTION	BALL VELOCITY (m/s)			
	Before or during contact	0.04s after contact	0.08s after contact	0.12s after contact
Stationary Backhand Slap Shot	0	17.5	20	X
Stationary Backhand Flick Shot	4.06	17.5	X	X
Moving Backhand Slap Shot	2.78	15	22.5	22.5
Moving Backhand Flick Shot	8	20	20	X
Stationary Forehand Slap Shot	0	20	25	X
Stationary Forehand Flick Shot	3.94	15	X	X
Moving Forehand Slap Shot	3.33	22.5	25	X
Moving Forehand Flick Shot	6.61	20	20	X
One-touch Pass	X	12.5	12.5	12.5
Stationary Pass	0	11.25	16.25	16.25

* X represents unknown velocities, due to the angle of motion of the ball, or to loss of visual contact with the ball.

DISCUSSION

The first aim of the third study within this thesis was to determine the muscles used to perform each roller hockey action. To achieve this, each action was broken down into movement phases and each phase was further broken down into joint actions; this enabled the theoretical identification of the muscles responsible for each joint action. The large number of roller hockey actions analysed (14) led to the establishment of an even larger number of movement phases. The major joint actions that were identified in this study were hip flexion, hip extension, knee flexion, knee extension, plantar flexion, leg abduction and adduction, and lateral and medial leg rotation in the lower limbs, and rotation of the torso, abduction and adduction of the arms, extension and flexion of the shoulders and arms, and the action of the forearms and the wrists (whilst gripping the stick) in the upper body.

There were many active muscles, both eccentrically and concentrically during each action and many of the different roller hockey actions involved similar joint actions resulting in similar muscular activity. Consequently Appendix 2 contains lists of all the muscles that were theoretically active during each movement phase.

As well as establishing major joint actions and muscular activity, the qualitative analysis also revealed a number of unusual characteristics. Firstly, during pushing the power to propel the subject forward was exerted perpendicular to the direction of motion. For example, to move forwards the subject had to push-off sideways. This characteristic was also reported in 'ice speed skating' by De Boer *et al.* (1987b), De Koning *et al.* (1991a) and De Koning *et al.* (1991b). Secondly, during shooting and passing the qualitative analysis indicated the 'reversal of the hands' just before contact. This manoeuvre was also reported by Walter (1966) in the field hockey flick shot and Halliwell *et al.* (1978) during the slap shot in ice hockey. Halliwell *et al.* (1978) reported that the reversal of the upper hand occurred earlier during the low shots. They also found that for high shots the lower hand was 14 cm ahead of the puck at contact, and for the low shots it was 8 cm behind the puck at contact. It must be remembered that due to the length of the ice hockey stick (58 cm longer than the roller hockey stick) these measurements are not transferable to roller hockey. Thirdly, the qualitative analysis in this investigation described the motion of the back leg during shooting and high intensity passing. During these actions the power to propel the ball came from the rotation of the shoulders and arms towards the direction of the pass or shot, followed by rotation of the hips in the same direction. These rotational forces might have been translated into the lower body causing instability, but the back leg rotated behind the body in the opposite direction to counteract them. This movement of the back leg was essential to maintain balance and counteract the rotational force of the trunk.

This study is the first kinesiological analysis in roller hockey and limited comparable research exists. The pushing action adopted by roller hockey players is similar to the movement used by ice speed skaters. De Boer *et al.* (1987b) and De Koning *et al.* (1991a) analysed the muscle co-ordination patterns during 'ice speed skating' and reported similar joint actions and muscular activity as those observed during pushing in this investigation.

The joint actions and the muscular activity observed during shooting support the findings of Alexander *et al.* (1963) in ice hockey. This group analysed ice hockey shooting using cine film, and determined the muscular actions of the shoulders, arms and wrists during the flick shot and the slap shot; their results were similar to those observed during this investigation.

The quantitative analysis of the phasic activity during skating actions (table 6.0) revealed that the duration of the sprint stride was almost half that of the pushing stride. In both sprinting and pushing the longest phase was the recovery phase. When pushing to gain maximum speed, the duration of the 'double support' phase represented 20% of the total action; this phase should be kept to a minimum to minimise the loss of speed through friction.

The phasic activity during shooting (table 6.2) demonstrated that the durations of all the moving shots were shorter than for corresponding stationary shots, and that all backhand shots had a shorter duration than the corresponding forehand shots. Flicks shots had a shorter duration than the corresponding slap shots, because the slap shot consisted of a back-swing and a fore-swing phase, whereas the flicks shot did not.

The horizontal ball velocity during shooting (table 6.3) indicated that all shots executed whilst skating created faster ball velocities than corresponding stationary shots. It is suggested that this difference is due to the transfer of momentum from the moving body into the ball. This suggestion was supported by Alexander *et al.* (1963) who, during analysis of ice hockey shooting, showed that all ball velocities for skating shots were faster than shots executed whilst stationary. The current investigation also showed that in most instances that the slap shots produced higher ball velocities than the flick shots, which also supported the observations by Alexander *et al.* (1963) during shooting in ice hockey.

It is interesting to note that the ball velocities at the start of the flick shots remained constant; however, at the start of the slap shots the ball velocities increased. The increase in velocity during the initial stages of the slap shot was evident because the force to propel the ball was imparted by the sudden impact of the stick and consequently the ball was still accelerating during the initial stages of the shot. During the flick shot the velocity of the ball increased whilst the ball was still in contact with the stick (during the fore-swing phase of the shot).

The kinesiological analysis identified a large number of muscles involved in the performance of key roller hockey actions (see Appendix 2). Although kinesiological analysis can be used to identify theoretical muscular activity during these actions, further objective information on actual muscular activity can be obtained using electromyography (EMG). The proposed EMG investigation was limited by the availability of an 8 channel EMG radio-telemetry system. So for the purposes of the EMG investigation, eight key muscles important across a range of roller hockey specific actions needed to be identified to ensure that maximum value could be gained from the EMG analysis.

Therefore, the second aim of this investigation was to establish a theoretical hierarchy of muscles that are central to the performance of roller hockey actions. The qualitative analysis established joint actions, while Appendix 2 lists all the active muscles during each of these joint actions. It must be remembered that skating actions occur during 100% of actual match play, whereas so-called hockey actions accounted for only 13% of match play (chapter 4). Consequently the demands placed on the skating muscles are greater from a temporal point of view, but this does not necessarily make them more important.

The information gained from the match analysis and the results of this kinesiological investigation enabled the identification of eight muscles central to the performance of roller hockey actions for use in the EMG analysis. Due to the constraints of the EMG recording procedures these muscles needed to be superficial and easy to locate; they also needed to be representative of as many key joint actions as possible and incorporate movements of the whole body. Due to the limited number of muscles that could be analysed, compromises had to be made.

The key joint actions identified during this investigation were firstly hip flexion, the major muscles involved in this movement being the rectus femoris, tensor fasciae latae, and sartorius (Daniels *et al.*, 1956). The rectus femoris is also involved in knee extension; this muscle was chosen for the EMG analysis due to its function in both key joint movements and its large, superficial nature. The sartorius as well as being involved in hip flexion, is also involved in hip abduction and external hip rotation with knee flexion (Daniels *et al.*, 1956). This muscle was chosen for analysis using EMG during roller hockey because of its possible role during the pushing action. Hip extension is another key joint action identified in roller hockey; the major muscles involved in this action are the gluteus maximus, semitendinosus, semimembranosus, and the biceps femoris. The gluteus maximus was chosen for the EMG analysis due to its action as a hip extensor and because of its large, superficial surface area. The other three muscles involved in hip extension are also knee flexors, therefore the semitendinosus was chosen for the EMG investigation due to its role as both a hip extensor and knee flexor and its easy identification. There are five major muscles involved in hip adduction, the largest being the adductor longus (Daniels *et al.,* 1956), which due to its superficial nature and ease of identification was chosen for EMG analysis. In the lower leg the gastrocnemius is the largest and most superficial of the plantar flexor muscles and consequently this muscle was also selected for EMG analysis. In the upper body, rotation of the torso was identified as a key movement during performance of actions specific to roller hockey. There are many muscles both superficial and deep involved in the movement of the torso. The latissimus dorsi is the largest superficial muscle across the lower back; as well as being involved in the movement of the torso it is also a major shoulder extensor muscle. Due to its superficial nature, easy identification and its role in the movement of the torso and extension of the shoulder, the latissimus dorsi was selected for analysis using EMG. The major muscle involved in shoulder adduction is the pectoralis major; this muscle is superficial and easy to locate and was therefore selected for EMG analysis.

The eight muscles selected were involved in as many key joint actions as possible, but due to the limited number of muscles that could be analysed, compromises had to be made. There are some key joint actions that are not covered by the muscles selected; these are medial hip rotation, ankle inversion and eversion, shoulder flexion, arm abduction, and the actions of the forearms and the wrists. Medial hip rotation during roller hockey was considered more of a passive action and therefore other joint actions were considered of greater importance for the EMG analysis. Ankle inversion and eversion, arm flexion and abduction, and the movement of the forearms and wrists, may all involve key muscular activity, therefore it is suggested that future research may benefit from analysing the EMG activity of the tibialis anterior and the peroneus longus (for ankle inversion and eversion), the deltoids (for shoulder flexion and abduction), the biceps and triceps brachii (to monitor the movement of the forearms) and the brachioradialis or flexor carpi ulnaris (to monitor the actions of the wrist).

Error Section

An important factor to remember when drawing conclusion from this kinesiological investigation is that the actions analysed were performed in isolation, outside of a match setting and performance of these actions during a match may occur under many different circumstances. These actions may be affected by many internal and external factors such as the opposition, the score, and fatigue, to name but a few. The intensity and the speed of application of these actions may also vary in a match situation. The demands of the skating actions may be altered if performed with the ball, although chapter 4 reported only 13% of a match was spent in contact with the ball. All of these factors may affect the overall timing of individual phases and for some actions, the level of the muscular activity.

Other factors that should be considered when performing any joint and muscular analysis include the activation and action of multi-joint muscles, the co-contraction of synergists and antagonists, and contributions to segmental kinetics by passive sources, that is, elastic energy from stretched muscles and passive joint torques arising from ligaments, cartilage and joint capsules (Rasch, 1989).

This study used only one subject; this approach was adopted due to the amount of data derived from this analysis. It was considered more important to analyse as many actions as possible rather than using more subjects and limiting the number of actions under investigation. Future research may benefit from analysing a small number of actions and using more subjects. However, the current investigation successfully established a theoretical understanding of the major joint actions and the muscles involved in each roller hockey movement, but it should be noted that these might have been influenced by the technique of the subject.

This study also involved a two-dimensional video analysis; a three-dimensional video analysis may have been more desirable, but again this would have increased the workload considerably for limited gains. The subject performed all the actions in this study on the same day; due to the length of time taken to collect all the data, there may have been a performance detriment towards the end of the data collection; however, verbal feedback from the subject suggested that this was not so. Future research may benefit from limiting the time of the data collection sessions.

Finally the selection of 8 muscles that appeared central to the performance of roller hockey actions for the EMG analysis was a subjective choice. This choice was based on information gained from this kinesiological analysis and information from the match analysis (percentage of time spent performing each action). However, due to the limited number of muscles that could be chosen, compromises had to be made. Future research on muscular activity during roller hockey may benefit from analysing the EMG activity of other muscles, excluded from this analysis during roller hockey match play.

CONCLUSION

This study was the first kinesiological investigation in roller hockey. Chapter 4 (the match analysis) established the main actions performed by a roller hockey player in a match situation. This kinesiological analysis then established all the movement phases and joint actions involved in each of these roller hockey actions. This enabled the theoretical identification of the muscles that were active during each of these roller hockey actions. The key joint actions during roller hockey were identified as hip flexion and extension, knee flexion and extension, plantar flexion, leg abduction, adduction, and medial and lateral rotation, rotation of the torso, abduction and adduction of the arms, flexion and extension of the shoulders and arms, and movement of the wrist.

Establishment of the key joint movements during roller hockey actions enabled the theoretical identification of the key muscles during roller hockey. These were rectus femoris, sartorius, gluteus maximus, semitendinosus, adductor longus, gastrocnemius, latissimus dorsi, pectoralis major, tibialis anterior, peroneus longus, deltoids, biceps brachii, triceps brachii, and brachioradialis.

Having gained a theoretical understanding of the muscular activity during roller hockey, the only way to objectively assess muscle activity is electromyography. This thesis will now move on to study the actual activity of these key muscles during roller hockey training and match play. Due to the EMG equipment available only 8 muscles could be analysed, therefore compromises had to be made. Future research may continue to analyse the EMG activity of the other muscles (emitted from this analysis) during roller hockey training and match play.

CHAPTER 7

ANALYSIS OF ELECTROMYOGRAPHY ACTIVITY DURING ROLLER HOCKEY TRAINING

INTRODUCTION AND REVIEW OF LITERATURE.

Electromyography or EMG is the study of muscle function through analysis of the electrical signals the muscle emanates (Basmajian and De Luca, 1985). Its value in objectively assessing muscle activity in sport is unquestionable; it is a procedure that encourages more focused training and the optimisation of technique. The kinesiological analysis (chapter 6) established a hierarchy of muscles' importance during performance in roller hockey. Electromyography (EMG) is the most important method of objectively assessing when a muscle is electrically active (Grieve, 1975). Consequently, to validate the kinesiological analysis and offer roller hockey players a comprehensive understanding of muscular activity during roller hockey, an electromyographical analysis of these muscles during roller hockey match play is essential.

The aim of the final study within this thesis is to monitor, using electromyography, the activity of the muscles defined in the previous chapter as central to roller hockey match play during training sessions and training matches.

Electromyography is a complex procedure, so this chapter begins with a brief review of the historical development of EMG. This is followed by a review of the processes involved in electromyography; these are the neuromuscular system, the recording system, data processing, and normalisation. Factors influencing the EMG signal and the relationship between EMG and force are then discussed, and finally relevant scientific research is considered.

In 1666 Francesco Redi was the first scientist to deduce that muscles generate electricity (Biederman, 1898 cited in Clarys and Cabri, 1993). The terminology of the electromyogram originated in 1890 as Marey modified an instrument of Helmholtz and called it a "myograph", and denoted muscular activities as "myographic patterns" (Clarys and Cabri, 1993). Improvements in EMG technology led to an increase in the application of EMG in many areas including neurology, neurophysiology, neurosurgery, bioengineering, functional electrical stimulation, orthopaedics, rehabilitation, ergonomics, occupational biomechanics, zoology, physical therapy, sports medicine and sport science (Clarys and Cabri, 1993). This list of diverse applications of EMG highlights its value across science in general.

The growth of EMG research primarily occurred in two areas. The first area is clinical electromyography, where EMG is used to differentiate various types of conditions that affect the neuromuscular system. The second is kinesiological EMG, which aims to study muscular function and co-ordination (Clarys and Cabri, 1993). This review now focuses on kinesiological EMG research.

The pioneering work in kinesiological EMG occurred at the University of California, in the 1950s (Clarys and Cabri, 1993). Much of the early research in this area was concerned with isometric contractions in a controlled laboratory environment. The range of EMG applications, studies within kinesiological EMG research may be further broken down. Clarys and Cabri (1993) offered a comprehensive list of the research areas within kinesiological EMG, and one such research area is the study of muscle activity in complex sports, which is the focus of this investigation. The value of testing muscular activity during a sporting setting in a field environment was clear, and at the end of the 1960s work began on miniature telemetric devices for monitoring and recording EMG signals remotely (Clarys and Publie, 1987). Since the development of remote telemetry systems and the technological advances in EMG systems, the study of muscular activity in complex sports has become a more widely used research method. As in all areas of sports science, some sports have generated more interest than others. Despite these technological advances the process behind EMG data collection is still complex and should be fully understood by the electromyographer before conclusions can be drawn.

Consider first the neuromuscular system. During muscle activation an electrical signal travels along the nerve fibre, which innovates a number of muscle fibres. These fibres are collectively known as a motor unit. Once the electrical signal reaches the motor unit, it then travels in both directions along all the muscle fibres within that motor unit simultaneously. This electrical signal causes the depolarisation and repolarisation of the surface membrane of the muscle fibre, and the muscle contracts. Muscle fibres from one motor unit are distributed throughout a muscle. This depolarisation and repolarisation of the surface membrane of the muscle fibre is the ultimate source of the electrical potential changes from within the muscle; the EMG signal is a representation of these electrical potentials changes that are known as action potentials (Clarys and Cabri, 1993).

The recording system of the EMG is complex and consists of a number of elements, beginning with the signal detection electrodes. There are two different types of electrodes, indwelling and surface electrodes. Indwelling electrodes can be used to study deep muscles or the electrical activity of a single motor unit or muscle fibre; these electrodes are more common in a clinical setting. There are two types of indwelling electrodes, needle and fine wire electrodes. Needle electrodes are typically used for clinical pathology investigation as they can identify and locate the signals from individual muscle fibres. Fine wire electrodes consist of a pair of twisted alloy wires. They are inserted into the muscle with a hypodermic needle, and taped to the skin at entry. Bartlett (1997) recognised a number of disadvantages of this type of electrode; firstly, it is difficult to locate deep muscles and the signal recorded is a function of the length of the tip exposed on the wire. The wires may deform, fracture or even break whilst in the muscle. There is the possibility of damaging the muscle fibres, and also the risk of infection.

Surface electrodes on the other hand are attached by adhesive to the surface of the skin. There are two types of surface electrodes, passive and active (Bartlett, 1997). Passive surface electrodes vary in construction and size. Clarys and Cabri (1993) stated that they usually consist of a simple silver or silver chloride disk surrounded by some form of adhesive. They are usually used in conjunction with electrode gel to enhance the skin electrode contact. Bartlett (1997) noted the advantages of passive surface electrodes as convenient and readily available, require little operator training and cause little or no discomfort to the subject. Passive surface electrodes are not ideal for fine movements and are mainly used for fairly large groups of muscles; also due to the large pick-up area of some surface electrodes, they may register activity from muscles other than that being tested (this phenomenon is known as 'cross talk'). Furthermore, it is often necessary to reduce the contact resistance between the skin and the electrode and this skin preparation may prove to be relatively time consuming (Bartlett, 1997). Active surface electrodes on the other hand require no skin preparation or electrode gel. They do, however, require a power supply to the electrodes, which increases the overall noise levels and may raise health and safety issues. This type of electrode has only recently become commercially available (Bartlett, 1997).

The passive surface electrode is the most commonly used electrode within sports kinesiological EMG research. Passive surface electrodes are also the most advocated of all the electrodes discussed and therefore were adopted for the current study and form the focus of the following review.

The size of the signal detected in passive surface electrodes is very small (up to 5mV; Bartlett, 1997). This makes it vulnerable to interference from other electrical sources, which is known as 'noise'. To reduce noise a bipolar electrode configuration is adopted. This means that two electrodes are used for each muscle; they are attached to a differential amplifier, which eliminates the electrical activity common to both electrodes. The success of the system at removing all common activity is expressed by the common mode rejection ratio and, according to Winters *et al.* (1980), this should be between 80 – 90 dB.

In order to make comparisons of EMG studies between subjects and between laboratories, not only should similar types of electrodes be used, but also the placement of the electrodes on each muscle must be controlled, despite vast differences in anatomical structure between subjects (e.g. the size and the definition of the muscles). According to Zipp (1982) the placement of passive surface electrodes should meet several requirements, namely good repeatability, consideration of individual body dimensions and a high signal yield. In order to provide good repeatability in the placement of the surface electrodes, Zipp (1982) recommended measuring from one designated point to another on each muscle, calculating the mid-point and then placing the two electrodes either side. This process requires a comprehensive list of designated points for each muscle and may prove to be time consuming. Clarys and Cabri (1993) recommended placement of the electrodes over the mid-point of the contracted muscle belly. This method is less time consuming, it allows for individual differences in body dimensions and provides reasonable repeatability both within and between subjects, and hence was the method employed in this investigation.

It is commonly acknowledged that bipolar electrodes should be placed in line with the muscle fibres (Clarys and Cabri, 1993). If, however, the fibres are not linear or parallel to each other, Clarys and Cabri (1993) recommended that the electrodes should be placed in line with the origin and insertion of the muscle.

The inter-electrode distance is another variable that needs to be controlled as it may also affect the EMG signal. The separation of the electrodes determines the degree of localisation of the signal pick up. Basmajian and De Luca (1985) recommended an inter-electrode distance of 1 cm. The size of the muscle itself also has a bearing on the inter-electrode distance. In this study the muscles under investigation are large muscles and the focus of this study is the global activity of these muscles. In this situation Zipp (1982) recommended an inter-electrode distance of 4 – 5 cm and a contact area of 50 mm^2, suggesting that this is a good compromise for medium to large size muscles regarding selectivity, representativity and signal amplitude.

The skin itself presents some resistance to the conduction of the electrical activity emitted from the muscle to the electrode. The amount of resistance is complex and varies depending on the skin site, the subject, the time, and the skin preparation (Clarys and Cabri, 1993). Therefore the application of passive surface electrodes requires some form of skin preparation. Common recommendations are the shaving of surface hair, cleaning the skin with alcohol to remove the dead surface layer of the skin along with its protective oil (Clarys and Cabri, 1993) and abrading the skin with a rough material such as sandpaper or wire wool. Bartlett (1997) recommended that after skin preparation and electrode attachment, the resistance or impedance of the skin should be checked. Clarys and Cabri (1993) suggested that the level of skin resistance should be lowered to less than 10 kΩ. The cables connecting the electrodes to the differential pre-amplifier should be secured to the skin to prevent movement, as this may cause artefacts in the recorded EMG trace.

Artefacts are a common problem in electromyography; the recognition and elimination of these is essential when processing the EMG signal, as the inclusion of an artefact could distort the results, severely. Artefacts can originate from a number of sources; 1) electrode movement (movement artefacts), 2) from electrical power cables in the surrounding area (interference), and 3) movement of the leads (mechanically induced artifacts). Each manifests itself in different forms in the resultant EMG trace. Recognition of the type of artefact by the electromyographer is important both at the time of recording so that the cause can be eliminated, and during subsequent analysis to protect the quality of the data.

Electromyography amplifiers should meet several requirements, the main one being a high ratio of output to input voltage; this is know as the gain (Winter, 1990; and Bartlett, 1997). Bartlett (1997) listed the requirements of a good EMG amplifier as, linear amplification over the whole frequency and voltage range, high input impedance (which counterbalances high skin resistance) and minimal noise. The frequency response should be between 10 – 1000 Hz for surface electrodes and a high common mode rejection ratio is also required (Winter, 1990).

Once the signal has passed through the amplifier it can then be monitored immediately using a continual feedback system (e.g. oscilloscope), or recorded for subsequent analysis. Immediate feedback of the EMG signal can be a useful biofeedback aid. Using biofeedback of EMG activity, Basmajian and DeLuca (1985) reported that subjects could be trained to isolate one motor unit and control it very effectively, increasing and decreasing the firing rate. Biofeedback of EMG activity could also be useful during relaxation, and technique analysis. However, regularly within EMG research it is important for the signal to be recorded for subsequent analysis. Many different instruments have been used to record the EMG signal including ink writers, tape recorders, oscillographs (Bartlett, 1997) and more recently with the advancement in technology the most commonly used recording device is the computer processor.

Some EMG systems require the subject to be attached by cables to a computer or recording device; this is obviously not ideal for recording EMG activity in a sports environment. More recently systems consisting of a compact, portable digital data logger, that records EMG activity for a short period of time and can subsequently download the EMG data onto a computer, have become commercially available. Finally, there are radio telemetry systems that remotely transmit the electromyographic signal in real time to a computer.

Clarys and Publie (1987) believed the greatest advantage of the telemetry system is that it allows the subject total kinesiological freedom within a sports environment, without inhibiting performance in any way. The other advantages of the telemetry system are that the set up can be adapted to the specificity of the field and movement circumstances, long term movements can be measured continually over several minutes, 6 or 7 muscles can be monitored simultaneously, and it is simple to operate (Clarys and Publie, 1987). More recently radio telemetry devices have been developed that record more than 6 or 7 muscles simultaneously and data can be recorded over longer time periods (limited only by the memory capacity of the recording device). Other advantages of the telemetry system not mentioned by Clarys and Publie (1987) are the ability of the system to record over relatively large distances, which open up analysis of numerous sports where the subjects cover large surface areas, and also that it is possible to monitor a subject's activity when an opponent or opposition are involved, which was not possible previously. Clarys and Publie (1987) acknowledged the disadvantages of the telemetry system to include the difficulty of linking more than 2 or 3 transmitters in parallel due to limited radio-wave possibilities, and the occurrence of uncontrollable breaks in transmission due to atmospheric, static or other disturbances.

Having recorded the EMG activity, it is then important to match this activity to the performance of the subject. O'Connell and Gardner (1963) suggested "the most accurate method of correlating multi – joint movements with EMG recordings is through synchronisation of motion pictures with the EMG" (p 181). Accurate synchronisation is essential. Various methods have been reported, such as lights flashing on the visual recording when the EMG data collection commences or occurrence of artefacts in the EMG signal when visual recording commences (O'Connell and Gardner, 1963).

Having accurately synchronised and recorded the EMG and visual images, the EMG signal can then be analysed. The recorded electromyogram consists of positive and negative components, oscillating about a zero baseline and may be referred to as the raw EMG. The raw EMG provides important information on the electrical activity of the muscle under observation; "visual inspection of the raw EMG is the most common way of examining muscle activity as it changes with time" (Dainty and Norman, 1987, p 117). Artefacts are also evident in the raw EMG and should be recognised and eliminated. Having examined the raw EMG and eliminated artefacts, the data can then be processed in many different forms, making them more manageable and easier to interpret. Dainty and Norman (1987) suggested that the quantification of the amount of activity was necessary as it enables researchers to compare results not only in their own laboratory, but also between laboratories.

Within kinesiological EMG processing, two major techniques are commonly used – temporal processing and frequency domain processing (Clarys and Cabri, 1993). There are various temporal processing methods such as half and full wave rectification, average rectified EMG, root mean squared EMG, integrated EMG, linear enveloped EMG and differentiated EMG. Bartlett (1997) and Winter (1990) reviewed these processes. Frequency domain processing usually involves processing the EMG signal as a power spectrum. The frequency of the EMG signal is affected by fatigue (Bigland-Ritchie, 1981) and therefore frequency domain processing is valuable in the study of muscular fatigue. In the current investigation, interest is in the comparison of the amount of EMG activity over time and therefore this review focuses on the temporal processing of the EMG signal.

Within temporal processing De Luca (1997) regarded root mean squared and the average rectified value as the two most commonly used processing methods within kinesiological EMG; "both are appropriate and provide useful measurements of signal amplitude" (De Luca, 1997, p 142). The root mean squared processing "is the square root of the average power (voltage squared) of the signal in a given time" (Bartlett, 1997, p 240). Basmajian and De Luca (1985) suggested root mean squared processing provides a measure of the number of motor units recruited during voluntary contraction where there is little correlation among motor units.

The average rectified EMG, according to Basmajian and De Luca (1985), is used widely due to "its historical precedent.....its application has been continuously employed over the past three decades" (p 111). De Luca (1997, p 142) stated that "the average rectified value is a measure of the area under the signal and hence does not have a specific physical meaning". Clarys and Cabri (1993) stated that after full wave rectification (reversing the sign of all negative values), it is useful to observe the changes in activity with time. The mathematical expression for the average of the rectified EMG signal (AREMG) is:

$$AREMG = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} |EMG| \, dt$$

Clarys and Cabri (1993)

This equation involves rectifying the EMG signal, integrating it and dividing by a given time integral. Clarys and Cabri (1993) noted that if the time decreases, the smoothing effect also decreases. The time of the integral is determined by the focus of the study and could be the total activity time, or it could be a moving average often referred to as a moving window.

Simply processing the raw EMG data does not allow comparisons between muscles, between subjects or between laboratories. This is because muscles vary greatly in many ways which affect the amount of activity recorded, e.g. muscle size and training status. Two muscles (one small and one large) may both be maximally activated but may display very different levels of EMG activity. This makes it impossible to drawn a conclusion that the large muscle is more active than the small muscle. Consequently various techniques have been developed to normalise EMG data and enable cross comparisons. During EMG normalisation Clarys and Cabri (1993) stated that generally the subject is asked to perform a maximum voluntary effort (MVC) of the muscle being studied. This amplitude, either raw or rectified, is then used as a reference value. However, some investigators have found dynamic activities that exceed the MVC. Therefore other normalisation techniques have been suggested in kinesiological EMG e.g. normalising to the highest peak activity in dynamic conditions (maximum dynamic contraction, MDC), normalising to the mean integrated EMG (ensembles average), or normalising to the EMG per unit of monitored force (net moment) (Clarys and Cabri, 1993).

Obtaining an accurate and relevant MVC is difficult for a number of reasons. It is impossible to know (without the aid of an electrical stimulator) whether the subject has actually generated an MVC (De Luca, 1997). There is the problem of motivating the subject to elicit an MVC, and it is imperative to determine the best angle for the appropriate contraction. De Luca (1997) suggested that an MVC requires "a comprehensive knowledge of the biomechanics and anatomy of the muscles and joints.... such attempts are susceptible to subjectivity and outright failure" (p 154). Dainty and Norman (1987, p 120) stated that "there is no consensus at present as to a standard method of eliciting a maximum contraction because of variations in muscle length with different limb positions and the inhibitory influences present in agonist and antagonist muscle groups. However, such normalisation techniques are indispensable for comparisons between different subjects and for retrials on the same subject". Therefore EMG normalisation is an area that needs to be carefully considered during EMG studies.

So far this chapter has highlighted the complexity of both EMG data acquisition and EMG signal processing. It is important that the electromyographer is aware of the factors affecting the EMG signal and controls for these factors where possible. Care must be taken during data analysis to choose suitable procedures and retain data integrity.

There are many factors that influence the EMG signals. Bartlett (1997) and De Luca (1997) divided the factors that affect the EMG signal into two categories intrinsic and extrinsic factors. Intrinsic factors were described by Bartlett (1997) as either physiological, e.g. firing rate of motor units, fibre type, conduction velocity of the muscle fibre, and volume of the muscle, or anatomical, e.g. muscle fibre diameter and position. These are factors over which the electromyographer has little control. Extrinsic factors are controllable and include the orientation, location and configuration of the electrodes (De Luca and Knaflitz, 1992; Bartlett, 1997; and De Luca, 1997).

Another factor reported by Clarys and Cabri (1993) that may influence the EMG signal is that muscles do not always stay in the same place during complex dynamic movements. The entire muscle belly may not be fully under the detection electrodes, but covered by parts of other muscles and tendons. There is also the problem of cross-talk, where the EMG signal picks up activity from neighbouring muscles. In the leg De Luca and Merletti (1988) reported as much as 17% of electrical activity from nearby muscles may be detected on the surface of the muscle of interest. Various methods have been suggested to reduce or eliminate cross-talk. De Luca (1997) suggested double differentiation, where three electrodes produce two differential signals, which are again differentiated. Other methods, such as stimulating the surrounding muscles, have been suggested. These factors must be considered, as valid conclusions have to be based on the assumption that the researcher knows exactly from which muscles the signals are being recorded (Clarys and Cabri, 1993).

When reviewing electromyography, it is impossible to ignore the relationship between the EMG signal and the resultant muscular force. The relationship between the two is unclear, although logic suggests that if EMG indicates the level of excitation in the muscle and force is dependent on the excitation in the muscle, there should be a relationship (Bartlett, 1997). This relationship is not necessarily linear. De Luca (1997, p 137) believed that the relationship is unclear because the EMG "is the result of many physiological, anatomical and technical factors". Bigland-Ritchie (1981) believed that the relationship between EMG and force is dependent on the physiological properties of the individual muscles. Due to the ambiguity of the EMG/force relationship when examining, analysing and drawing conclusions from EMG studies, results should refer to levels of electrical activity and not to levels of muscular force or contraction.

The monitoring of electromyographic activity during a sporting context brings added complications. There are many factors that influence the movement of the subject within the sport, "the majority of activities involve complex movement patterns often complicated by external forces, impacts and the sports equipment used during the movement" (Clarys and Cabri, 1993, p 386). These factors are often uncontrollable and may actually be the focus of the EMG investigation. Consequently Clarys and Cabri (1993) acknowledged the importance of understanding an EMG of a sports movement pattern as an expression of the dynamic involvement of specific muscles within a determined range of that movement.

Despite the number of factors that may affect the EMG signal, it can still be used with confidence to determine, in a particular subject, when muscle activity starts and finishes. Electromyography has also provided invaluable information in many different sporting disciplines. "The knowledge of such muscular actions in all its aspects, its evaluation and its feedback should allow for the optimisation of movement, of sports materials, of training possibilities and in the end of sports performance" (Clarys and Cabri, 1993, p379).

Having reviewed EMG data acquisition, EMG data processing and the factors that may influence the EMG signal, this chapter now moves onto review EMG research in sports relevant to roller hockey. A review of sports kinesiological EMG research revealed that some sports have received a lot more attention than others. Clarys and Cabri (1993) presented an excellent review of the sports in which EMG research has been conducted. To date no reports of EMG studies during roller hockey have been located. Previously in this thesis roller hockey was likened to ice hockey, but there are no reports of EMG research in ice hockey. Roller hockey consists of roller-skating and hockey skills, however, no EMG research was located in roller-skating, and the EMG research available in field hockey is considered irrelevant to roller hockey due to large differences that exist between the sports. Finally ice-skating involves a similar skating technique to roller hockey (referred to in this report as 'pushing'). Clarys and Cabri (1993) in their review of EMG research mentioned four studies in 'ice speed skating', though they only identified two, De Boer *et al.* (1987b) and De Koning *et al.* (1991a).

De Boer *et al.* (1987b) examined the pattern of moments of force and power output at the ankle, knee and hip joints during 'ice speed skating', by studying push-off forces and muscle co-ordination (using cinematography and EMG). This report was the first EMG study in 'ice speed skating'; the subjects were two well-trained male speed skaters. A portable EMG data logger and active surface electrodes were used to collect data from the gluteus maximus, biceps femoris, semitendinosus, vastus medialis, rectus femoris and gastrocnemius lateral head. The EMG activity was processed using a linear envelope, and expressed as a percentage of maximum dynamic activity (MDC). The authors used a 10% threshold to distinguish on and off phases of activity. During the gliding phase EMG analysis showed knee extensor (vastus medialis and rectus femoris) and knee flexor (biceps femoris and gastrocnemius lateral head) activity, resulting in a locked knee joint; this activity was followed by a decrease in biceps femoris and gastrocnemius lateral head activity, as the vastus medialis and rectus femoris extended the knee during the push-off phase. For the hip joint the power mainly came from the gluteus maximus. The results showed that the biceps femoris and semitendinosus did not contribute to the generation of power during the skating stride due to their contraction being eccentric. Power for knee extension came from concentric contractions of vastus medialis and rectus femoris. The gastrocnemius lateral head was not active during push-off. De Boer *et al.* (1987b) concluded that the majority of the power during 'ice speed skating' came from the gluteus maximus and the vastus medialis.

In a similar study De Koning *et al.* (1991a) examined the co-ordination patterns of the leg muscles during 'ice speed skating' and compared skaters of different standards. They used eleven subjects and again recorded synchronised EMG, force and cinematography data. Electromyography data were collected from the semitendinosus, biceps femoris, gluteus maximus, rectus femoris, vastus lateralis, vastus medialis, gastrocnemius medial head, gastrocnemius lateral head, soleus and tibialis anterior, on one side of the body. The skin was prepared and passive surface electrodes with a 4 cm inter-electrode distance were used in conjunction with a telemetry system. The data were processed using AREMG and expressed as a percentage of MDC.

During the gliding phase the vastus medialis and vastus lateralis displayed constant activity while the gluteus maximus activity increased. The biceps femoris and semitendinosus activity peaked during the gliding phase (as reported by De Boer *et al.*, 1987b). Also in agreement with De Boer *et al.* (1987b), De Koning *et al.* (1991a) reported decreased biceps femoris and semitendinosus activity during the push-off phase, but increased activity of the rectus femoris. De Koning *et al.* (1991a) reported no difference between EMG activity of trained and elite skaters.

In a similar study De Koning *et al.* (1991b) examined muscle co-ordination and power during the curved sections in 'ice speed skating'. They used seven subjects and again recorded cinematography, force (using strain gauges in skates) and EMG activity from the semitendinosus, biceps femoris, gluteus maximus, rectus femoris, vastus lateralis, vastus medialis, gastrocnemius lateral head, gastrocnemius medial head, soleus, tibialis anterior, but this time from both legs. After preparing the skin, passive surface electrodes were placed over the muscle belly at a distance of 4 cm; the impedance levels were less than 10 kohms. The system was telemetric and synchronised with the other components being measured. The AREMG was expressed as a percentage of MDC.

The outside and the inside leg displayed differences in timing for the gastrocnemius lateral head, semitendinosus, and rectus femoris. The reported differences in the semitendinosus between the two legs were attributed to the adduction of the inside leg to push-off around the curve. There were also differences in velocity and force outputs of the inside and outside leg. The different co-ordination pattern of the muscles of the inside leg was concluded to be a result of hip extension being followed by both knee extension and plantar flexion simultaneously.

Having presented an overview of EMG and the relevant research in this area, the following study aims to monitor the activity of the muscles defined in the previous chapter as central to roller hockey match play during training sessions and training matches, using electromyography. The EMG results will be analysed using two data processing methods (peak value analysis and average rectified EMG analysis); this will enable comparison of these two forms of EMG data processing.

METHODS

The subjects were six members of a Premier League roller hockey team (top English league) during the 1997/1998 season. All players were male, free from injury and illness and were regular members of the first team. The characteristics of the players were: age 23.6 ± 3.9 years, mass 74.2 ± 5.9 kg, playing experience 12.6 ± 2.7 years (mean ± S.D.). No subject participated regularly in any other sport. All subjects gave written consent to participate in this study and completed a short questionnaire about their training activities, injuries and illnesses.

Subjects were monitored individually at their normal roller hockey training session. The muscles under investigation were established during the kinesiological analysis (chapter 6). Surface EMG activity of the following eight muscles was monitored: pectoralis major, latissimus dorsi, gluteus maximus, rectus femoris, semitendinosus, adductor longus, sartorius and gastrocnemius. Players' heart rates were recorded every 5 s using Polar Vantage Night Vision heart rate monitors. Video recordings were made of each player's movement throughout the session.

Subject preparation: For the purpose of familiarisation, the equipment and procedures were demonstrated to each subject. The eight muscles were identified using vision and palpation whilst performing specialised contractions to isolate the relevant muscle (Daniels *et al.*, 1956). The muscles in the upper body (pectoralis major and latissimus dorsi) were analysed on the side of the body that corresponded with that of the lower hand on the stick (it is suggested that this is the side where the power for shooting and passing the ball originates). The muscles in the lower body (gluteus maximus, adductor longus, sartorius, rectus femoris, semitendinosus, and gastrocnemius) were analysed on the dominant leg. Having carefully identified the correct muscle, a 5 cm grid (giving a standard electrode spacing of 3.5 cm from the mid-point of each electrode) was used to mark the position of the electrodes and to ensure standard inter-electrode distance on all eight muscles. This grid was placed over the visible belly of the muscle during contraction, as recommended by Clarys and Cabri (1993).

To reduce the impedance levels of the skin, the marked area was shaved to remove surface hair and cleaned using an alcoholic Medi Swab (Smith + Nephew) to remove any surface oil. Medicotest skin rasps were used to abrade the surface of the skin gently and to remove any dead skin cells. The area was then cleaned again with a Medi Swab to remove the dead skin. Neptic Electrode Gel (Sander Ltd) was then applied to the area and left on the skin for 2 min. The gel was then removed using Kimberley Clark Medical Wipes, to ensure the surface of the skin was dry before attaching the electrodes.

Bipolar silver chloride passive surface electrode discs (Blue Sensor disposable N-50-K, Medicotest, UK Ltd) 1.5 cm in diameter, were then attached to each muscle, in line with the muscle fibres. Each muscle had a reference electrode, which was attached to a non-muscular skin surface area (clavicle, hip and patella), which had been prepared in a similar manner. Some reference points were used more than once, by means of a bridging wire. All electrodes were further secured to the skin using Sleek tape (5 x 5 cm, Smith + Nephew). This tape is waterproof and was found to be the most effective due to the heavy levels of sweating that occurred during the training session.

The electrodes from each muscle and the reference electrode were then attached to the differential pre-amplifiers, which were mounted on the skin (again using Sleek tape) as close to the detection electrodes as possible. They were placed in a position so as not to hinder movement and cause minimal injury if fallen upon. Again due to excess sweating the differential pre-amplifiers were sealed completely using the waterproof Sleek tape. The differential pre-amplifiers had a gain of 4000, with a balance input impedance of 10 mΩ, a common mode rejection ratio of 110 dB and a signal to noise ration of –50 dB. The differential pre-amplifiers also had a frequency pass band of 6 – 330 Hz (3 dB point). The differential pre-amplifiers were connected to a portable eight-channel transmitter unit MT8 TX (MIE Medical Research Ltd), which for safety reasons (potential impacts) was covered completely in thick foam, and attached to the subjects back by a belt around the waist. Connecting wires were secured to the skin using Sleek tape to prevent movement artefacts. The subjects wore tight lycra shorts which were pulled over the electrodes and differential pre-amplifiers. This acted to secure further the instrumentation to the body and prevent the chances of injury to the subject or to others.

The myoelectric signal was transmitted to MTR8 biomedical telemetry receiver (MIE Medical Research Ltd) that was positioned at the edge of the rink. A Yagi aerial (2 metres high and 1 metre across) was used to minimise interference. The signal was displayed and recorded for subsequent analysis on a Viglen Genie 45X25 personal computer, with an Amplicon 16 channel 12-bit analogue to digital conversion card, and using the software Myo-Dat 3.0 Digital Data Analysis System (Orthodata GmbH D-Schwerten). The signal was sampled at 500 Hz. Recordings of the EMG activity were 17 s in duration (the longest duration available using the Myo-dat 3.0 software) these were made continually during actual training activity, with approximately 10 s downloading time to store information, between each recording. Recordings of EMG activity were not made during rest time. There was an average of 78 EMG traces of 17 s recorded for each player; which is equivalent to 22 min and 2 s, or 28% of actual training.

To record heart rate data the subjects wore a heart rate monitor band and transmitter (Polar Vantage Night Vision) around their chest. The transmitter unit was attached at the back of the chest strap for safety reasons and to prevent the subjects from obtaining visual information about their heart rate activity. The heart rate was recorded every 5 s throughout the 2-hour training session.

Having prepared the subject, the functioning of the EMG and heart rate systems were checked. Following this the three systems (video recording, EMG system and heart rate monitors) were synchronised. This was achieved using two Panasonic SVHS AGDP800E video cameras with field-by-field time coding; the two video cameras were synchronised using a clapperboard method, and the fields of the cameras were synchronised using a Genlock cable between the two cameras. The start of the heart rate analysis was recorded audibly into both video cameras. Following this, video camera (a) tracked the subject during the entire training session and video camera (b) focused on the visual display unit and keyboard of the EMG system. Thus the start of each EMG trace visible on video camera (b) could be synchronised with the activity of the player visible on video camera (a) and the heart rate response.

All analysed training sessions were supervised by the same coach (the England Men's Coach) and were two hours in duration. After the synchronisation of the equipment, the subject participated in the normal warm up procedure, without the ball at first and then with the ball. Following this warm up the subject performed maximum voluntary contractions (MVC). These were completed off the rink whilst the coach was talking to the other players. The MVC involved the subjects maximally contracting each of the eight muscles, individually. For each contraction the subject was carefully placed in the desired position (Daniels *et al.*, 1956), the procedure was explained to the subject and the MVC was practised. When the subject was ready, he performed the MVC, holding the contraction for a couple of seconds. Electromyography data were collected for 5 s, starting just before the MVC commenced. The subject gave feedback on whether he felt the contraction was maximal, if not the MVC was repeated. Subjects were given adequate rest between each MVC. Two MVC trials were performed for each muscle and the greater of the two chosen as the true MVC. Maximum voluntary contractions were repeated in an identical manner for all the subjects. The order of the MVC was also standardised across the subjects.

The subject then participated normally in the training session. Following the training session, the pre-amplifiers were removed and the impedance levels were tested (Appendix 3) using a Specialised Laboratory Equipment (Croyden, UK) impedance meter. This data collection aimed to disturb the training session as little as possible and to be as un-intrusive to the player's performance as possible. The feedback from the players regarding this was very positive.

Data analysis.

The heart rate data were downloaded on to Viglen Genie 45X25 Personal Computer using Polar Heart Rate Analysis Software version 5.04.02, and heart rate traces were then printed. The printed heart rate data were matched to the synchronised video recording and the subject's activity was noted.

Each raw EMG trace was analysed for the existence of artefacts, which were then eliminated from the subsequent analysis. For each muscle the EMG activity during the MVC recordings was processed to yield a linear envelope. From the linear envelope, maximum values for each subjects MVC were obtained. This procedure was repeated to obtain the maximum values achieved during the dynamic situation (MDC values). The EMG data analysis was divided into two parts, a qualitative analysis and a quantitative analysis. The data processing technique employed varied for each section and is described in detail within the results section.

RESULTS

The results are divided into two sections. The qualitative section contains descriptive reviews of the pattern of muscular recruitment during various roller hockey specific actions. In the quantitative section, the EMG results are analysed using two temporal data processing techniques; these are enveloped peak value analysis and average rectified EMG analysis (AREMG).

The EMG analysis took place during normal Premier league roller hockey training sessions. The activity during these sessions could be divided into six categories:

- Warm up skating and stretching; this was performed individually at the start of the session. It was always at low intensity and involved skating forwards and backwards around the rink at a self-selected pace, performing stretches whilst on the move, without a ball. Six training sessions were analysed and the average duration of warm up skating and stretching was 8 min and 14 s.
- Warm up with the ball; again this was performed individually at a slightly higher intensity and involved skating with the ball, dribbling, shooting and some dynamic stretching. The average duration of this part of the training session was 7 min and 6 s.
- Tactical training; consisted of unopposed attacking and defending formation practice. The average duration of this part of the training session was 3 min and 28 s.
- Shooting practice; involved individual shooting at the goalkeeper, and passing between players and shooting. The average duration of this part of the training session was 22 min and 11 s.
- Training matches; these varied in length and fouls were rarely committed or penalised. Training matches always consisted of four players and a goalkeeper on each team. The average duration of this part of the training session was 37 min and 21 s.
- Rest time; this consisted of 'off rink' breaks, 'on rink' breaks, team talks, demonstrations and waiting in a queue. The average duration of this part of the training session was 41 min and 41 s.

Of the six 2-hour training sessions analysed, the mean actual training time (excluding rest time) was 78 min and 19 s. Figure 7.0 shows the mean distribution of training and the heart rate values during each category of training. The EMG data were collected during five of the training categories; no EMG data were recorded during rest time.

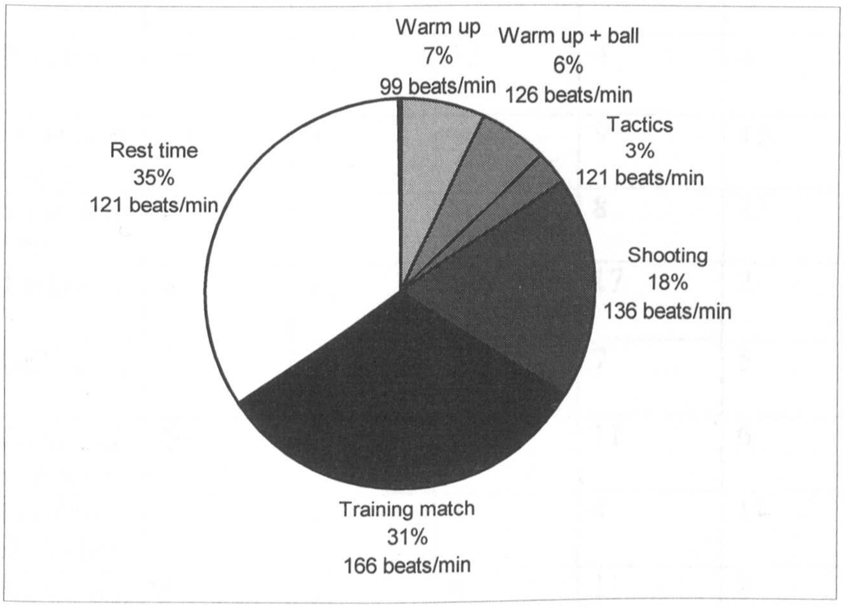


Figure 7.0: Pie chart displaying mean heart rates and the average division of the 2-hour training sessions.

Both the qualitative and quantitative analyses of EMG activity began with the synchronisation of the video recording and the raw EMG traces; the subject's actions were then marked on the EMG traces. The match analysis (chapter 4) established and defined the basic actions performed by a roller hockey player during match play. In order to understand muscular activity during roller hockey, twelve of these actions were analysed using EMG during training sessions. The actions analysed were the skating actions: sprinting, pushing and slide stopping (left and right). Rolling movements and stationary stances were excluded from the EMG analysis, as both of these actions require minimal muscular activity. The hockey actions analysed were: dribbling, tackling, passing, receiving a pass and shooting. Shooting analysis was divided into four shots: these were the forehand and backhand slap and flick shots. The number of actions analysed for each subject is presented in table 7.0.

Table 7.0: The number of actions analysed for each subject.

Action	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Total
Sprinting	30	33	30	22	33	21	169
Passing	15	13	15	19	4	14	80
Pushing	28	16	12	4	4	10	74
Slide stop Right	18	9	6	9	15	11	68
Slide stop Left	15	12	17	8	13	1	66
Tackling	6	9	14	17	2	11	59
Dribbling	7	6	12	7	5	12	49
Forehand slap shot	10	2	8	11	6	10	47
Forehand flick shot	4	8	4	4	11	14	45
Receiving pass	6	6	8	11	2	11	44
Backhand slap shot	1	2	4	1	3	14	25
Backhand flick shot	1	1	4	1	0	1	8
Total	141	117	134	114	98	130	734

Qualitative Analysis

To understand muscular activity during roller hockey, it is important to analyse the muscular recruitment patterns for each action. Therefore this section of the results analyses all the actions performed by all the subjects, to establish a general muscular recruitment pattern. Illustrations of each action and descriptions of the movement phases are presented in chapter 6.

During all the skating actions few general recruitment patterns were observed in the upper body (pectoralis major and latissimus dorsi), possibly due to the varying demands placed on the trunk during ball possession.

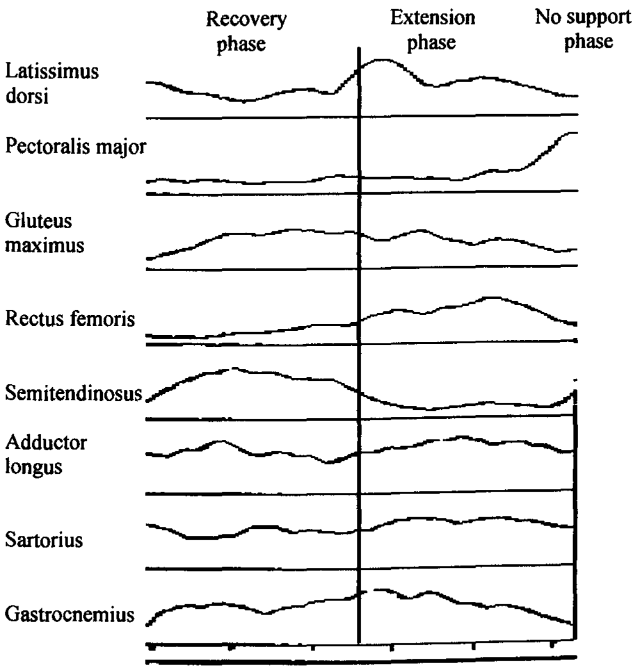


Figure 7.1: Sprinting: Linear enveloped EMG trace (similar scale for each muscle).

This section begins with the sprinting skating action. As defined in the kinesiological analysis (chapter 6) sprinting could be divided into three movement phases; the recovery phase, where the leg was flexed under the body ready to plant, the extension phase, where this leg was then rapidly extended, and the no support phase where the body was lifted from the floor by the powerful extension phase. The recovery phase began as the leg was flexed at the knee following full extension; this can be seen in figure 7.1 where the first EMG activity is seen in the semitendinosus. The gastrocnemius also displayed EMG activity at this point, as the knee flexed (concentric contraction), and as the foot was dorsiflexed (eccentric contraction). Semitendinosus activity then peaked as the leg was fully flexed at the knee. The leg was then brought under the body, flexing at the hip (there was a slight increase in rectus femoris and sartorius activity). The lower leg was now extended at the knee to touch the floor (seen in figure 7.1 by a decrease in semitendinosus activity to resting levels), contact with the floor marked the end of the recovery phase. Activity in the gluteus maximus increased during the recovery phase, peaking and then decreasing until the extension phase. Activity of both the adductor longus and the sartorius increased steadily during the recovery phase of the first sprint stride, but then remained relatively active during the following strides (the adductor longus had slightly more distinct peaks of activity following a similar activity pattern to the rectus femoris).

The extension phase began with peak gastrocnemius activity as the foot was planted; this activity then decreased gradually during the extension phase and returned almost to resting values before the next stride. The gluteus maximus activity increased and peaked as the hip was extended. Following this there was a second peak in rectus femoris activity that caused the knee to extend; there was also slight semitendinosus activity (eccentrically) as the leg extended (in some cases the semitendinosus showed a second peak here). This EMG analysis suggests that the power for the extension of the leg in sprinting came firstly from the hip (gluteus maximus), then the knee (rectus femoris), but not from plantar flexion as was originally thought (due to the decrease seen in the activity of the gastrocnemius).

The no support phase resulted from the powerful extension of the push-off leg, EMG activity during this phase decreased in all the lower limb muscles.

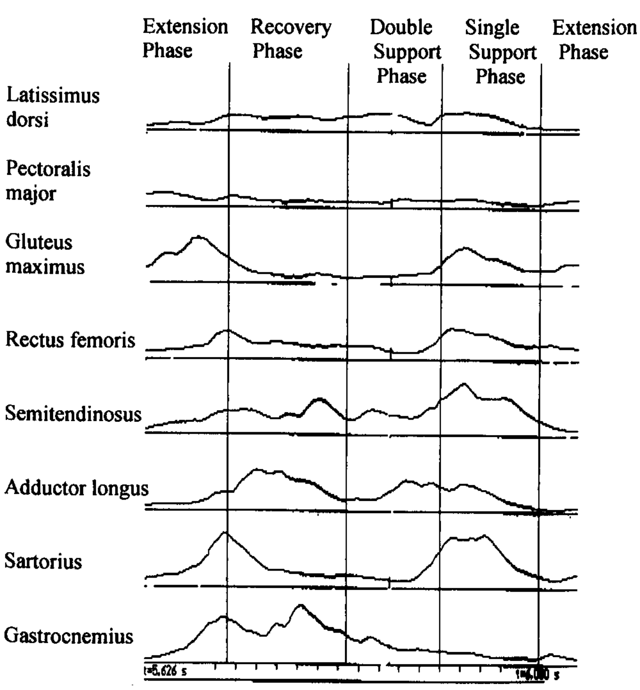


Figure 7.2: Pushing: Linear envelope EMG trace (similar scale for each muscle).

The kinesiology analysis (chapter 6) broke the pushing stride into a number of movement phases; these were the extension phase, the recovery phase (as the extension leg was brought under the body), the 'double support' phase (as the extension leg was planted and the other leg began extending), and finally the 'single support' phase (as the other leg was lifted off the floor, this is also known as the gliding phase).

During the extension phase, primary EMG activity was seen in the gluteus maximus; this activity extended the hip (see figure 7.2). Following the peak gluteus maximus activity, the rectus femoris then extended the knee; there was also some eccentric contraction of the semitendinosus as the leg extended. Unlike the activity during sprinting, the sartorius and adductor longus did not show constant activity. As the rectus femoris extended the knee, the sartorius was active in aiding knee extension but also laterally rotating the leg. Activity in the adductor longus increased gradually. The extension phase ended as rectus femoris, sartorius, and gastrocnemius peaked for the first time as the leg was maximally extended and lifted from the floor. The recovery phase displayed a more rapid increase in adductor longus activity as the leg was adducted; it was then flexed at the knee (increased semitendinosus activity) still off the floor. Prior to the 'double support' phase, activity in the gastrocnemius peaked again as the foot avoided contact with the floor for as long as possible; there was also a small peak in semitendinosus activity as the leg was flexed ready for planting (to become the supporting leg).

In the 'double support' phase activity in all the muscle analysed decreased with the exception of the adductor longus. Adductor longus activity increased as the other leg extended; it is suggested that this may have been to counterbalance the force of the other leg as it extended perpendicular to the direction of motion, adductor longus activity was required to maintain the supporting leg on its intended path.

The 'single support' phase saw a steady simultaneous rise in gluteus maximus, rectus femoris, semitendinosus and sartorius activity as the body weight was transferred on to this supporting leg, which was flexed at the hip, knee and ankle to maintain a low gliding position. This activity peaked and then decreased as the other leg finished its extension phase. Little gastrocnemius activity was evident in the support phases.

Sliding stopping.

The slide stop can be performed on both the left and the right side. Consequently the muscular activity of the inside and the outside leg vary (shown in figures 7.3 and 7.4, respectively). For both the inside and the outside leg, the kinesiological analysis (chapter 6) divided the slide stop into the preparation phase, the one-footed and two-footed turn phases, the slide and the recovery phase.

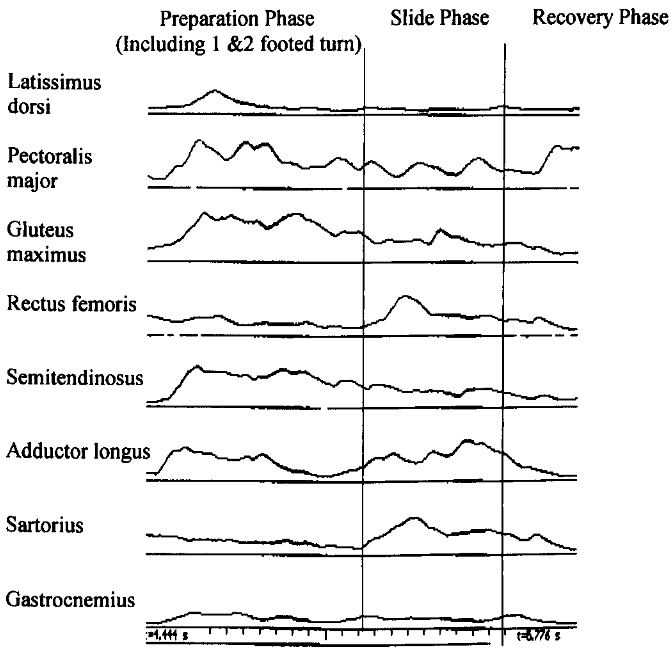


Figure 7.3: Slide stopping for the outside leg: Linear envelope EMG trace (similar scale for each muscle).

For the outside leg (see figure 7.3) the gluteus maximus and semitendinosus displayed very similar patterns of recruitment throughout the slide stop. Both rose sharply and peaked during the preparation phase, as the knees bent and the centre of gravity was lowered. This peak in activity of the gluteus maximus and semitendinosus remained until approximately half way through the stop. The adductor longus was also active during the preparation phase and peaked for the first time. The activity in the adductor longus may have been to keep the legs and feet together.

After the preparation phase the wheels stopped rolling and began sliding; this was seen by an increase in sartorius and adductor longus activity, which stabilised the legs and prevented over-rotation of the lower body. The rectus femoris activity also increased, peaking during the sliding phase; it is suggested that this was to straighten the leg and push into the stop. The gluteus maximus and semitendinosus activity decreased gradually during the sliding phase to baseline levels at the end of the stop. The gastrocnemius showed little activity during the stop. As the slide phase finished there was a gradual decrease in the EMG activity of all muscles during the recovery phase.

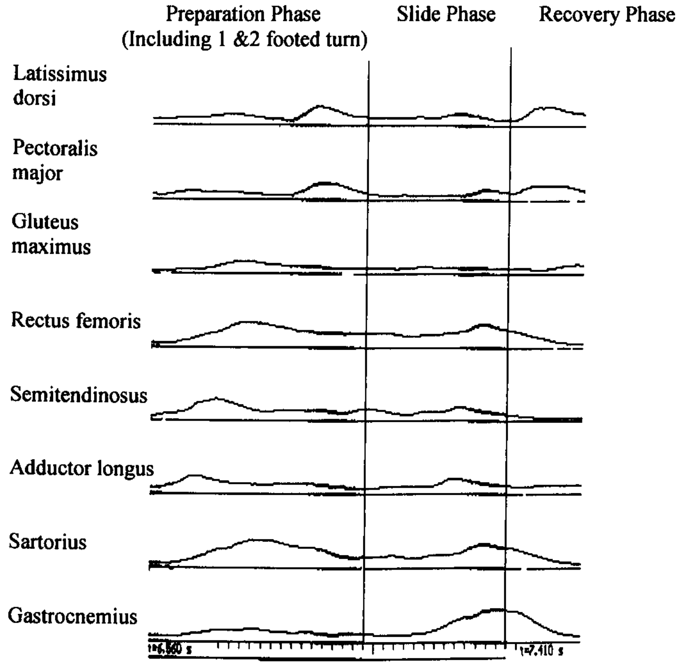


Figure 7.4: Slide stopping for the inside leg: Linear envelope EMG trace (similar scale for each muscle).

During the slide stop, the inside leg showed little gluteus maximus activity (figure 7.4). The rectus femoris, semitendinosus, adductor longus, sartorius and gastrocnemius all displayed double peaks in EMG activity, the first during the preparation phase and the second (which was generally a smaller peak) during the slide phase. During the preparation phase, activity in the adductor longus was followed by activity in the semitendinosus, then the rectus femoris and sartorius, and finally a slight increase in gluteus maximus and gastrocnemius activity as the legs were bent and the centre of gravity was lowered. During the slide phase the adductor longus again showed the first activity peak, followed by semitendinosus, rectus femoris and sartorius as the slide phase finished. The gastrocnemius also peaked as the slide phase finished and remained active during the recovery phase, as the legs were straightened.

Dribbling and Tackling

Due to the situation-dependency of these two actions, no general recruitment patterns were identified throughout the EMG analysis.

Passing, and receiving a pass

Both of these actions are again situation-dependent and in general displayed minimal recruitment patterns. However, it was noted that during passing there was a general simultaneous increase in activity for both latissimus dorsi and pectoralis major, during the back-swing, fore-swing and follow-through. When receiving a pass there was generally an increase in pectoralis major activity, but this was not always accompanied by an increase in latissimus dorsi activity.

Shooting.

All shooting analyses were divided into four phases; these were the back-swing, fore-swing, contact or lose of contact, and the follow-through.

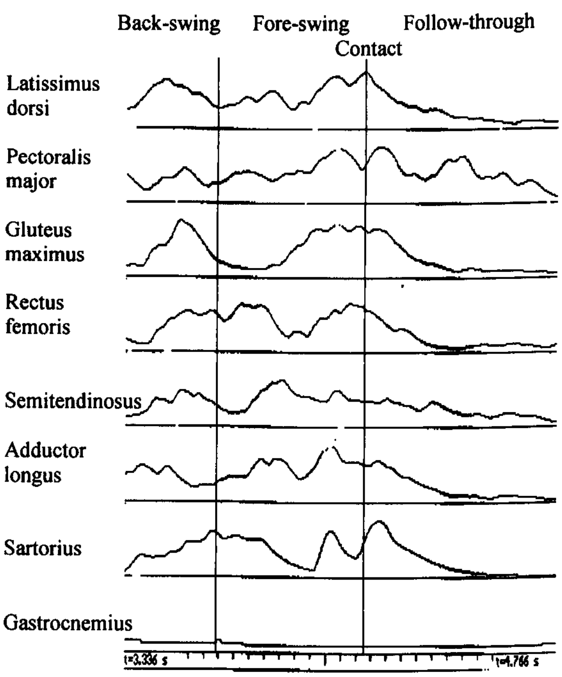


Figure 7.5: Forehand slap shot: Linear envelope EMG trace (similar scale for each muscle).

During the forehand slap shot the latissimus dorsi initiated the back-swing as the upper body rotated away from the direction of the shot. As this happened the back leg was lifted from the floor, which produced a rapid increase in gluteus maximus, rectus femoris, semitendinosus, adductor longus, and sartorius activity in the supporting leg. As the trunk flexed there was an increase in activity of the gluteus maximus, rectus femoris, and adductor longus. The semitendinosus was also eccentrically contracted as the trunk flexed, and sartorius activity increased with the rotation of the trunk. The activity of the pectoralis major slowly increased during the back-swing as the stick was swung across the body. Following the first peak, gluteus maximus activity decreased rapidly almost to baseline levels at the top of the back-swing, then increased again during the fore-swing, peaking for a second time at contact. The rectus femoris followed a similar pattern but with a less pronounced decrease in activity at the top of the back-swing. At the top of the back-swing semitendinosus activity increased, then steadily decreased until the end of the shot.

During the fore-swing the pectoralis major activity increased as the arms swept across the body; interestingly, there was a reduction in pectoralis major activity at contact, and an increase in activity again after contact as the arms followed through. During rotation towards the ball, latissimus dorsi activity increased. Just before contact the latissimus dorsi activity fell slightly and then increased again at contact. The gluteus maximus, rectus femoris and adductor longus displayed high activity levels at contact, but the sartorius peaked slightly after contact; this may have been due to the sartorius counter-balancing the over-rotation of the trunk.

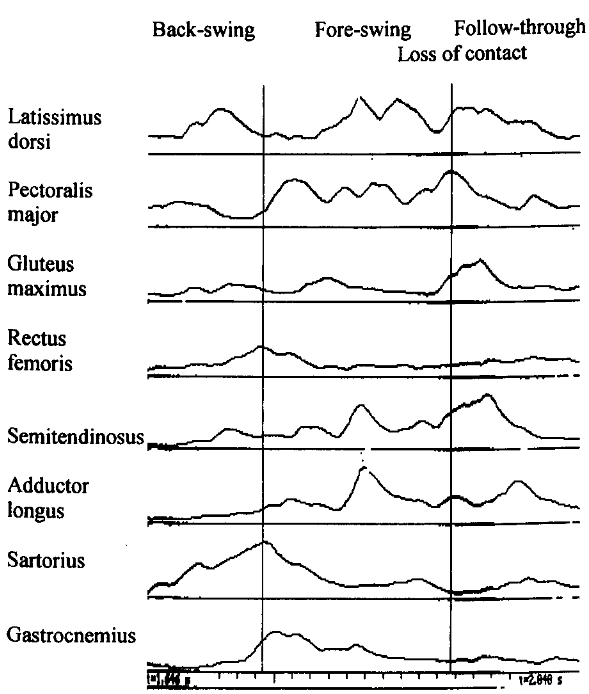


Figure 7.6: Forehand flick shot: Linear envelope EMG trace (similar scale for each muscle).

During the forehand flick shot there was a minimal back-swing phase, followed by the fore-swing phase, as the body rotated towards the direction of the shot, and then contact was lost as the ball was released. The back-swing phase began with the rotation of the trunk away from the direction of the shot; this can be seen by the first peak in activity of the latissimus dorsi. As the trunk rotated there was also activity in the sartorius of the supporting leg, which peaked at the top of the back-swing.

As the body started to rotate towards the direction of the shot in the fore-swing phase, sartorius activity decreased and pectoralis major activity increased. The increased activity in the pectoralis major was due to the sweeping action of the arms across the body. During the fore-swing phase the hips rotated first, followed by the shoulders, the centre of gravity was then lowered considerably and body weight was transferred onto the front foot as the back leg extended behind the body. The front leg was flexed at the hip, knee, and ankle, causing increased activity in the gluteus maximus, semitendinosus and gastrocnemius. Just prior to loss of contact, the centre of gravity was lowered further and the back leg was extended maximal behind the body; consequently there was an increase in activity of the gluteus maximus and semitendinosus in the supporting leg. Activity in the pectoralis major peaked at loss of contact as the ball was forcefully released.

During the follow-through phase the activity of the pectoralis major gradually decreased, activity in both the gluteus maximus and sartorius increased as the supporting leg was extended to return to a more upright position. This was followed by an increase in adductor longus activity as the back leg was adducted and eventually planted.

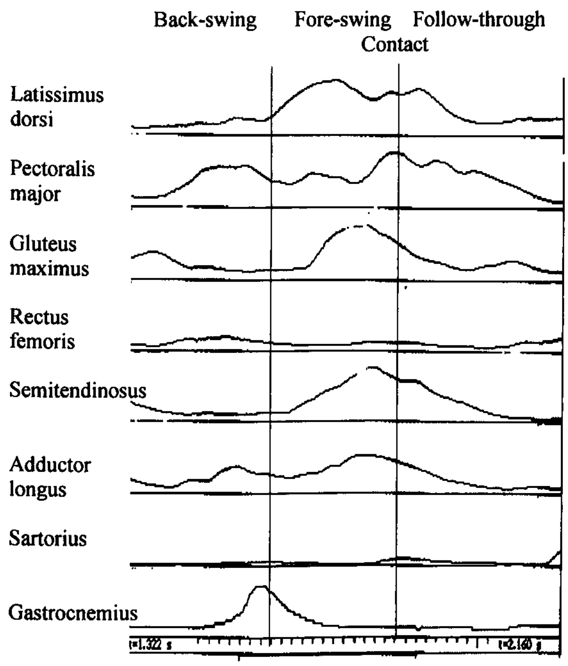


Figure 7.7: Backhand slap shot: Linear enveloped EMG trace (similar scale for each muscle).

The backhand slap shot contained similar movement phases as the forehand slap shot. The back-swing phases saw the trunk rotate away from the direction of the shot and the stick move across the body, this caused increased activity in the latissimus dorsi and the pectoralis major. Half way through the back-swing, the back leg was lifted from the floor (gastrocnemius activity). During the fore-swing the latissimus dorsi activity increased significantly as the trunk rotated towards the direction of the shot. The pectoralis major remained active as the stick was drawn across the body, towards the ball. This activity increased and peaked at contact. In order to prevent the over-rotation of the upper body, the back leg flexed at the knee and extended at the hip behind the body, consequently there was an increase in semitendinosus and gluteus maximus activity. All muscle activity decreased after contact except the latissimus dorsi and the pectoralis major, which displayed slight increases in activity levels after contact, as the trunk rotated during the follow-through.

Due to the small number of backhand flick shots performed during the training session in this investigation, no representative EMG traces were identified. However, following an overview of all backhand flick shots, a general pattern of muscle recruitment was identified.

The backhand flick shot displayed similar movement phases as the forehand flick shot, beginning with a small back-swing phase. This back-swing produced a small increase in activity of the latissimus dorsi as the trunk was rotated away from the direction of the shot. During the fore-swing the pectoralis major swept the arms, stick and ball across the body. As the legs separated and the body weight was slowly transferred onto the front foot, the back leg showed increased activity in the gluteus maximus and semitendinosus as it extended behind the body. As the back leg extended further and there was increased activity in the rectus femoris, gastrocnemius and adductor longus, while activity in the gluteus maximus and semitendinosus remained high. The front leg flexed at the hip, knee and ankle. The activity in gluteus maximus, semitendinosus, gastrocnemius and pectoralis major peaked as contact was lost. The activity of the latissimus dorsi peaked slightly after loss of contact due to the rotational follow-through of the trunk. For the back leg, activity in rectus femoris and sartorius remained fairly low during this shot.

Quantitative Analysis

The first procedure that should be undertaken in quantitative EMG analysis is normalisation of the EMG data. Preliminary analysis of the MVC values revealed that they were considerably lower than values observed during the dynamic activities (figure 7.8). Figure 7.8 shows that for every muscle the maximum value found during the dynamic situation (MDC) exceeded the MVC value and in some cases by over 100% (rectus femoris and gastrocnemius). This undermined the validity of the MVC in this study, and consequently the MDC was chosen as the normalising criterion for this investigation, rather than the MVC.

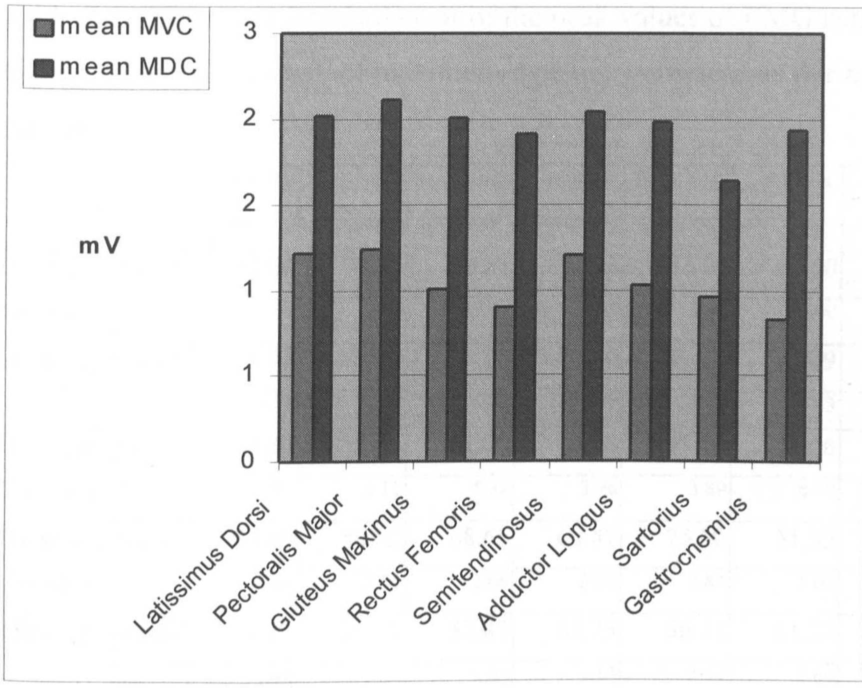


Figure 7.8: A comparison of mean maximum voluntary (MVC) and maximum dynamic (MDC) contraction for each muscle.

Having established a normalising factor, in order to compare results between studies it is necessary to quantify the EMG activity. In this investigation two forms of EMG temporal data processing have been used; these were peak value analysis and average rectified EMG (AREMG) analysis. Both processes provided different and valuable quantification of the EMG results.

Peak Values Analysis:

Having identified every player's movements on the EMG traces using the synchronised video data, times were obtained for the beginning and end of each action. The raw EMG data were then processed using a linear envelope (as described earlier) and peak values (μV) were obtained for every action, for all muscles. These peak values were then expressed as a percentage of the MDC also obtained from the linear envelope and averaged across all subjects (see table 7.1).

Table 7.1: Mean and standard error of the peak values of EMG activity for all subjects expressed as a percentage of maximum dynamic contractions during roller hockey actions.

		Pectoralis major	Gluteus maximus	Semitend-inosus	Adductor longus	Latissim-us dorsi	Sartorius	Rectus femoris	Gastrocn-emius	Mean
Forehand slap shot	Mean	83.66	79.31	70.81	73.13	82.07	69.60	64.19	55.13	74.68
	S.E.	2.18	2.43	2.13	1.73	2.38	3.00	2.83	2.86	2.54
Sprinting	Mean	59.41	72.97	74.00	70.30	57.91	75.09	71.57	62.02	68.75
	S.E.	2.12	1.46	1.22	1.20	2.03	1.43	1.44	1.20	2.50
Backhand flick shot	Mean	69.40	73.70	82.30	71.18	77.18	57.66	46.11	35.64	68.22
	S.E.	3.53	3.11	5.32	3.96	3.89	8.70	4.52	5.60	4.38
Backhand slap shot	Mean	77.45	80.52	68.65	60.87	75.80	51.85	56.53	62.57	67.38
	S.E.	3.45	3.55	2.66	3.03	3.84	5.00	4.46	4.40	3.95
Tackling	Mean	58.77	59.12	57.85	63.75	56.12	61.27	64.49	48.40	60.20
	S.E.	3.98	2.67	2.65	3.13	2.54	2.66	2.81	2.25	1.10
Dribbling	Mean	61.21	62.91	57.47	60.49	48.51	53.17	51.58	50.98	56.48
	S.E.	3.44	3.72	3.38	3.14	3.32	4.12	3.46	3.11	1.93
Forehand flick shot	Mean	67.76	50.46	58.06	45.48	50.83	41.54	41.93	40.72	50.87
	S.E.	2.52	4.89	3.70	3.15	3.86	4.55	4.21	3.58	3.33
Pushing	Mean	46.69	57.35	50.98	53.83	43.77	52.04	46.30	50.69	50.14
	S.E.	3.60	2.62	2.49	3.03	3.30	2.76	2.43	2.35	1.69
Pass	Mean	57.96	39.77	39.72	41.87	41.55	36.30	31.85	31.67	41.29
	S.E.	2.63	3.05	2.37	2.81	2.62	2.60	2.64	2.38	2.88
Receiving pass	Mean	54.65	39.11	36.30	38.25	35.00	35.84	34.21	29.60	39.05
	S.E.	3.51	4.45	2.97	3.09	3.31	3.73	3.63	3.24	2.51
Slide stop Inside leg	Mean	33.29	32.48	40.36	42.95	33.03	44.66	29.53	42.33	36.62
	S.E.	4.16	2.51	2.60	2.67	3.18	3.36	2.68	2.99	2.09
Slide stop Outside leg	Mean	33.11	32.36	33.97	44.24	29.64	37.15	30.90	30.90	34.48
	S.E.	3.73	2.95	2.06	2.59	3.10	2.91	2.52	2.29	1.74
TOTAL	Mean	58.61	56.67	55.87	55.53	52.62	51.35	47.43	45.05	54.01
	S.E.	4.51	4.77	3.98	3.03	5.29	2.98	3.68	2.63	3.08

In table 7.1 the values of peak EMG activity range from 29% to 84% of MDC, with a mean value of 54% recorded during all roller hockey actions. The mean peak values for each muscle and the mean peak values for each action are presented in figure 7.9 and 7.10, respectively. Figure 7.9 shows that the pectoralis major displayed the highest mean peak value during all actions, followed by the gluteus maximus. The gastrocnemius displayed the lowest mean peak values overall. Figure 7.9 also shows that mean muscle activity for all muscles remained above 45% of MDC. Figure 7.10 shows the actions that displayed the highest mean peak values for all muscles were the forehand slap shot and sprinting. These were followed by backhand shooting, hockey actions and finally slide stopping produced the least peak EMG activity. The forehand flick shot displayed unexpectedly low peak activity values relative to other shots.

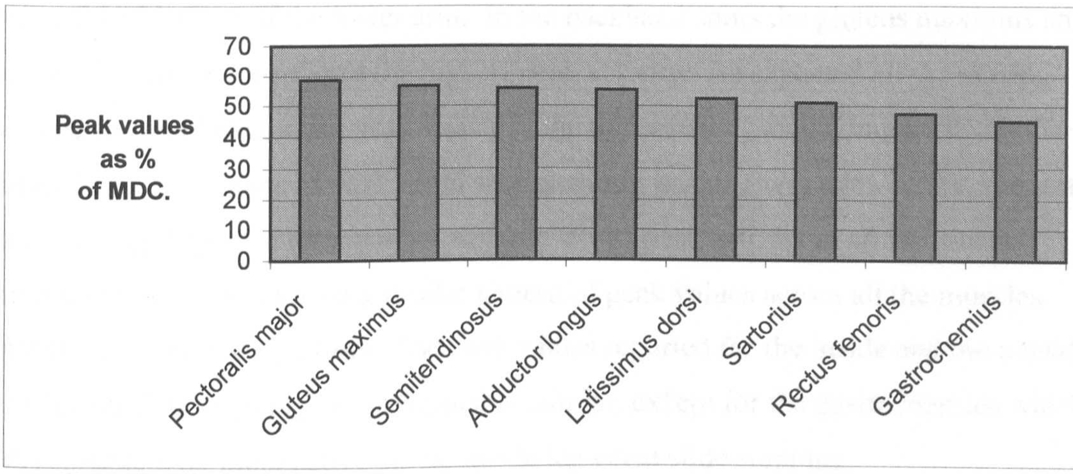


Figure 7.9: A comparison of mean peak values for each muscle.

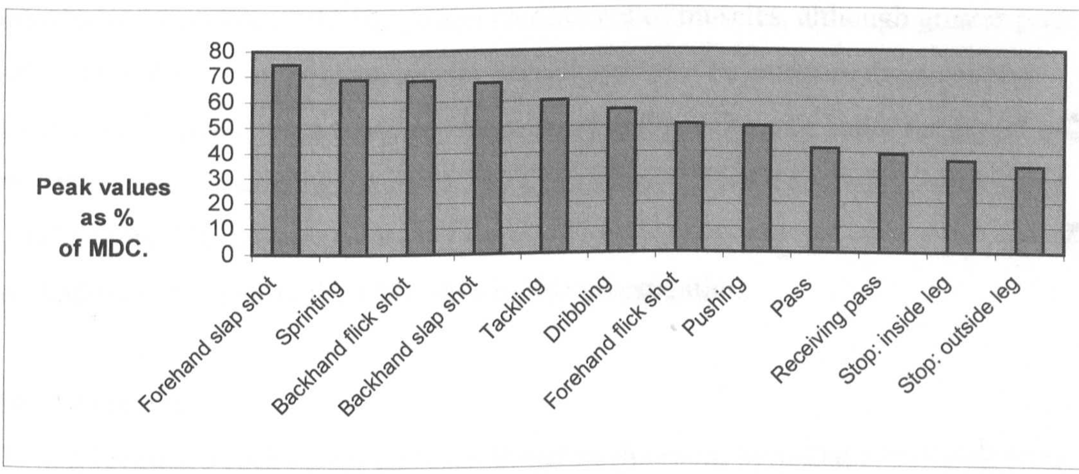


Figure 7.10: A comparison of the mean peak values for each action.

To establish whether any of these differences were statistically valid, a two-way analysis of variance (ANOVA) with repeated measures (muscle and action) was performed. The data were normally distributed; however, the Mauchly Sphericity Test revealed a lack of homogeneity of the data, so the Greenhouse-Geisser test was used to modify the data. The results showed a significant difference between peak values for each action, ($F_{(3.31,\ 1.66)} = 9.79$, $p = 0.042$ with a power of 1), but no significant differences were found between the peak values for each muscle. The interaction effect was approaching significance ($F_{(3.8,1.9)} = 5.3$, $p = 0.08$ with a power of 1). Due to the small sample size, the lack of homogeneity, and the range of the data, it was decided to analyse the data descriptively.

Analysis of the muscle activity within individual actions in table 7.1 shows, as expected that the forehand shots displayed higher peak activity in the pectoralis major due to the powerful adduction of the lower arm. In the backhand shots the gluteus maximus and the semitendinosus displayed the highest peak activity. As expected all the skating actions showed lower mean peak values in the upper body, when compared with the lower body. The range of peak EMG values within pushing was 44% - 57%, suggesting that pushing displayed reasonably similar levels of peak activity in all the muscles monitored. Passing showed a similar pattern of peak values across all the muscles monitored as receiving a pass. The peak values reported for the inside and the outside leg during slide stopping were reasonably similar, except for the gastrocnemius which was considerably more active on the inside leg when slide stopping.

Analysis of peak EMG values derived from the linear enveloped EMG provided valuable information on the maximum recruitment of muscles, although greater peak values do not necessarily mean greater overall activity. To compare the amount of electrical activity between muscles and between actions, the area under the signal must be established. Processing the raw EMG data using AREMG, according to De Luca (1997), represents the area under the signal. The AREMG was the second processing method used to quantify the EMG data in this investigation.

AREMG analysis:

Having identified each action and established its duration, Myo-Dat 5.0 Digital Data Analysis System enabled the integrated EMG over the duration of the whole action to be calculated. The comparison of integrated EMG values between actions is not possible due to the varying duration of each action. To standardise the duration and make comparisons possible, the integrated EMG values were divided by the duration of the action. Bartlett (1997, p 241) stated that having obtained the integrated EMG value "an average value of the EMG can then be obtained by dividing the total integral by the time of integration. This will give a value identical to the AREMG for the same time period." Following the calculation of the AREMG values for all actions, the same method was used to establish the AREMG maximum dynamic contraction; all values were then normalised to this value.

Table 7.2: Mean and standard error of the average rectified EMG values for all subjects expressed as a percentage of the maximum dynamic contractions.

		Pectoralis major	Adductor longus	Latissimus Dorsi	Rectus femoris	Semitendinosus	Gluteus maximus	Sartorius	Gastrocnemius	Mean
Sprinting	Mean	49.12	55.76	48.32	58.51	53.82	50.70	43.60	36.83	49.58
	S.E.	5.09	4.77	3.67	6.34	7.23	7.54	9.11	5.60	2.45
Forehand slap shot	Mean	60.48	57.13	59.83	46.91	48.32	46.95	35.65	28.97	48.03
	S.E.	7.79	7.95	10.85	6.21	7.65	8.13	8.22	6.05	4
Backhand slap shot	Mean	63.42	47.68	56.80	44.04	47.97	54.34	30.90	27.99	46.64
	S.E.	5.93	5.28	8.78	5.87	4.89	8.69	5.96	3.95	4.33
Backhand flick shot	Mean	48.28	47.54	45.57	38.97	47.49	41.86	25.82	41.05	42.07
	S.E.	10.92	4.58	11.74	6.37	12.69	10.27	6.22	17.01	2.62
Tackling	Mean	44.20	40.32	42.54	43.03	33.83	32.06	30.57	21.96	36.06
	S.E.	4.63	5.71	4.32	4.48	4.37	5.85	6.72	4.25	2.75
Forehand flick shot	Mean	48.20	43.69	39.01	34.95	36.67	32.18	21.29	20.96	34.62
	S.E.	2.94	11.58	4.19	6.90	6.07	6.32	4.81	4.02	3.43
Receiving pass	Mean	49.48	31.53	34.57	33.92	32.77	29.19	22.73	22.68	32.11
	S.E.	1.11	4.56	3.67	6.01	6.39	4.76	5.10	7.37	2.98
Passing	Mean	46.41	31.21	37.46	30.30	34.36	27.87	21.16	20.79	31.19
	S.E.	4.67	3.34	3.02	3.63	4.43	5.67	3.80	3.98	2.99
Dribbling	Mean	36.58	34.31	33.02	30.73	33.99	30.32	28.37	21.53	31.11
	S.E.	4.12	2.84	6.88	3.91	5.74	4.37	4.66	3.81	1.65
Pushing	Mean	30.74	31.65	29.65	38.63	32.51	31.97	24.34	21.54	30.13
	S.E.	4.66	2.69	2.78	6.91	5.76	5.51	3.70	2.81	1.85
Slide stop Inside leg	Mean	26.06	32.20	32.98	27.81	29.98	20.93	30.42	20.47	27.61
	S.E.	2.97	3.88	3.86	3.16	4.68	4.11	9.24	3.95	1.7
Slide stop Outside leg	Mean	30.88	32.89	24.07	36.22	26.77	25.29	23.75	20.17	27.50
	S.E.	2.76	3.75	3.33	6.50	4.79	3.63	3.55	2.71	1.9
TOTAL	Mean	44.49	40.49	40.32	38.67	38.21	35.30	28.22	25.41	36.39
	S.E.	3.49	2.42	2.58	2.28	2.35	3.00	1.58	1.69	1.81

The AREMG values in table 7.2 indicate which muscles are the most active and enable a hierarchy of muscle activity to be established (see figure 7.11). Figure 7.11 indicates that the most active muscle during the performance of all roller hockey actions was the pectoralis major, with the gastrocnemius being the least active.

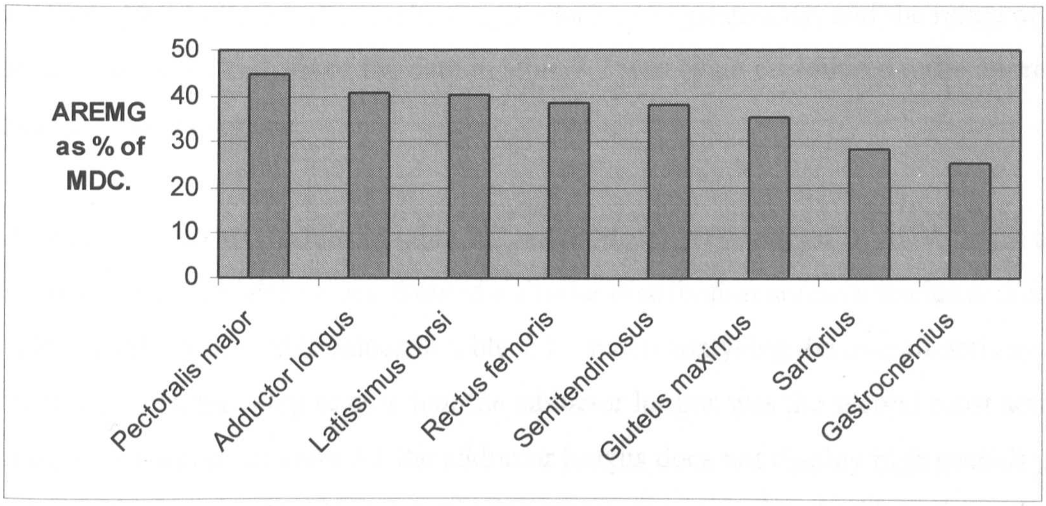


Figure 7.11: A comparison of the mean average rectified EMG activity for each muscle.

The AREMG analysis in table 7.2 also indicates the most demanding actions (see figure 7.12). Figure 7.12 again shows similar results to the peak values analysis, with sprinting and shooting the most demanding the actions, followed by ball related activities such as dribbling and passing, and finally the skating activities of pushing and slide stopping produced the least activity in the muscles analysed.

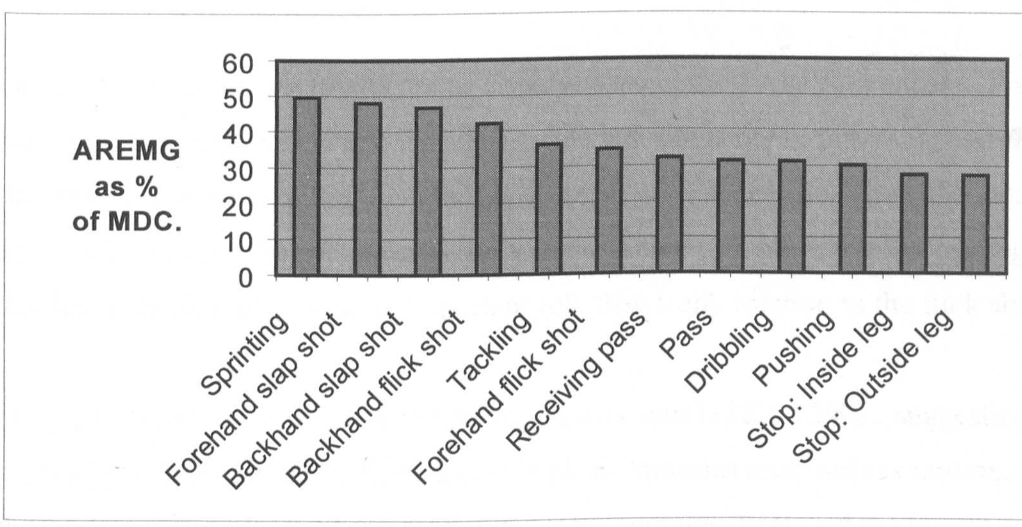


Figure 7.12: A comparison of the mean average rectified EMG activity during each action.

Again, a two-way analysis of variance (ANOVA) with repeated measures (muscle and action) revealed a lack of homogeneity, so the Greenhouse-Geisser test was used to modify the data. This revealed that there were no significant differences between muscle AREMG values or between actions AREMG values and no interaction effect (at

$p < 0.5$). Due to the small sample size, the lack of homogeneity, and the range of the data, descriptive analysis of the data in table 7.2 was again considered more appropiate than statistical analysis.

Overall the AREMG values in table 7.2 ranged from 20% to 63% of MDC, with a mean of 36%. The AREMG values showed a similar distribution across muscles and across actions as the peak EMG values in table 7.1. When analysing the overall activity of the muscles, it is interesting to note that the adductor longus was the second most active muscle. However, in table 7.1 the adductor longus does not display high overall peak values, which suggests that this particular muscle was associated with prolonged sub-maximal effort rather than short bursts of maximal effort. This may mean that the adductor longus was of underlying importance during most roller hockey actions.

The muscular activity of individual actions showed, as expected, that the rectus femoris was the most active during sprinting (table 7.2). The kinesiological analysis (chapter 6) assumed that during sprinting, speed was derived from the powerful extension of not only the hip and knee, but also the ankle. The results of this EMG analysis showed that the gastrocnemius had the lowest level of activity during sprinting.

During all shots, the pectoralis major displayed the highest AREMG values. For the slap shots the next most active muscle was the latissimus dorsi; this was possibly due to the powerful rotation of the trunk during these shots. For the flick shots the next most active muscle after the pectoralis major was the adductor longus, which may suggest that leg adduction plays a more important role than trunk rotation in the flick shot.

During pushing the range of AREMG values was small (22% - 39%), suggesting that pushing produced similar activity levels in all the muscles analysed (as reported during the peak value analysis). As expected the gastrocnemius displayed the lowest activity levels during pushing, due to the lack of plantar flexion in this action. Passing and receiving a pass showed similar patterns of AREMG activity across all the muscles, as seen in the peak values analysis.

When looking down the columns in table 7.2, the activity within each muscle was as expected. The only noticeable outlier was the activity of the gastrocnemius during the backhand flick shot. This value seemed unusually high compared to the activity of the gastrocnemius in all other actions. Table 7.1 revealed that peak activity for this muscle during the backhand flick shot was unusually low and suggests that the gastrocnemius was constantly activity during this shot, but it did not display large peak values.

Comparison between peak EMG activity and AREMG activity in tables 7.1 and 7.2, indicated a relationship between the distribution of both sets of data, both in terms of roller hockey actions and muscular involvement. However, the overall mean peak value of 54% was considerably higher than the overall mean AREMG value of 36%. Figure 7.13 illustrates the strong similarities in the distribution of peak EMG values and corresponding AREMG values. These similarities may question the necessity of using both processing techniques to analyse EMG activity. To test the relationship between the results of both processing methods statistically, a correlation analysis was performed between all the mean peak EMG values and their corresponding mean AREMG values. The results showed a significant correlation ($r = 0.768$, $p = 0.0001$).

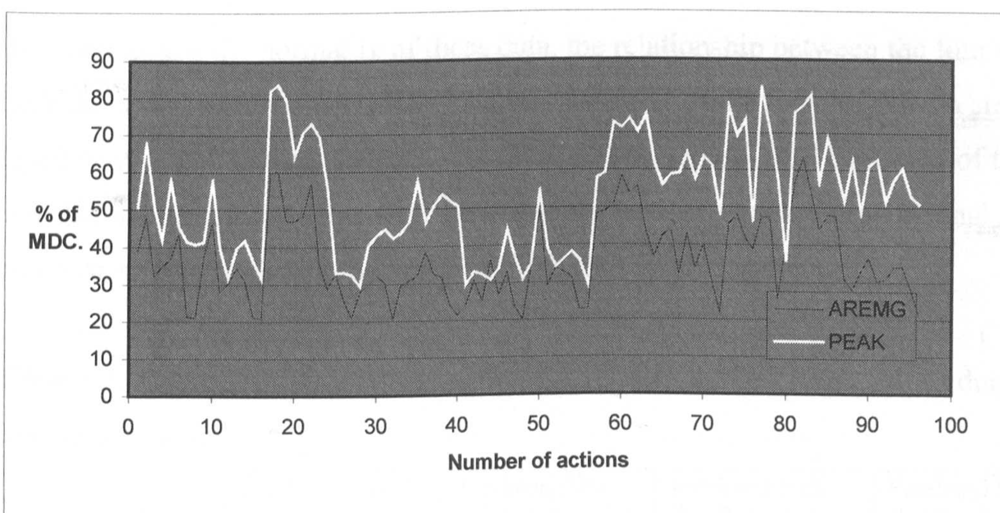


Figure 7.13: Comparison of all mean peak EMG values and the corresponding mean average rectified EMG values.

When analysing the AREMG values for individual subjects, it became apparent that there might be some proportional similarities between the recruitment of muscles for each action. For example, subject 1 performed four forehand flick shots trials which, regardless of intensity, showed a similar pattern in the proportional muscle activity, e.g.

as activity in one muscle increased or decreased, so did the activity in the next (see figure 7.14).

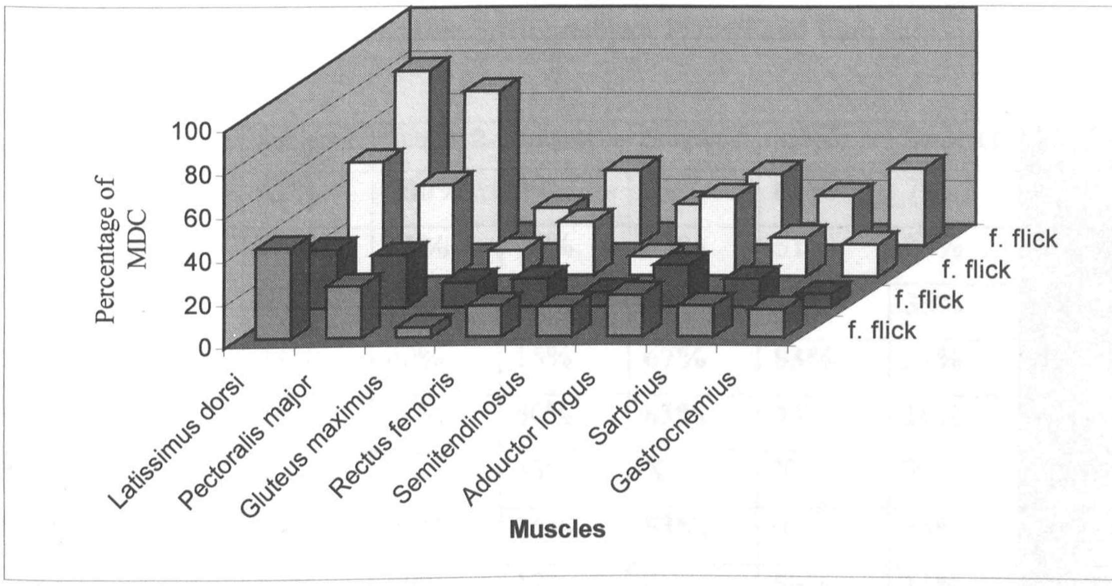


Figure 7.14: Subject 1, average rectified EMG values during four forehand flick shots, expressed as a percentage of maximum dynamic contractions.

Having checked the normality of these data, the relationship between the four forehand flick shots was assessed using a correlation matrix. Results indicated that a strong significant correlation existed between all trials (see table 7.3). The results of this correlation analysis indicated that there is some form of standard proportional muscle recruitment pattern during the forehand flick shot for this subject.

Table 7.3: Correlation matrix for Subject 1, average rectified EMG values during four forehand flick shots.

	Forehand flick shot 1	Forehand flick shot 2	Forehand flick shot 3	Forehand flick shot 4
Forehand flick shot 1		$r = 0.8172$ $p = 0.013$	$r = 0.8958$ $p = 0.003$	$r = 0.8938$ $p = 0.003$
Forehand flick shot 2			$r = 0.9571$ $p < 0.0001$	$r = 0.8430$ $p = 0.009$
Forehand flick shot 3				$r = 0.9034$ $p = 0.002$
Forehand flick shot 4				

This procedure was repeated for all the trials of every action for each subject. This produced a large number of correlation matrices (72) and therefore it is not possible to display them all. Consequently, the percentage of the number of trials that were significantly correlated is presented in table 7.4. For example, in table 7.3 subject 1 showed that all trials of the forehand flick shot were significantly correlated, hence the 100% correlation value seen in table 7.4 for subject 1, forehand flick shot.

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Mean
Forehand slap shot	**62%**	**100%**	39%	**85%**	**67%**	7%	60%
Forehand flick shot	**100%**	**61%**	17%	**83%**	**51%**	25%	56%
Backhand slap shot	X	**100%**	16%	X	**67%**	36%	55%
Dribbling	33%	40%	15%	**67%**	**83%**	21%	43%
Sprinting	26%	34%	40%	**63%**	45%	16%	37%
Backhand flick shot	X	X	33%	X	X	X	33%
Tackling	**60%**	28%	16%	**53%**	0	15%	29%
Pushing	22%	**50%**	17%	0	**50%**	11%	25%
Passing	20%	45%	13%	37%	17%	7%	23%
Receiving pass	40%	**53%**	11%	15%	0	7%	21%
Slide stop: inside leg	21%	26%	28%	18%	15%	X	19%
Slide stop:outside leg	24%	19%	7%	19%	15%	7%	15%
Mean	41%	51%	21%	44%	37%	15%	

X - where no action was analysed. Bold type highlights correlations of 50% and over.

Table 7.4: The percentage of the amount of trials that were significantly correlated for each subject and each action.

In table 7.4 the bold type highlights the actions in which the levels of muscle activity for more than 50% of the trials were significantly correlated. The majority of significantly correlated actions occurred during shooting, and the overall mean values for each action showed that forehand shooting had the highest percentage of trials significantly correlated. These results may suggest that the majority of subjects have a standard proportional pattern of muscle recruitment during shooting. This does not mean that each subject's proportional muscle recruitment pattern is the same, as the correlations reported so far are within subject and not between subjects. A between-subject correlation would suggest that a standard pattern of proportional muscular recruitment existed and this would be invaluable for technique training.

Correlation matrices were used to investigate whether different subjects had a significant relationship between the proportional muscle recruitment for each action. Having checked the normality of the data, the results showed significant correlations during receiving a pass for subjects 1 and 2 ($r = 0.81$, $p = 0.026$), during sprinting for subjects 3 and 6 ($r = 0.85$, $p = 0.008$) and during tackling for subjects 3 and 5, and subjects 3 and 6, ($r = 0.9$, $p = 0.038$ and $r = 0.8$, $p = 0.017$, respectively). Finally subjects 5 and 6 showed a significant correlation during backhand slap shots ($r = 0.78$, $p = 0.04$). There were no overall patterns common for all subjects, for any action.

DISCUSSION

The aim of this final study was to monitor the activity of the muscles defined in the previous chapter as central to roller hockey match play during training sessions and training matches, using electromyography. In order to begin to understand muscular activity during roller hockey, altogether 734 actions were analysed during the training sessions of 6 subjects. The qualitative analysis in this investigation provided descriptive reviews of the muscle recruitment patterns for each action. The quantitative analysis provided quantifiable data that could be used to cross compare muscles and subjects, and to assess the levels of muscular activity during these roller hockey actions.

As previously mentioned, Bartlett (1997) and De Luca (1997) defined two categories of factors that may influence the EMG signal, namely intrinsic and extrinsic factors. During this investigation the intrinsic factors were taken into account, and the extrinsic factors were controlled for in every possible instance. Artefacts were minimal and were due mainly to interference from atmospheric static electricity and these were eliminated before any data were processed. In spite of the complexities of analytical EMG, the EMG results obtained in this investigation were deemed adequate to provide a sound basis on which further analyses could be planned.

The results of the qualitative analysis showed many similarities to the muscle recruitment patterns reported in the kinesiological analysis (chapter 6). The only noticeable differences were firstly, that the kinesiological analysis over-estimated the role of the sartorius during pushing; and secondly, that during sprinting, the kinesiological analysis presumed plantar flexion contributed to the overall power during the maximal extension of the leg. However, the EMG analysis revealed a lack of plantar flexion during the powerful extension phase in sprinting.

This lack of plantar flexion requires some explanation. In chapter 4 of this thesis (the match analysis) it seemed that sprinting involved running on the toe stops; however, the toe stops are very low to the ground on roller hockey skates (approximately 1.5 cm off the floor, and at an angle of approximately 19 degrees from the horizontal: see figure 7.15). Consequently the foot can only tilt by the same angle, allowing for minimal plantar flexion when the foot is still in contact with the floor and justifying the observed lack of activity in the gastrocnemius.

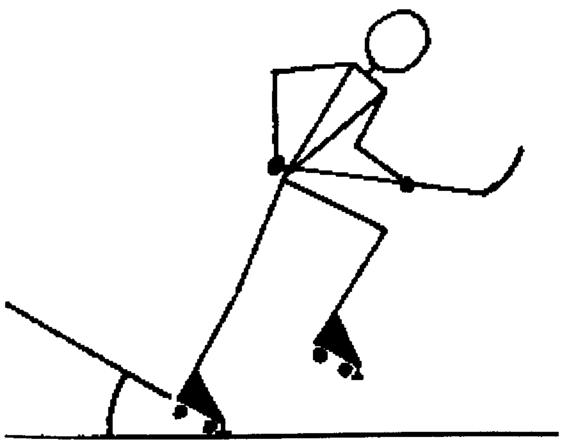


Figure 7.15: Relative position of the toe stop to the horizontal.

Following on from this, sprinting speed is fundamental to the roller hockey player's performance. Speed of sprinting is conditional on a number of factors: the speed of the recovery of the leg, and the duration of the no support phase, but most importantly the speed of extension and the power exerted by the extension leg. This explosive extension of the hip and knee lifts the player off the floor; however, there is a relatively small amount of plantar flexion. During athletics, sprinting without plantar flexing the foot (if possible) would severely hinder speed. Consequently, if the extension of the leg during roller hockey sprinting could incorporate plantar flexion this might have a positive effect on sprinting speed. In order to make plantar flexion possible the design of the roller hockey toe stop would have to be modified; a suggested improvement would be a semi-cylindrical toe stop design (see figure 7.16). However, an ergonomic analysis of the roller hockey skate is beyond the scope of this investigation.

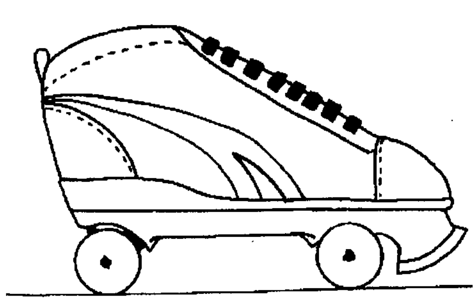


Figure 7.16: Suggested alterations in roller hockey toe stop design.

The findings of the qualitative analysis in this investigation can be compared to those of other research groups (De Boer *et al.*, 1987b; De Koning *et al.*, 1991a; and De Koning *et al.*, 1991b) who analysed muscle co-ordination patterns during 'ice speed skating'. As previously mentioned, the pushing action adopted by roller hockey players is similar to the action of the ice speed skater. De Boer *et al.* (1987b) described the EMG activity of the legs during 'ice speed skating', reporting activity of the rectus femoris and gluteus maximus during the extension phase and eccentric contraction of the semitendinosus, which is similar to the EMG activity reported during pushing in this investigation. De Boer *et al.* (1987b) reported activity in the gastrocnemius during the gliding phase that was not observed in the current investigation. De Koning *et al.* (1991a) additionally reported a peak in semitendinosus activity during the gliding phase that was found at a similar time in this study, as the recovery leg was flexed in preparation for planting.

The second section of the results was the quantitative analysis. In order to compare the quantified data from this investigation with the findings of other studies, it was essential to use a reliable normalisation technique. The normalisation value acts as a reference, against which the experimental EMG results can be compared. In this investigation the use of MDC as a normalising value was considered more appropriate than the MVC values. As stated by De Luca (1997), without sufficient training and practice of both the investigator and the subject, it is very difficult to elicit a true MVC. Due to the maximal stress placed on the subjects during the training sessions (demonstrated by maximum heart rate levels), it was felt that the MDC was a true maximum contraction and a consistently reliable reference value. However, the use of MDC as the normalising value was based on the assumption that maximum values were achieved during the dynamic situation. This is a common assumption but it is one that has not been proved and therefore should always be noted when drawing conclusion from these data.

The quantitative analysis utilised two forms of temporal processing, peak EMG value analysis and average rectified EMG analysis (AREMG) (table 7.1 and 7.2). Figures 7.9 and 7.11 represent the overall mean peak values and AREMG values for each muscle; both processing techniques show that the most active muscle was the pectoralis major. During all hockey actions the pectoralis major is required to produce maximum activity quickly and consistently. The gastrocnemius showed the least overall activity, this may be expected due to the restricted plantar flexion of the foot, resulting from the current design of the roller hockey skate.

Figure 7.10 and 7.12 represent the overall mean peak EMG values and AREMG values for each action from tables 7.1 and 7.2. Both figures display similar results, with sprinting and shooting (forehand slap shot, backhand slap shot and backhand flick shot) producing the greatest activity in the muscles analysed. The next most demanding actions were hockey related activities such as tackling, dribbling, receiving a pass and passing. Finally skating actions such as pushing and slide stopping required the least EMG activity from the muscles studied.

The demanding nature of sprinting and the forehand slap shot is well known within roller hockey. Maximum sprinting speed can, in some situations, determine successful match play performance. The forehand slap shot is the most powerful shot, demanding the most instantaneous power. Table 7.1 and 7.2 showed that slide stopping required the least EMG activity from the muscles analysed. However, experience suggests that slide stopping is very demanding and fatigue inducing, which may indicate that other muscles not included in this study e.g. peroneus longus and brevis (ankle eversion), tibialis anterior (ankle inversion) and gluteus medius (medial thigh rotation) (Appendix 2) meet the muscular demands of this action.

Table 7.1 and 7.2 show the forehand flick shot was less demanding than the other three shots. This result is surprising, as the forehand flick shot is a demanding action when performed maximally. The forehand flick shot is also one of the easiest shots to perform and can be performed quickly but effectively at a fairly low muscular intensities. It may be that low intensity forehand flick shots have reduced the mean values seen in table 7.1 and 7.2. The high activity levels of the pectoralis major and the latissimus dorsi during the slap shots supports the assumption made in chapter 6, that power for shooting comes from the rotation of the upper body. The same was assumed for the flick shots; however, the role of leg adduction was underestimated during chapter 6. Pushing displayed a lack of gastrocnemius activity supporting De Boer *et al* (1987b) who reported a lack of plantar flexion during 'ice speed skating'.

The mean peak EMG value for all muscles and all actions was 54% of MDC. In practical terms this means that on average, every action produced peak EMG activity level of 54%; in some cases this value actually exceeded the values measured during the MVC manoeuvres. Overall the AREMG data highlighted the importance of the adductor longus, but the sartorius displayed lower overall activity levels than expected. Due to the specific action of the sartorius, hip flexion, abduction and external rotation with knee flexion (Daniels *et al.,* 1956), the sartorius was originally thought to be the prime mover during pushing (chapter 6). The low overall activity level of the sartorius reported in this EMG analysis and its low activity level during pushing did not support these assumptions made in chapter 6.

Analysis of the EMG data using two forms of temporal processing (peak EMG values analysis and average rectified EMG analysis) enabled the comparison of these two forms of EMG data processing. The overall range of the peak EMG values was greater than the AREMG values. This was expected, as peak EMG values are instantaneous, whereas AREMG values are averaged over time; the averaging of values has a smoothing effect, thus reducing the range. Regardless of the similarities found between the two forms of data processing, each gave further insight into muscular activity during roller hockey. Consequently it was considered valid in this investigation to use both forms of data analysis.

Descriptive analysis was performed on the data in table 7.1 and 7.2. Statistical analysis was limited due to the small sample size, and the range of the data, which caused a lack of homogeneity of covariance. This meant employing a correctional test, which reduces the degrees of freedom making the ANOVA "more conservative" (Kinnear and Gray, 1995).

The correlations reported in standard proportional muscle recruitment within actions were interesting and important results (table 7.4). The 100% significant correlation between forehand flick shots for subject 1 (table 7.3) meant in practical terms, that this subject had a standard proportional muscle recruitment pattern during every forehand flick shot. Overall shooting displayed the highest percentage of correlations between trials, with all the 100% correlations appearing in shooting. Shooting is probably the most practised and the most technique orientated roller hockey action. The results of this study show that shooting demands a specific pattern of events to occur in the same order and at the same relative intensity. This is regardless of the position of the player on the rink or any other external factors. Whilst other hockey skills such as dribbling, tackling, passing and receiving a pass, require less definite proportional muscle recruitment patterns between trials, they adapt to the environment and become more situation-dependant.

Identification of a mean correlation between subjects proportional muscle recruitment pattern would suggest a common technique. However, no overall correlations were found. One factor that may influence proportional muscle recruitment between trials of the same action is experience, with inexperienced subjects showing greater variability in their proportional muscle recruitment patterns between trials. Dainty and Norman (1987) acknowledged the characteristics of skilled performance to be that the muscles responsible for the execution of a movement exhibited a specific sequential and temporal order of activation; measuring this parameter would provide the coach with an indicator of the level of skill. During the current investigation the subjects were highly experienced, elite English roller hockey players, and therefore it is suggested that the effect of experience on the proportional muscle recruitment patterns within this investigation were eliminated. If this is so, it can be concluded that the subjects adopted their own shooting technique. This conclusion supports the findings of Dore and Roy (1976) using a different analysis method. They analysed the variation in time of the forces applied on the hockey stick during ice shooting (using the wrist shot, which is identical to the roller hockey flick shot, and the slap shot which is also identical in both sports). Their results showed a general pattern could be identified within trials for the same player, but for each shot there was no overall pattern among players in terms of the shape of the force-time diagrams. Dore and Roy (1976, p 282) concluded that the similarities within players in the force-time diagram and the differences between players made possible "the recognition of the signature of a player".

Despite the lack of a standard proportional muscle recruitment pattern between subjects, the results of the qualitative analysis in this investigation indicated general recruitment patterns for all action. It should be noted, however, that the qualitative analysis was only concerned with the on-set, off-set and peaks in activity, in the linear envelope of the EMG. Further qualitative analysis may establish differences in techniques between subjects. This current investigation was more concerned with the overall EMG activity of all subjects, rather than analysis of individual subjects' technique, however valuable.

Measurement Error

During this EMG analysis a number of assumptions were made; for example it was assumed that the orientation, location and configuration of the electrodes were correct. Also that the EMG equipment itself did not interfere with the subjects' performance during the roller hockey training session and training matches. It was also assumed that the EMG data represented the activity of the appropriate muscle. Cross-talk (the detection of EMG activity from surrounding muscles) is a common problem within electromyography and one that should be acknowledged. Two of the muscles analysed in this study (the sartorius and the semitendinosus) are muscles that might move under the skin when contracting and relaxing. As the electrodes were placed on the surface of the skin over the belly of the contracted muscle, it may be suggested that as the muscle returned to a more relaxed state the electrodes may no longer be positioned over the appropriate muscle, though the relative muscle size and training state of this group of subjects reduced the likelihood of this. This study assumed that the EMG activity recorded from the sartorius and the semitendinosus was representative of these muscles, however it is acknowledged that this may not have been the case. The pattern of EMG activity recorded for the sartorius was checked against that recorded for the rectus femoris and found to display very different results.

The use of maximum dynamic contractions as an EMG normalising factor, presumes that maximum values were achieved during the dynamic condition. The normalising of EMG activity is essential in order to compare across values, but in this study the maximum dynamic values were considered more valid than those obtained from the maximum voluntary contractions. Further research is required in the area of EMG normalisation to establish a universal normalising system.

To gain an understanding of the overall activity of specific muscles during roller hockey training sessions and training matches, this study may have benefited from an EMG recording system that could continually record EMG activity during the whole 2-hour training session. In the present study EMG activity was recorded during periods of the training session when the subject was active (rather than standing in a queue or during stationary team talks), therefore the results of this study do not represent the overall EMG activity during the training sessions. Instead the results of this study were analysed with respect to the EMG activity during individual actions.

It must also be acknowledged that the same coach (the England national team coach) directed all the training sessions analysed during this study and therefore the coach directly influenced the training activities. Future research may benefit from an analysis of roller hockey training activities at a number of different training sessions performed by various coaches.

The method used to synchronise the EMG data collection and the video recording system (using two synchronised cameras, one focusing on the EMG monitor and the other tracking the subject) was highly successful and is recommended for future research. Impedance levels were satisfactory, but varied considerably from electrode site to site and from subject to subject.

Finally, due to the large amount of data acquired from this analysis, a small number of subjects was used. Further research in this area is required to substantiate the results of this report.

CONCLUSION

The aims of this study were to monitor the activity of the muscles defined in the previous chapter as central to roller hockey match play during training sessions and training matches, using electromyography. Electromyography provided valuable qualitative and quantitative results regarding muscular activity during roller hockey. The data processing methods employed enabled thorough quantification of the results, making it possible for future research findings to be compared with the present reference values.

During performance of roller hockey actions the pectoralis major was the most active of the muscles analysed. Activity in the pectoralis major and the latissimus dorsi was prominent in the slap shots, suggesting that the training of these two muscles may benefit not only the power and speed of shooting, but also roller hockey performance in general. However, a balanced muscular training programme is also important. Overall the role of the adductor longus should not be underestimated in the performance of roller hockey actions. In general the gastrocnemius displayed a low level of activity throughout performance of roller hockey actions.

The peak EMG values and AREMG values displayed a similar hierarchy of roller hockey actions, with sprinting and the forehand slap shot being the most demanding actions, followed by shooting, then hockey actions and finally skating actions. The action demanding the least overall activity, was slide stopping. It was suggested that this result was not due to the action being of low intensity, but that the slide stop stressed muscles that were not analysed in this investigation. Therefore future research should continue to analyse the EMG activity of other muscles throughout the body.

The correlations observed in the proportion muscle recruitment patterns between trials of various shots, suggest that future roller hockey research may benefit from individual technique analysis during shooting, in order to understand and established the different muscle co-ordination patterns.

As well as providing unique information on muscular activity during roller hockey, this investigation also enabled the comparison of two forms of EMG temporal data processing. These techniques produced some similar results, with one technique representing maximal EMG activity (peak EMG values analysis) and the other representing average activity over time (average rectified EMG analysis). The positive correlation between the two data sets and the time taken to complete both processing methods, suggest that future EMG research may benefit from using one of these processing techniques, rather than both. The chosen technique is dependant on the experimental design.

For all the actions in this investigation, the average level of muscular activity for peak EMG values and AREMG values was reasonably high. It must be remembered that these values included the performance of roller hockey actions not only during match play but also during lower intensity training exercises. Consequently the EMG muscular activity during competitive match play may display even greater muscle activity than reported in this investigation.

CHAPTER 8

GENERAL DISCUSSION

DISCUSSION

This chapter begins by summarising the originals aims of this thesis stated in the rationale (chapter 2). To assess the success with which these aims have been met this chapter then briefly summarises the results of each discrete study. Following this the practical recommendations made throughout this thesis for English roller hockey training are discussed. The findings from each chapter are then combined to analyse the overall muscular activity during roller hockey match play. Finally this chapter concludes by discussing the limitations of the research within this thesis and any future research recommendations that have arisen during the course of this research.

This thesis began by detailing the historical decline of England's international roller hockey performance, from World leaders in the sport (before the First World War) to currently being unable to gain promotion into the top 14 teams of the Group A World Ranking. Roller hockey is a minority sport in England; nevertheless its dedicated associates strive voluntarily to improve England's international status. It was suggested at the start of this report that England's poor international performance was due to a lack of support, including financial, participation, sponsorship, publicity and coaching aspects. For coaches in this country the lack of coaching knowledge maybe due to the poor availability of valid and reliable scientific information. The lack of finance and a lack of facilities mean English players have little 'on-rink' training time and are forced to training for roller hockey in other ways. The components of this 'off-rink' training are crucial, but this area is often neglected by coaches.

The overall aim of this thesis was to investigate the muscular demands of roller hockey match play, to aid English players' match performance by improving both 'on-rink' and 'off-rink' training techniques. To achieve this, four discrete investigations were completed. The first investigation that needed to be undertaken was a thorough analysis of competitive roller hockey match play. An understanding of all the actions involved in roller hockey and the percentage of match time spent performing each of these actions not only acts as a basis on which further scientific research can be based, but also has implications for training. Having investigated the characteristics of match play, the second investigation analysed roller hockey players' heart rates, which provided easy to measure information on physiological activity during match play. The findings of this second investigation have implications for the relative intensity of training sessions. Having established the major actions performed during roller hockey match play the third study within this thesis was a detailed kinesiological analysis of the movement phases, joint actions and muscular activity within these actions. This investigation provided an in-depth understanding of the movement phases of roller hockey actions and detailed information on the muscular activity. Using the information gained during the kinesiological analysis, the fourth study monitored the activity of eight muscles during roller hockey training and training matches, using electromyography.

At the start of this thesis no scientific research had been located in roller hockey, but during this investigation foreign literature on roller hockey was gradually located and translated into English. By making this literature available to the English roller hockey community, the information may also progress the scientific understanding of roller hockey in this country.

To summarise the results of each study, the match analysis identified 17 skating and hockey actions performed by a roller hockey player in a match situation. For skating actions, rolling was the most common (71% of match play), followed by pushing (14%) and then sprinting (4%). Hockey actions accounted for 13% of match play, the most common were tackling (4%) and travelling with the ball (4%). Shooting accounted for only 0.4% of match play, but there were a large number of shots performed during matches (mean of 245 in each match). The match analysis also subjectively assessed the intensity of individual actions, classing them as either high intensity or low intensity. The results showed an overall ratio of 22 to 77, high to low intensity activity. In order to gain a greater understanding of the dynamics of a sport, it is useful to assess factors that influence match performance. This match analysis demonstrated only minor differences in match play activity between forwards and defenders, and between winners and losers. The main factor that influenced match play activity was the match half with the results showing significantly more sprinting in the first half and rolling in the second half; the intensity analysis also showed a significant increase in low intensity activity in the second half.

Following the match analysis international research was identified which had also investigated match play activity during roller hockey. While providing some comparable results, these investigations did not have the same depth of analysis as the current study.

Exercise intensity was measured subjectively during the match analysis, but heart rate analysis provided a more objective and reliable measure of the physiological activity during roller hockey match play. In the second study in this thesis heart rate data were collected successfully during training and competitive roller hockey matches. The results showed that competitive roller hockey was a high intensity activity, with average heart rates of 176 beats/min. Competitive matches displayed significantly higher heart rates than training matches (166 beats/min); from this it was suggested that the training matches should be more physically demanding. This study also evaluated roller hockey players' performance and heart rate values during a maximal and progressive shuttle skate test. The test itself was considered highly specific to roller hockey and easy to use; it was recommended for the monitoring of English roller hockey players physical condition. The equation proposed by Blanco *et al.* (1995) to calculate $\dot{V}O_2$ values during this test needs more investigation perhaps using a portable gas analyser, before it can be universally adopted.

The third study in this thesis, the kinesiological analysis, identified the movement phases, joint actions and theoretical muscular involvement in various roller hockey specific actions. This was the first investigation of its kind in roller hockey and it revealed some interesting characteristics that have also been reported in other sports. Firstly, during pushing the force to propel the subject forwards acted perpendicular to the direction of motion. Secondly, during shooting and high intensity passing the top hand on the stick reversed direction just before contact. Finally, again during shooting and high intensity passing, the back leg rotated behind the body to counteract the rotational force of the trunk. This theoretical investigation assumed that a greater muscular demand would be placed on the muscles in the legs rather than the upper body, due to the time spent performing skating actions (100% of match play).

As well as providing valuable detailed information on the expected muscular demand during roller hockey, this kinesiological analysis also established eight muscles central to roller hockey performance, which would be the focus of the EMG analysis. The EMG investigation was also the first of its kind within roller hockey. The EMG data acquisition during normal roller hockey training session was highly successful. The qualitative results of the EMG investigation for the phasic muscle recruitment supported the results of the kinesiological analysis, with only a few exceptions. The exceptions were the lack of gastrocnemius activity during sprinting, which was presumed in the kinesiological analysis to aid the powerful extension of the leg, and the lack of activity in the sartorius during pushing. These results highlight the importance of performing both a kinesiological analysis to establish the theoretical muscular activity and an EMG analysis to objectively validate these results. The results of the EMG investigation showed the greatest EMG activity occurred in the pectoralis major. As expected sprinting and the forehand slap shot produced the greatest amount of muscle activity. Overall, shooting and sprinting produced the greatest muscular activity, followed by hockey actions, and finally skating actions.

The results of these investigations highlighted a fundamental difference between the flick shot and the slap shot. The muscle co-ordination patterns reported in the EMG analysis and the movement phases reported in the kinesiological analysis, showed that during the slap shot power was derived from the rotation of the shoulders and the arms towards the ball, followed after a short delay by the rotation of the hips. During the flick shot however, power was derived from a linear translation of momentum, as the ball was dragged forwards and the back leg extended behind the player, against a fixed point. Some trunk rotation still occurred during the flick shot, but it was in the reverse order to the slap shot, first the hips rotated in the direction of the shot, followed by the shoulders.

The heart rate analysis reported significant differences in the physiological activity (measured by heart rate) during competitive matches and training matches. The EMG analysis was undertaken during training; therefore it may be suggested that caution should be used when applying the EMG results to a competitive match setting.

Overall the EMG analysis showed reasonably high levels of muscle activity during performance of roller hockey actions. The match analysis demonstrated that these actions were performed in quick succession, and the high mean heart rate values reported in the heart rate analysis showed that roller hockey match play was of a high physical intensity.

Due to the lack of substantial scientific research within roller hockey and consequently the lack of scientific knowledge within the roller hockey coaching community in England, it is hoped that the findings of this thesis will increase the scientific information available to coaches in this country. Therefore this chapter now moves on to discuss the practical recommendation made throughout this thesis for roller hockey training that may benefit the roller hockey community of this country. In the first study, the match analysis defined 17 actions performed by a roller hockey player in a match situation. While sprinting accounted for only 4% of match time, sprinting speed and frequency can be crucial in a match situation and in some circumstances may even determine successful play. Therefore it is recommended that sprint training should be incorporated into all roller hockey training sessions. The results of the match analysis also showed that players performed more slide stops on the right side than on the left side; players should be able to perform the slide stop to the same ability on both side and training sessions should encourage this. The match analysis also revealed that 7% of match time was spent travelling backwards; this should also be reflected in a training environment. A fatigue effect was indicated in the second half; one of the recommendations to overcome this fatigue effect would be to increase the duration of the training matches to exceed that of competitive matches, or to reduce the stoppage time during training matches. This study also reported that the position a player occupied on the rink had no effect on match play characteristics; this suggests that forwards and defenders should not be trained separately. The English matches analysed in this study displayed substantially less stoppage time than was reported in the Spanish Honour Division (Blanco *et al.*, 1993). Therefore a tactical recommendation for an English team playing a Spanish Honour team would be to reduce the stoppage time by taking free hits quickly; this may resemble English match play and disrupt the rhythm of the Spanish team by not allowing them the recovery time to which they are accustomed.

The recommendation made during the match analysis to increase the intensity of training matches was concurrent with the results of the second study in this thesis. The heart rate values reported during roller hockey training matches were significantly lower than those reported during competitive matches. Therefore it was recommended not only to increase the intensity of training matches as already suggested, but also to increase the intensity of the entire roller hockey training session. This may be achieved by either cutting the amount of rest time, or by amalgamating team talks, breaks and demonstrations to reduce the number of interruptions to the training session.

The heart rate study also monitored players' performance during the maximal and progressive shuttle skate test. The test itself was considered highly specific to roller hockey and was recommended for the routine monitoring of roller hockey players' physical condition, regardless of oxygen consumption evaluation.

The kinesiological analysis theoretically established key muscular activities during roller hockey actions. The results of this study suggested that roller hockey specific muscular training programmes should concentrate on training the rectus femoris, sartorius, gluteus maximus, semitendinosus, adductor longus, gastrocnemius, latissimus dorsi, pectoralis major, tibialis anterior, peroneus longus, deltoids, biceps brachii, triceps brachii, and brachioradialis. The muscular exercises within this muscular training programme should mimic the roller hockey specific joint actions identified in this study such as hip flexion and extension, knee flexion and extension, plantar flexion, abduction, adduction, medial and lateral rotation of the leg, rotation of the torso, abduction and adduction of the arms, flexion and extension of the shoulders and arms, and movement of the wrist.

In general the results of the fourth study (the electromyography analysis) supported the findings of the kinesiological analysis. The EMG investigation provided valuable and unique information on the relative muscular activity within each roller hockey action. For example, if a player was particularly weak at slap shots, the results of this investigation would suggest that the player should increase training on the pectoralis major; additionally if a player wanted to improve his sprinting speed, muscular training should be increased for the rectus femoris and adductor longus. But the importance of a balanced muscular training programme, which includes the other muscles identified as central to roller hockey performance, should be emphasised. The results of the kinesiological analysis assumed that sprinting involved plantar flexion, however the electromyography study reported a lack of plantar flexion during sprinting. Further investigation suggested that this lack of plantar flexion might have been due to the design of the roller hockey toe stop. A practical recommendation from this finding was to change the shape of the toe stop from a flat surface to a semi-cylindrical shape, this may allow the player to roll off the toe stop and consequently plantar flex the foot. It was suggested that this may improve sprinting speed and efficiency.

Having discussed the practical recommendations that have resulted from this research this chapter moves on to combine the results of each investigation to analyse the overall muscular activity during roller hockey match play. The EMG analysis established that the pectoralis major produced the greatest amount of EMG activity during performance of individual roller hockey actions in a training environment. Analysing the EMG activity of individual actions provided valuable information on the muscular activity during roller hockey match play. However, this overall muscular activity will be influenced by the frequency of performance of these actions in matches. Therefore the results of the EMG investigation should be considered in conjunction with the results of the match analysis. The AREMG values (as a percentage of MDC) represent the average amount of activity for an individual action; multiplying this by the total time spent performing each of these actions in a match, will identify the relative importance of each muscle, during each action, within a match situation (see table 8.0).

The match analysis indicated that the most frequently performed action during a roller hockey match was rolling (71% of match play), but for experienced players this action requires minimal muscular activity. The EMG analysis revealed that compared to pushing, sprinting produced greater EMG activity in the muscles analysed. Table 8.0 shows that the overall muscular activity during pushing was actually greater than sprinting during a match, due to the relatively high percentage of match time spent pushing (14%, compared to 4% of match time spent sprinting). Table 8.0 also shows that tackling produced a relatively high level of EMG activity on the muscles analysed, again due to the relatively high percentage of match time spent tackling. Despite the very small percentage of match time spent shooting (0.4%), the forehand shots produced a large amount of EMG muscle activity, due to the intense nature of these actions. Right slide stopping produced greater EMG activity than left slide stopping, due to the higher frequency of right stops during match play. Overall the backhand flick shot and dribbling produced a low level of EMG activity on the muscles analysed, due to the small percentage of time spent performing each of these actions.

Table 8.0: Average rectified EMG values as a percentage of the maximum dynamic contractions, multiplied by the total time spent performing each action during an average match.

	Rectus femoris	Pectoralis major	Adductor longus	Latissimus dorsi	Semitendinosus	Gluteus maximus	Sartorius	Gastrocnemius	Mean
Pushing	20334	16181	16659	15609	17111	16828	12810	11341	15859
Sprinting	8637	7251	8230	7133	7944	7483	6435	5436	7319
Tackling	6811	6995	6382	6733	5354	5075	4838	3476	5708
Forehand slap shot	4770	6150	5809	6084	4913	4774	3624	2946	4884
Forehand flick shot	2782	3837	3478	3106	2919	2561	1695	1668	2756
Passing	2166	3318	2231	2678	2456	1992	1513	1486	2230
R. slide stop: outside leg	2558	2181	2323	1700	1891	1786	1678	1425	1943
Backhand slap shot	1822	2623	1972	2349	1984	2248	1278	1158	1929
Receiving pass	1635	2385	1520	1666	1580	1407	1096	1093	1548
L. slide stop: inside leg	1466	1374	1698	1739	1580	1103	1604	1079	1455
Backhand flick shot	676	837	824	790	823	726	448	712	730
Dribbling	361	429	403	388	399	356	333	253	365
Mean	4502	4463	4294	4164	4080	3862	3113	2673	

As suggested in the kinesiological analysis, table 8.0 shows that the muscles in the leg, notably the rectus femoris, demonstrated the greatest muscle activity during roller hockey match play. The importance of the upper body (the pectoralis major and the latissimus dorsi) as reported during the EMG analysis is also evident. Therefore it is concluded that of the muscles monitored, the rectus femoris was in fact the most active during roller hockey match play. There were also high contributions from the pectoralis major, the adductor longus, the latissimus dorsi, the semitendinosus, and the gluteus maximus.

The match analysis suggested that roller hockey players needed to be 'all-rounders', capable of performing all roller hockey actions, and that there should be no separation in training between forwards and defenders. Therefore a practical implication of this dissertation would be not to train one muscle selectively, e.g. the rectus femoris, but to train a collection of roller hockey specific muscles, using exercises that simulate the joint actions of roller hockey.

Limitations of this research:

There were a number of limitations of the current research that have led to recommendations for future research in this area. This analysis of roller hockey match play was performed manually, which proved to be very time consuming, and also meant that the results were not available immediately to the coach.

Whilst heart rate analysis provided a valuable insight into the physiological activity during roller hockey match play, analysis of blood lactate may have provided additional information in this area. Measurements of blood lactate may have been difficult to regulate during competitive matches, due to access to the players only being available before the matches, at half time, and at the end of the matches; however, future research may benefit from this type of analysis. Also without the use of a portable gas analyser, it was not possible to validate the equation proposed by Blanco *et al.* (1995) for calculating oxygen consumption during the maximal and progressive shuttle skate test. Therefore, future research needs to be conducted to validate this equation.

It may be suggested that the kinesiological analysis would have produced more accurate information on the phases within each roller hockey action if recorded image digitisation had been used. Due to the relatively large number of actions analysed this would also have been very time consuming, and the inclusion of more subjects in the analysis would have added to this problem.

Future research recommendations:

Due to limited previous scientific research in roller hockey, this thesis hoped to provide a broad understanding of the biomechanical and physiological demands of roller hockey match play, upon which future research could be based. As a result of this many areas worthy of more research were highlighted during each discrete study. Also the limitations experienced during the current investigation lead to suggestions for future research in this area. For example during the match analysis investigation, due to the time consumed during manual notation future research may benefit from either reducing the variables observed or using a more automated data collection system. This would also allow results to be available more quickly for research purposes and for coaching. The measurement of distances travelled during match play may also provide additional information on the demands of roller hockey.

During analysis of the heart rate responses, oxygen consumption values were calculated for the maximal and progressive shuttle skate test using an equation proposed by Blanco *et al.* (1995). Further research is needed using a portable gas analyser to validate this equation.

As discussed in the kinesiological investigation kinematic analysis of roller hockey actions would benefit both coaches and players by providing information on technique and movement patterns. Therefore future research may benefit from recorded image digitisation on a limited number of actions, for example shooting.

The vast amount of data recorded and processed during the EMG investigation would have made it difficult to analyse more subjects or more muscles. To gain a more complete understanding of the muscular activity during roller hockey, it is recommended that future research continues to analyse different muscles, using similar EMG methodology and data processing.

The results of the EMG study indicated that different shooting techniques existed in top English roller hockey players. Roller hockey coaching may benefit from an in-depth EMG, cinematography and recorded image digitisation analysis, correlated with shooting accuracy, to establish optimum shooting technique.

Other areas worthy of future investigation include analysis of the forces exerted by roller hockey players on their equipment and on the environment, electromyography normalisation, and an ergonomic analysis of the roller hockey skate and toe stop.

In summary this thesis has provided valuable and unique scientific information on muscular activity during roller hockey match play, using four discrete studies. Each study has provided additional information on the biomechanical and physiological demands of roller hockey competition and training. It is hoped that the research within this thesis may be used to increase the scientific understanding of roller hockey, both within the English game and for international competition preparation. In turn it is hoped that the results of this investigation may aid the development of roller hockey specific muscular training programmes, which could be used by top English roller hockey players when 'on-rink' training time is restricted.

CHAPTER 9

GENERAL CONCLUSION

This investigation is the first major long term study on roller hockey match play. The overall aim of this thesis was to analyse the muscular demands of roller hockey match play. To achieve this, a number of different techniques were used and each technique was essential to the next area of analysis. The four discrete studies that were carried out within this thesis were unique; the roller hockey match analysis and the heart rate analysis were the first to be performed on roller hockey in this country. The recording, measurement and identification of important factors and demands of match play has considerably increased the scientific data available about activity during roller hockey.

The kinesiological analysis appears to be the first such study to be undertaken on roller hockey. The electromyography analysis also appears to be the first such study within roller hockey, showing that such an analysis is possible during a dynamic, aggressive, semi-contact sport.

Each of the studies within this thesis provided valuable biomechanical and physiological information on roller hockey match play, and the combination of these results provides unique information on relative muscular activity during roller hockey match play. Combining the results of the electromyography analysis with the results of the match analysis revealed the high physical demands of the skating actions pushing, and sprinting, and the hockey shooting actions. It is hoped that the results of this thesis will aid the development of roller hockey specific muscular training programmes, which will improve 'off-rink' roller hockey training and consequently lead to an improvement in English roller hockey players' performance.

In conclusion, the analysis techniques employed during this research have allowed the assessment and comparison of observed and theoretical demands of the sport with those that occur during training and competition.

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APPENDIX 1

HEART RATE TRACES DURING THREE COMPETITIVE ROLLER HOCKEY MATCHES FOR THE EIGHT MEMBERS OF THE ENGLAND TEAM.

KEY

Playing	P
Substitution	S
Half Time	H
Warm up	W
First Half	1st
Second Half	2nd

Heart rate was measured in beats per minute

Subject 1

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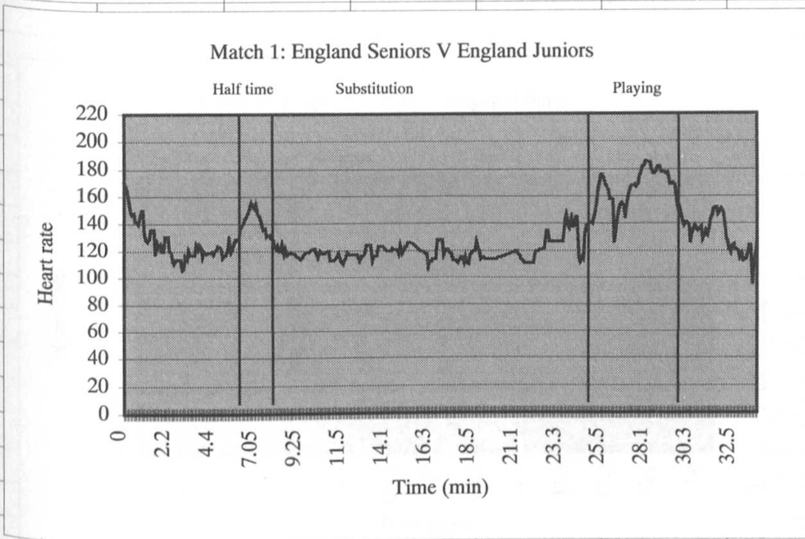

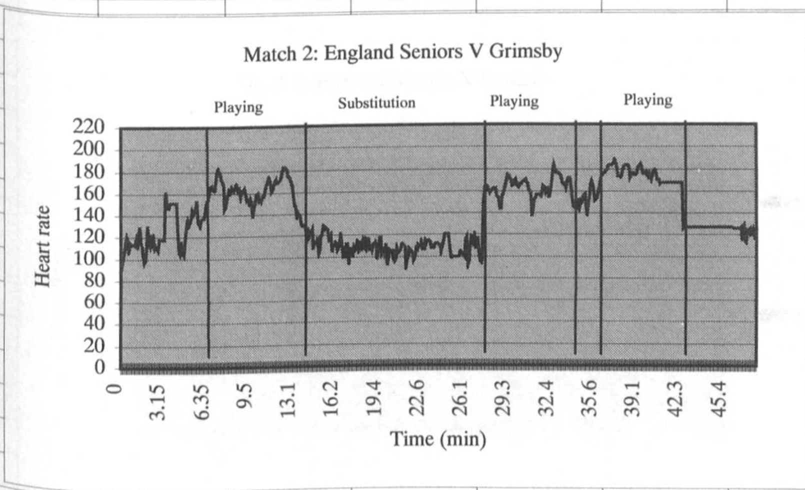

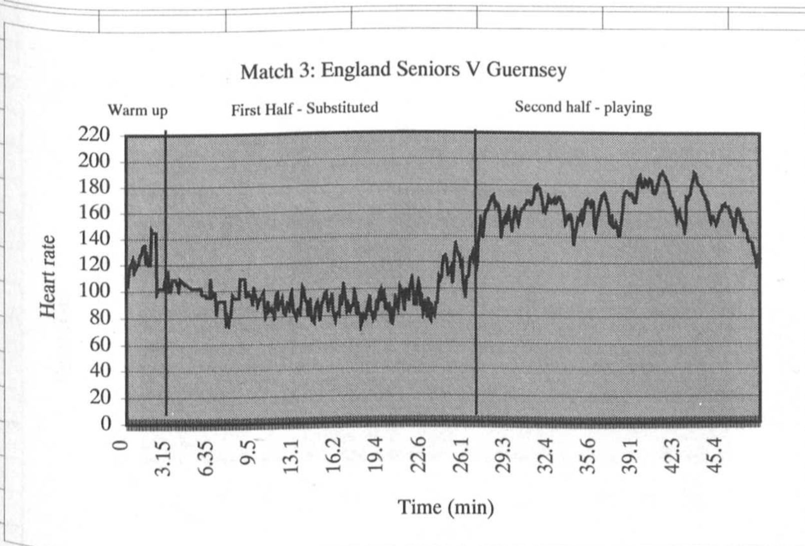

Max heart rate	Average playing heart rate
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185	164
190	164

Subject 2

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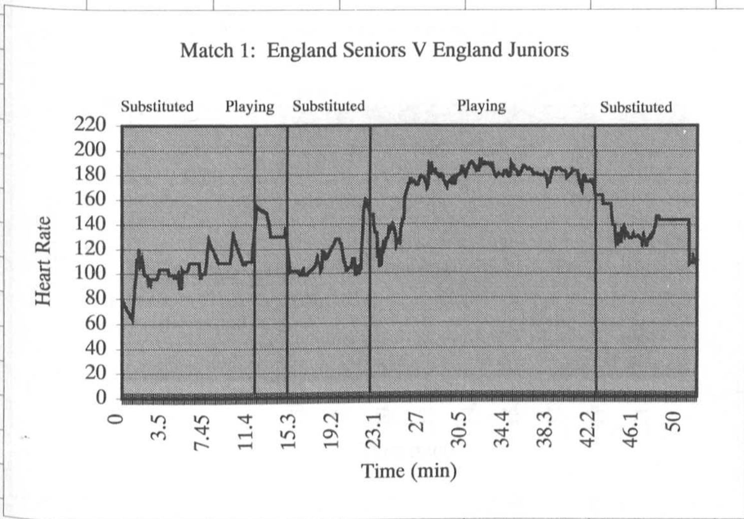
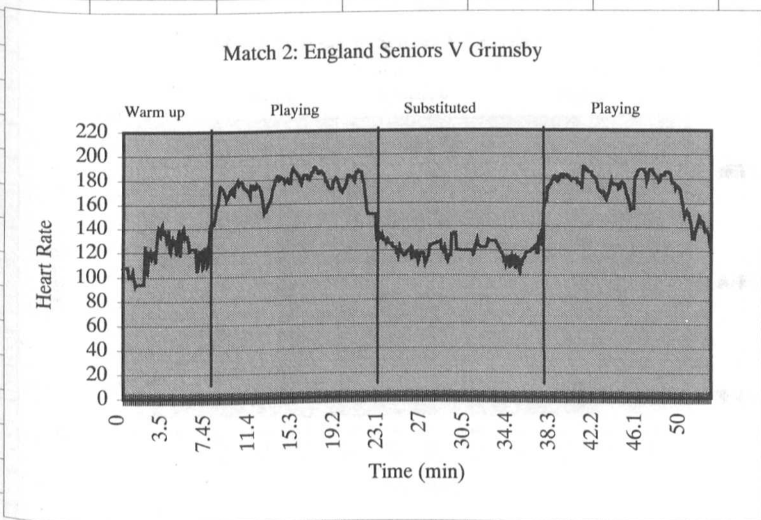
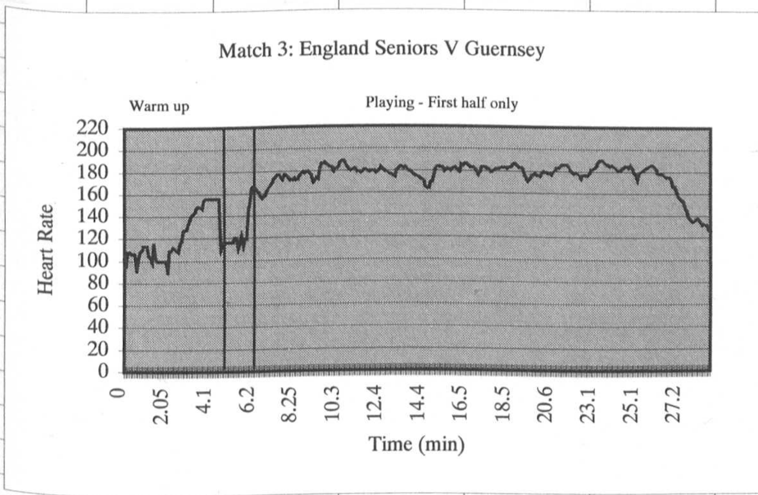
	191	159
	190	177
	190	179

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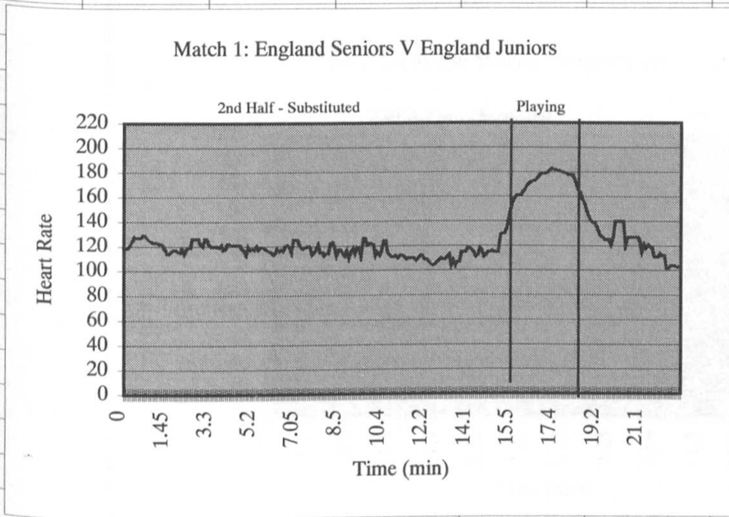
<tr><td>
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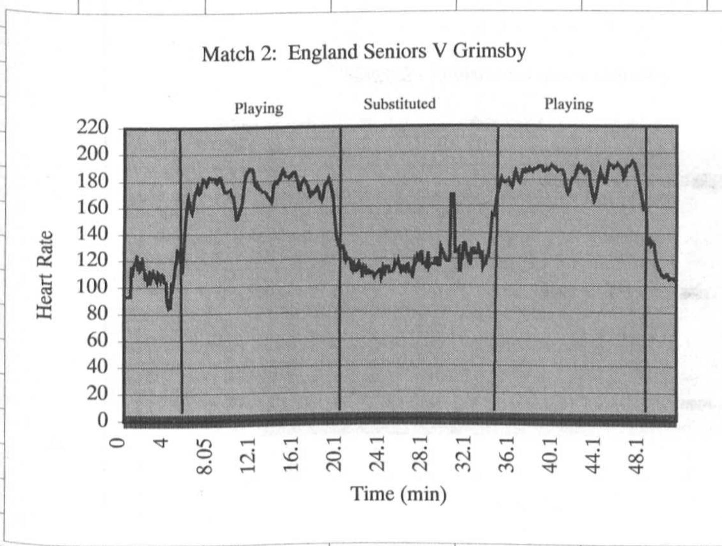
<tr><td>
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Subject 4

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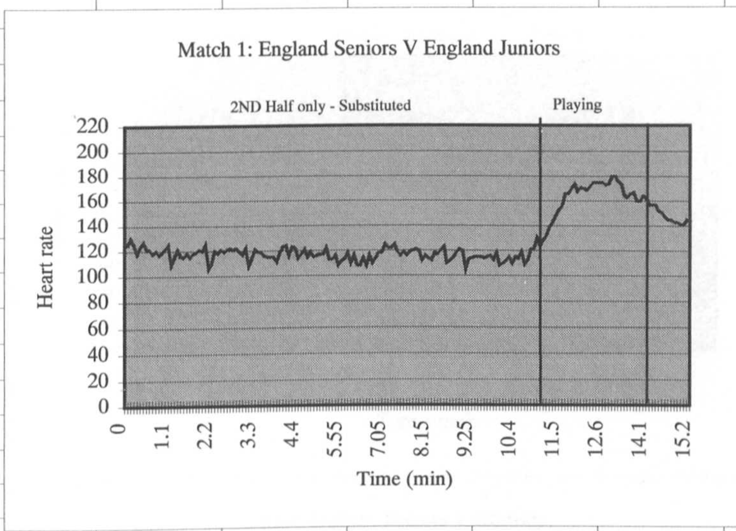
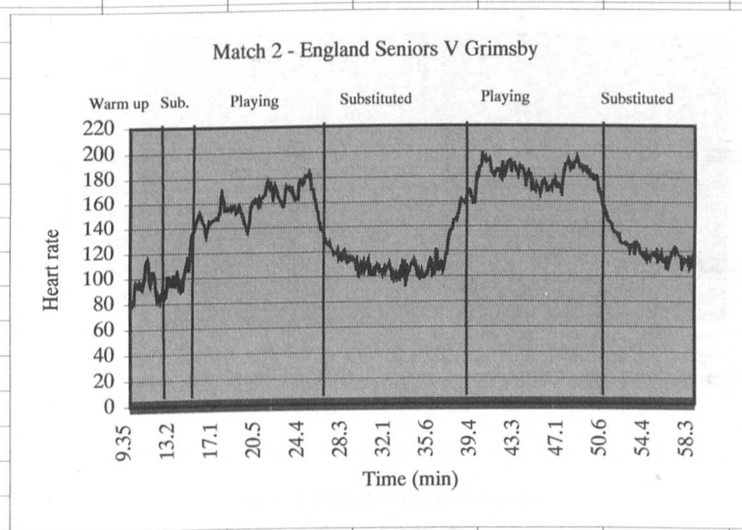
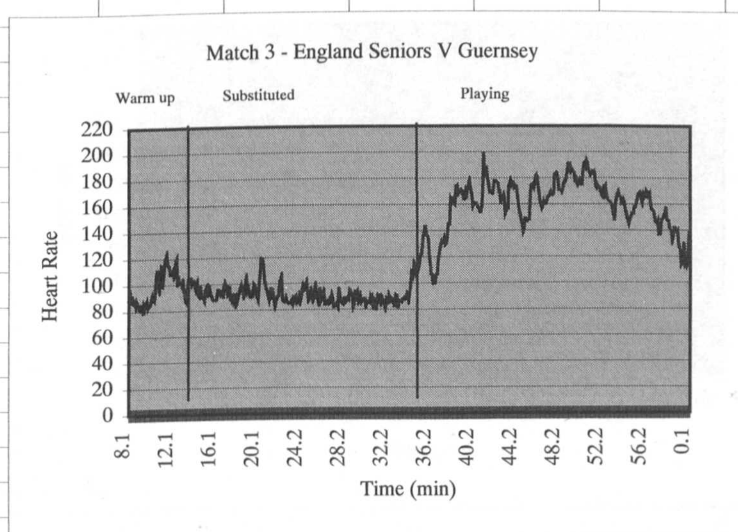
	180	158
	198	168
	200	165

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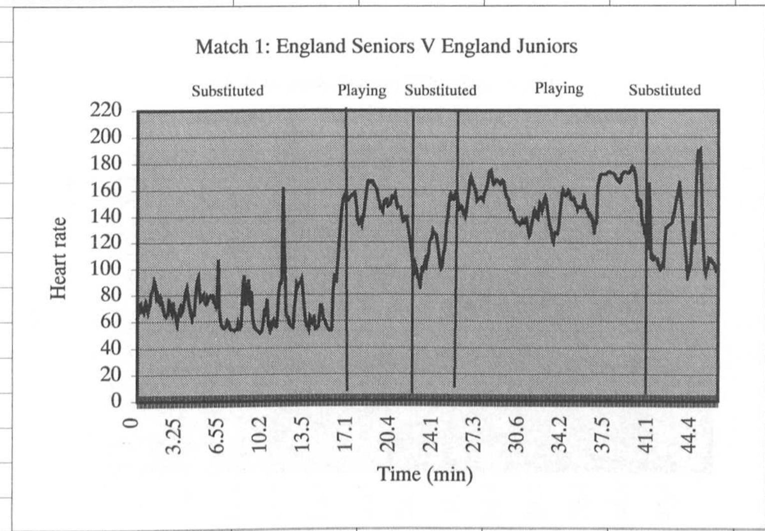
<tr><td>
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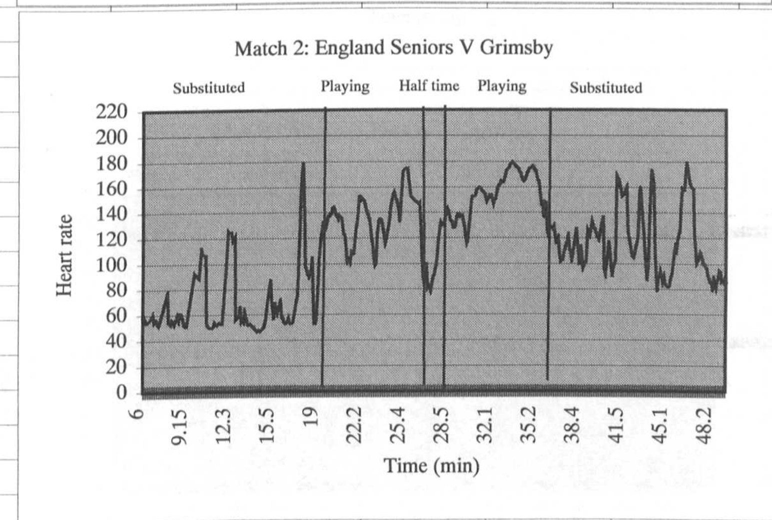
<tr><td>
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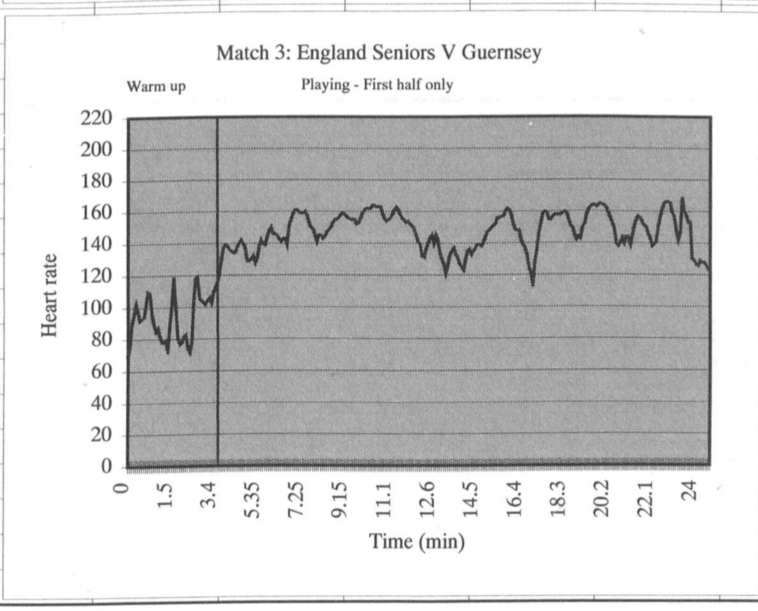
<tr><td>
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Subject 6

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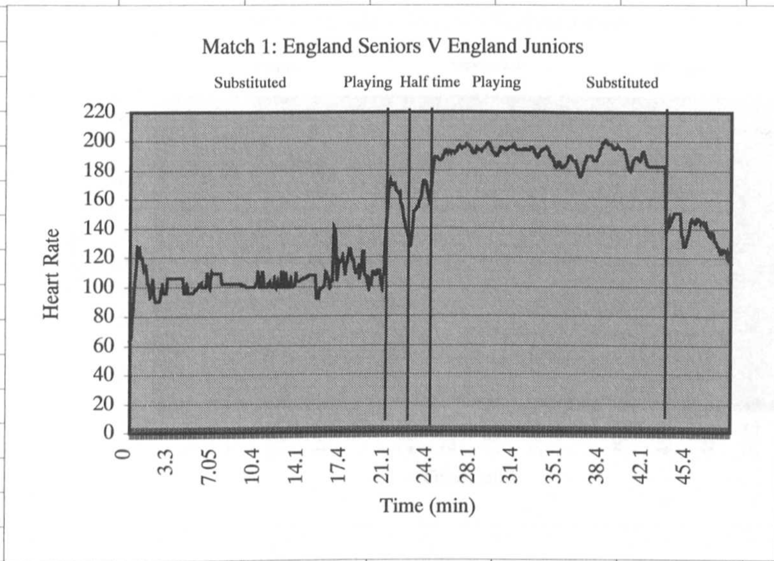
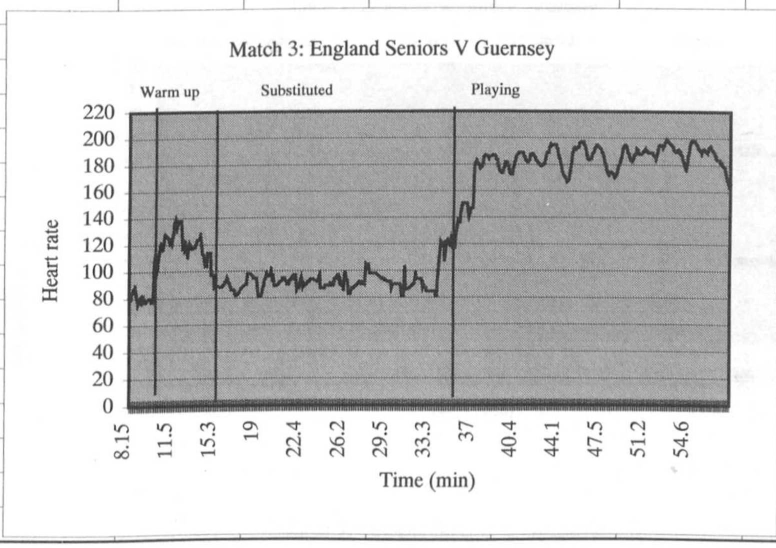
	201	188
	199	186

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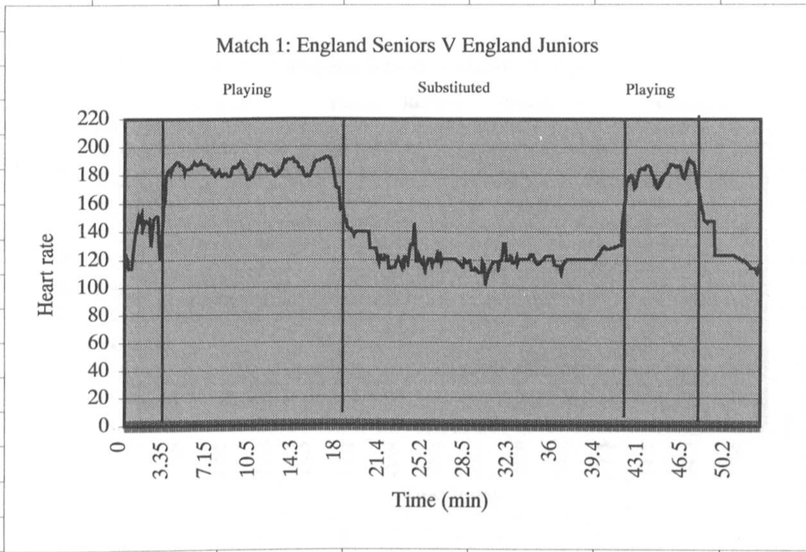

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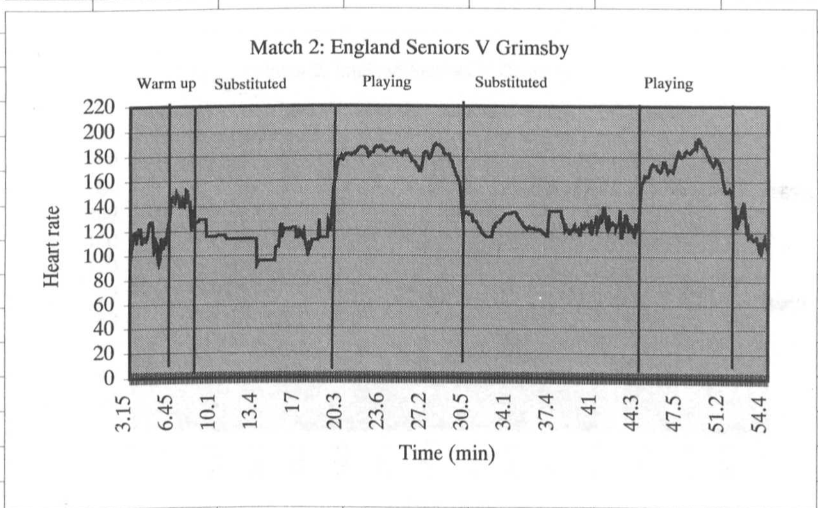

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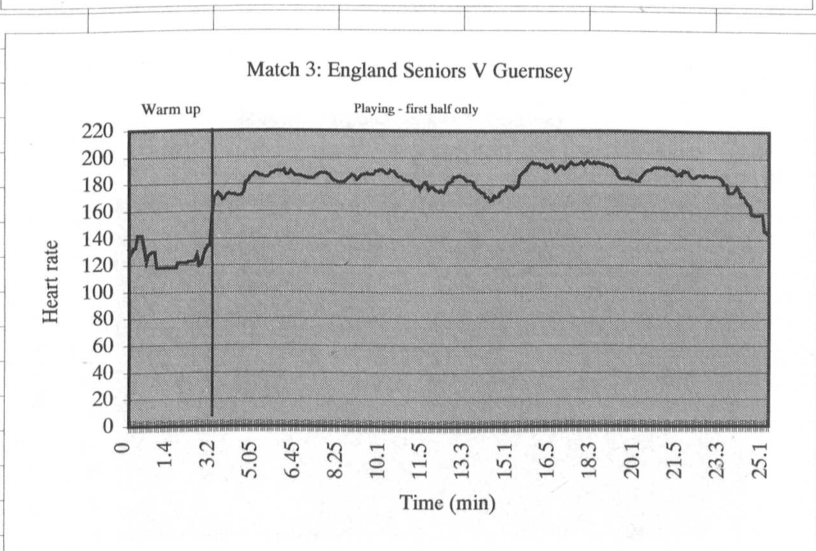

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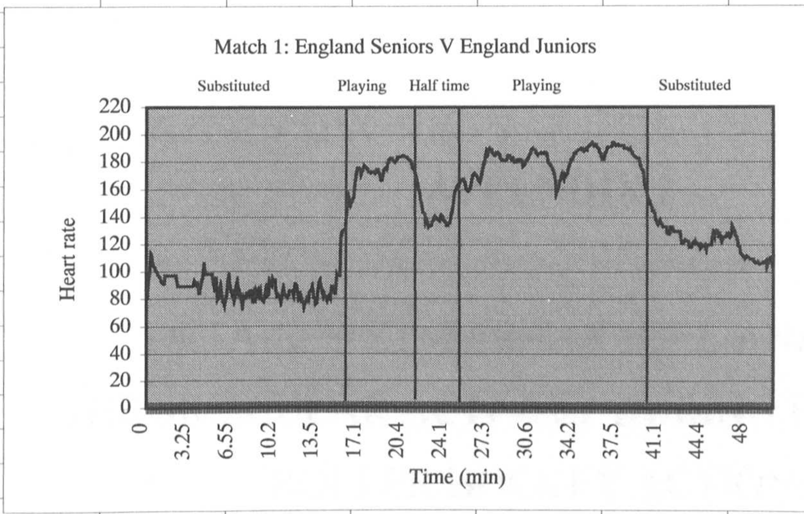
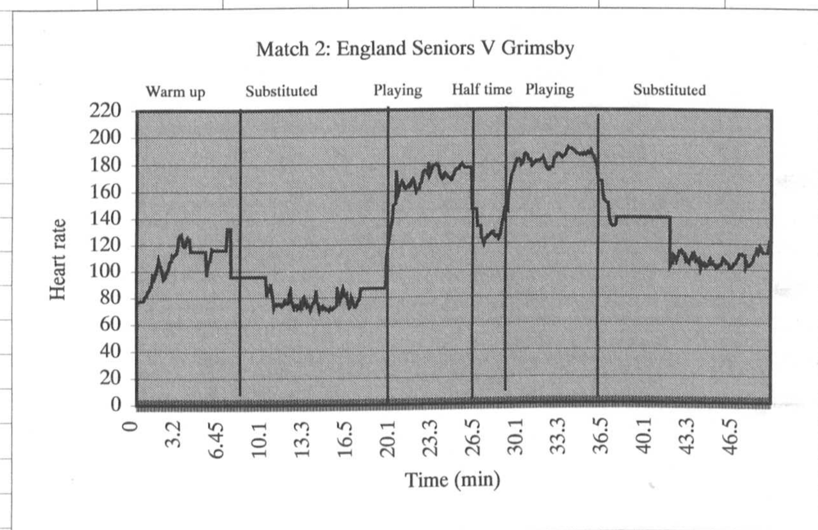
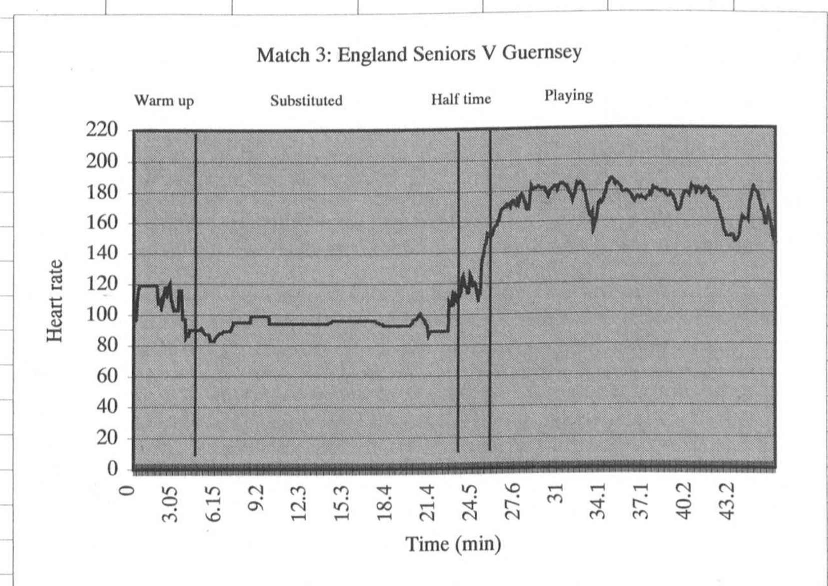
Subject 8

SOUTHSEA: 23.5.98	Max heart rate	Average playing heart rate
	194	177
	191	173
	188	172

APPENDIX 2

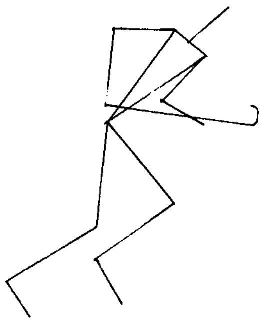
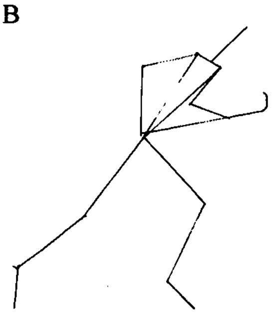
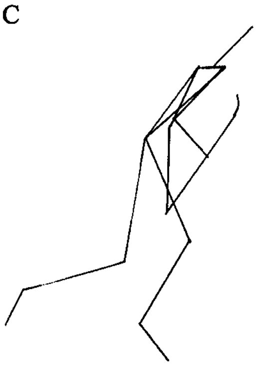
DETAILED KINESIOLOGICAL ANALYSIS: THE MUSCULAR ACTIVITY DURING INDIVIDUAL ROLLER HOCKEY ACTIONS.

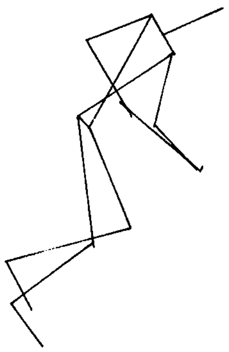
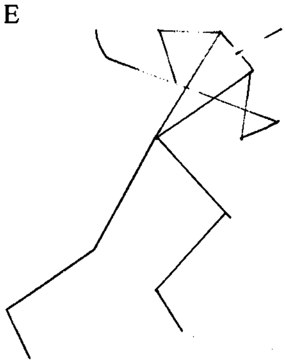
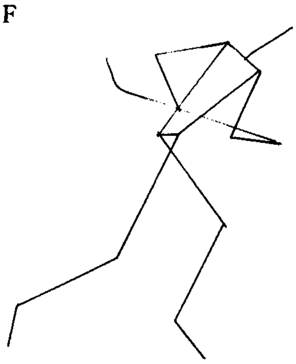
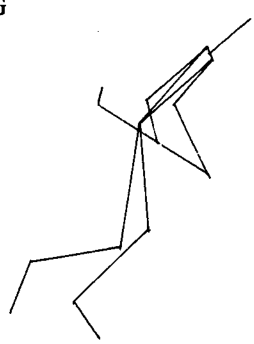
CONTENTS

ROLLING

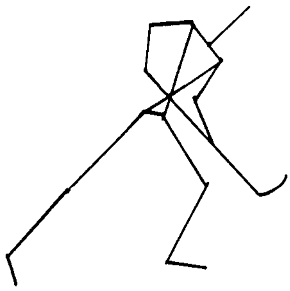
MOVEMENT	DESCRIPTION OF MOVEMENT	MUSCLES USED
A 	Rolling takes place at any speed. The stick is held close to the body with flexed forearms. The knees are flexed slightly for balance. The feet are shoulder width apart.	FOREARM FLEXION Biceps Brachii Brachialis Brachioradialis Pronator Teres KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris Vastus Lateralis Vastus Medialis Vastus Intermedius

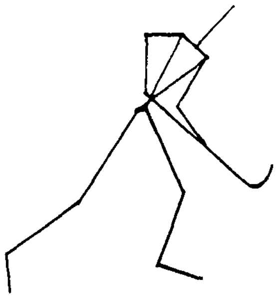
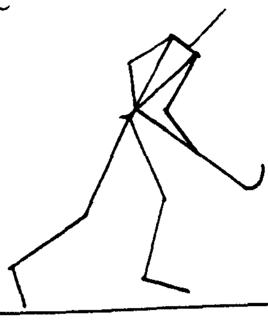
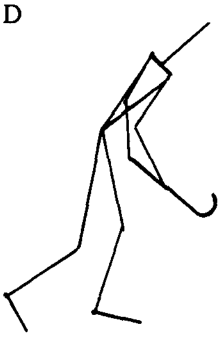
SPRINTING

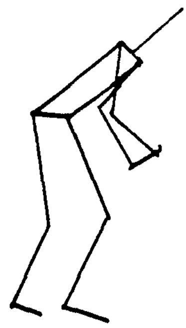
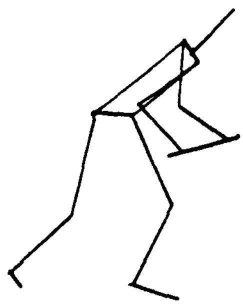
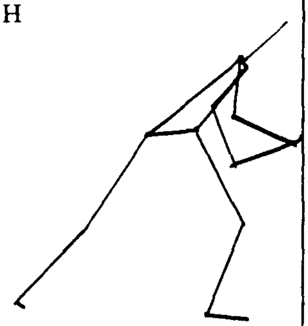
MOVEMENT	PHASE	MUSCLES USED
A 	Push-off	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior HIP FLEXION Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	No support	AS ABOVE.
C 	Single support	AS ABOVE

D 	Recovery period	AS ABOVE
E 		AS ABOVE INCLUDING ACTIVITY FROM; ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis
F 		AS ABOVE.
G 	Push-off	AS ABOVE.

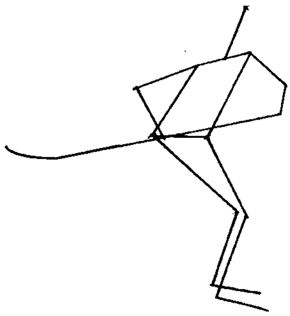
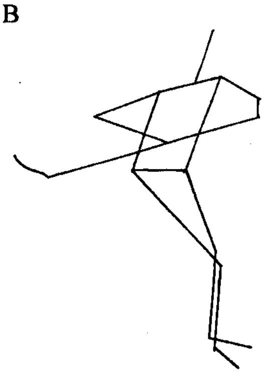
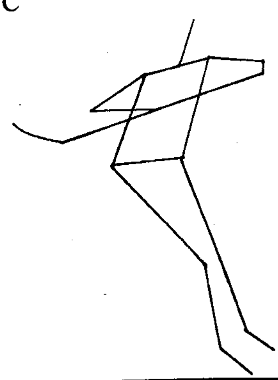
PUSHING

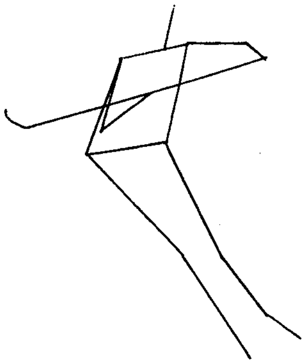
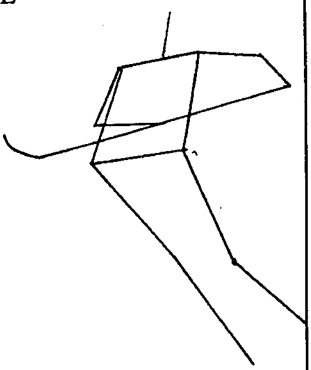
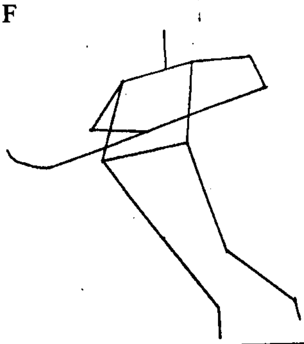
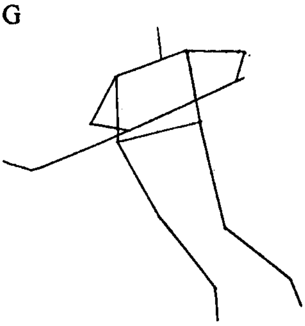
	PHASE	MUSCLES USED
A 	Full extension	HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius

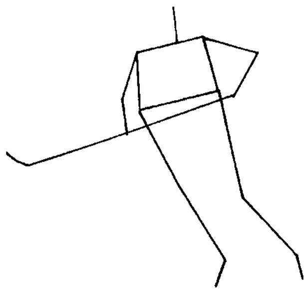
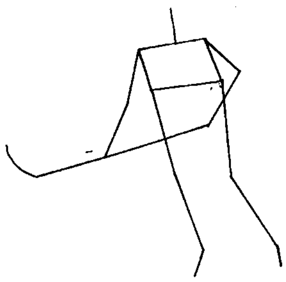
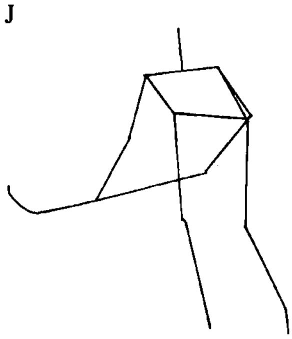
B 	Recovery	AS ABOVE INCLUDING ACTIVITY FROM; HIP FLEXION Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
C 		AS ABOVE INCLUDING ACTIVITY FROM; VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus
D 		AS ABOVE.
E 		AS ABOVE.

F 	Double support	AS ABOVE.
G 	Push-off	AS ABOVE.
H 	Full extension	AS ABOVE.

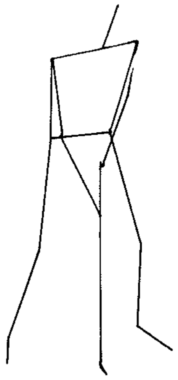
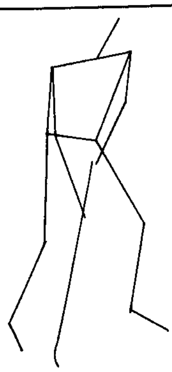
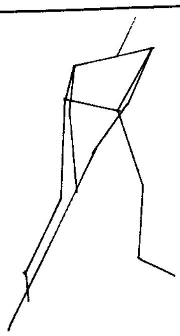
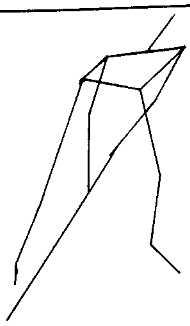
SLIDE STOPPING

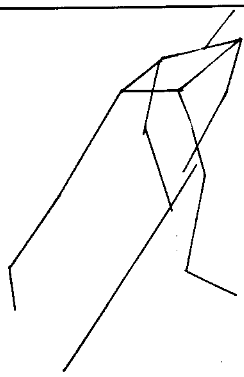
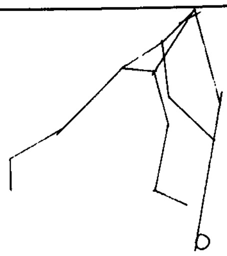
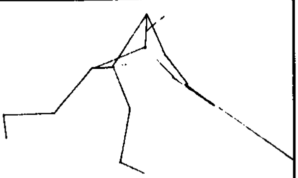
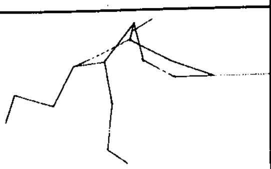
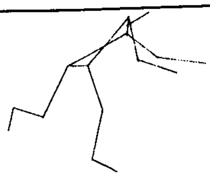
MOVEMENT	PHASE	MUSCLES USED
A 	Preparation phase	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	One foot turn	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris
C 	Two foot turn	AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius

D 		AS ABOVE INCLUDING ACTIVITY FROM; THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis ANKLE EVERSION Extensor Digitorum Longus, Peroneus Tertius, Peroneus Longus, Peroneus Brevis THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus ANKLE INVERSION Tibialis Anterior, Extensor Hallucis Longus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus Adductor Brevis, Adductor Magnus
E 	Slide phase	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM EXTENSION Triceps Brachii, Anconeus PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
F 		AS ABOVE
G 	Over-rotation of the feet	AS ABOVE.

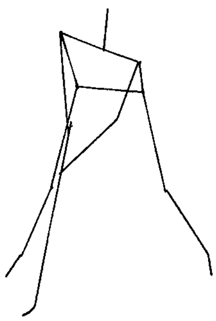
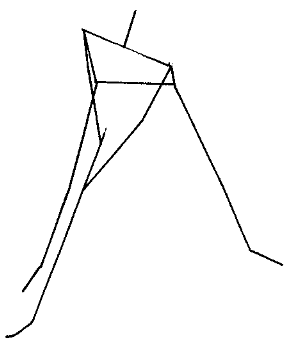
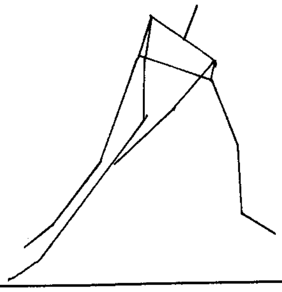
H 	End of slide	AS ABOVE.
I 	Recovery	AS ABOVE.
J 	Recovery	AS ABOVE.

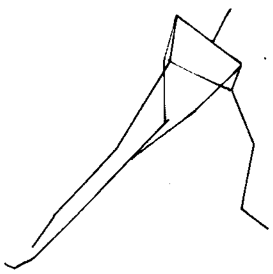
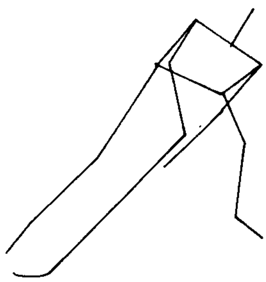
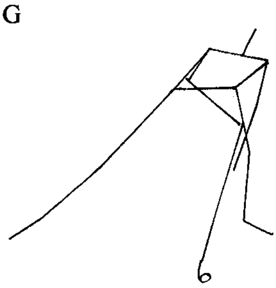
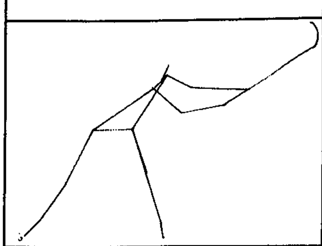
STATIONARY PASS

MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN EXTENSOR (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
	Back-swing phase	AS ABOVE INCLUDING ACTIVITY; VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ARM ADDUCTION: Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis ARM ABDUCTION: Deltoid, Supraspinatus LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris PLANTAR FLEXION: Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior THIGH ABDUCTION: Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus
		AS ABOVE INCLUDING ACTIVITY FROM; DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius ANKLE INVERSION Tibialis Anterior, Extensor Hallucis Longus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
	Fore-swing phase	AS ABOVE.

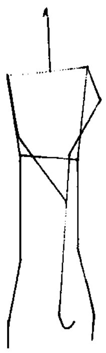
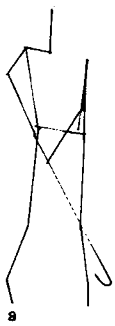
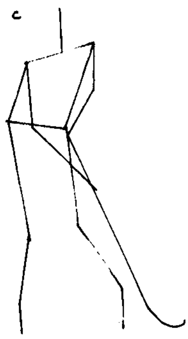
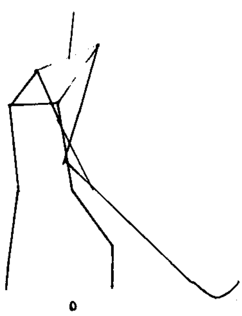
		AS ABOVE INCLUDING ACTIVITY FROM; FOREARM EXTENSION: Triceps Brachii, Anconeus FOREARM FLEXION: Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius
	Contact phase	AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
	Follow-through	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis
		AS ABOVE.
	Recovery phase	AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE HIP FLEXION Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis ACTIVE KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius ACTIVE PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior

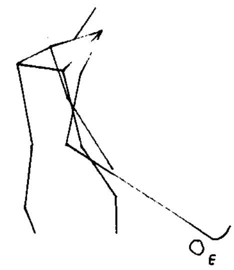
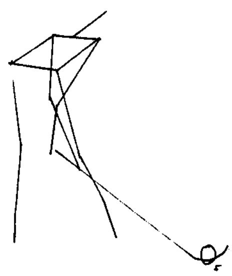
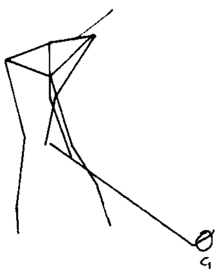
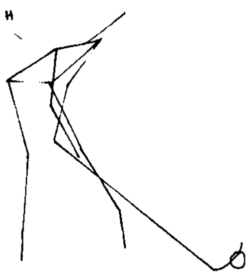
ONE TOUCH PASS

MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Back-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius
C 		AS ABOVE INCLUDING ACTIVITY FROM;; THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus
D 		AS ABOVE INCLUDING ACTIVITY FROM; ANKLE INVERSION Tibialis Anterior, Extensor Hallucis Longus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior

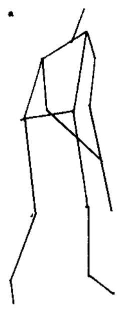
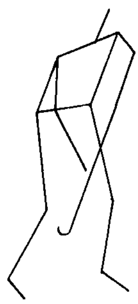
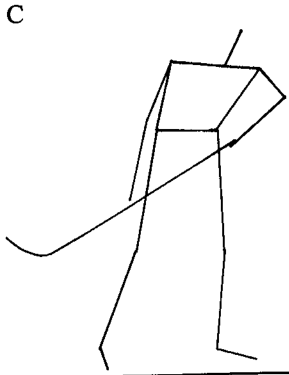
E 		AS ABOVE INCLUDING ACTIVITY FROM; ANKLE EVERSION Extensor Digitorum Longus, Peroneus Tertius, Peroneus Longus, Peroneus Brevis
F 	Fore-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; THIGH MEDIAL ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
G 	Contact phase	AS ABOVE INCLUDING ACTIVITY FROM; HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
H 	Follow-through	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus
I 		AS ABOVE INCLUDING ACTIVITY FROM; LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus
	Recovery	AS ABOVE.

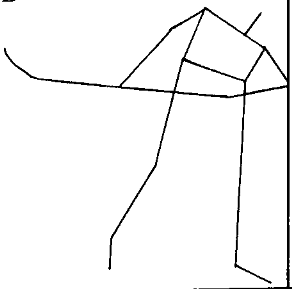
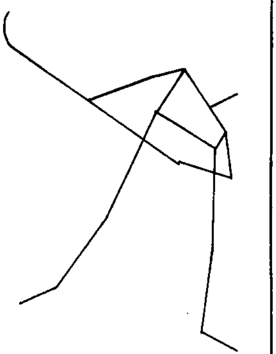
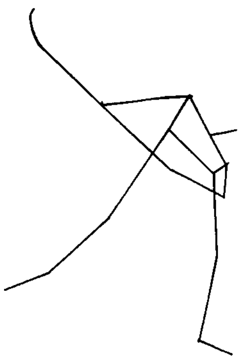
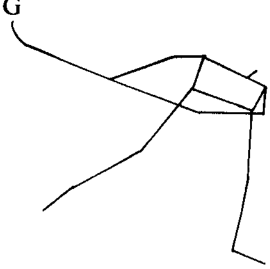
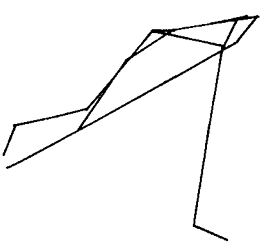
RECEIVING A PASS

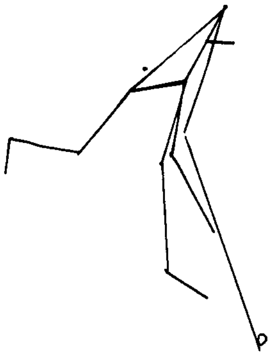
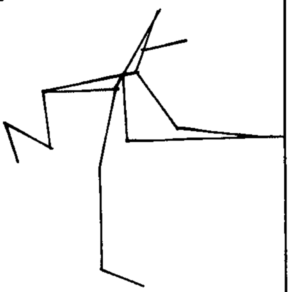
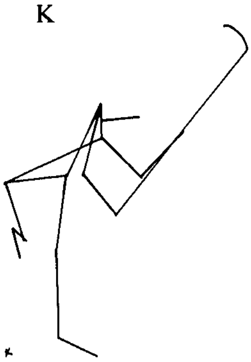
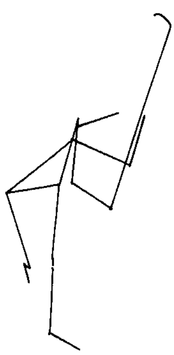
MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION): Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSORS (ISOMETRIC CONTRACTION): Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius
B 	Preparati on phase	AS ABOVE INCLUDING ACTIVITY; VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
C 		AS ABOVE INCLUDING ACTIVITY FROM; PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
D 		AS ABOVE INCLUDING ACTIVITY FROM; ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus

E 		AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis ARM ABDUCTION Deltoid, Supraspinatus
F 	Contact	AS ABOVE.
G 	Recovery phase	AS ABOVE.
H 	Recovery phase	AS ABOVE.

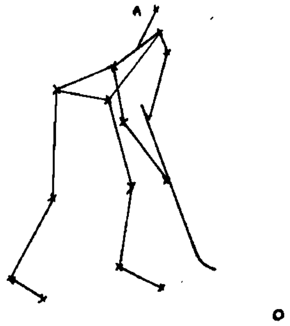
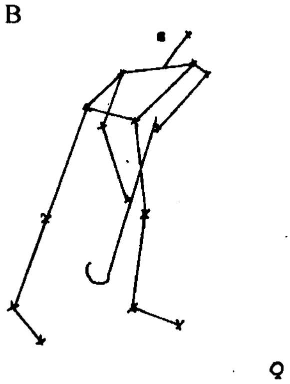
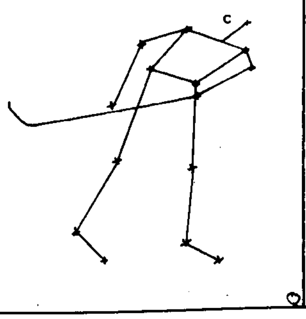
STATIONARY FOREHAND SLAP SHOT

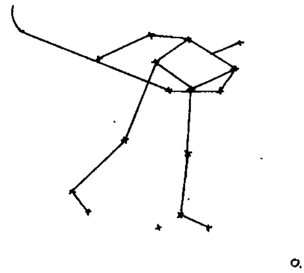
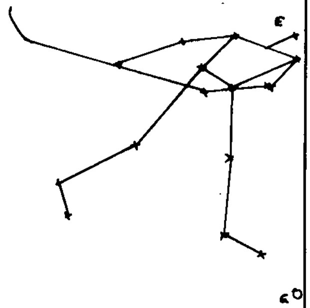
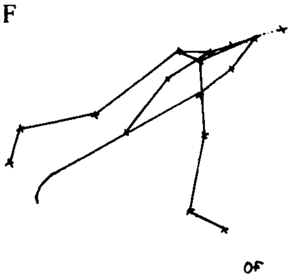
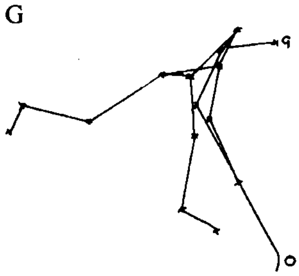
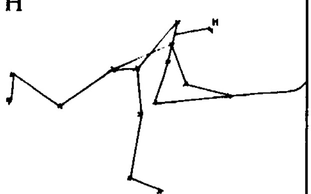
	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Back-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius
C 		AS ABOVE.

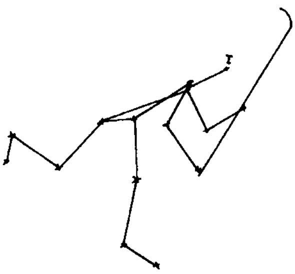
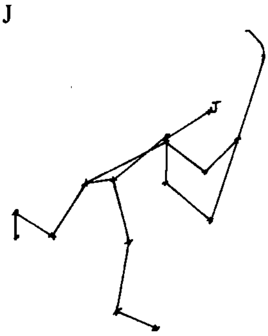
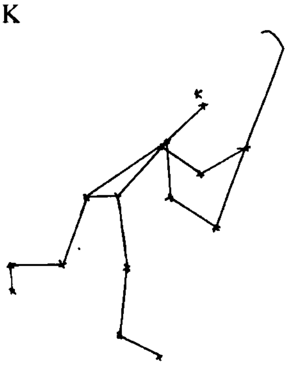
D 		AS ABOVE INCLUDING ACTIVITY FROM; LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris
E 		AS ABOVE.
F 	Top of back-swing	AS ABOVE.
G 	Fore-swing	AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
H 		AS ABOVE INCLUDING ACTIVITY FROM; THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis FOREARM EXTENSION Triceps Brachii, Anconeus

I 	Contact	AS ABOVE INCLUDING ACTIVITY FROM; KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus
J 	Follow-through phase	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
K 		AS ABOVE.
L 	Recovery phase	AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior

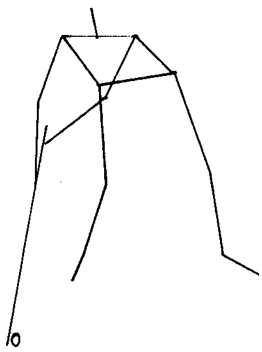
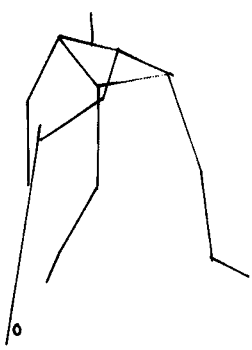
MOVING FOREHAND SLAP SHOT

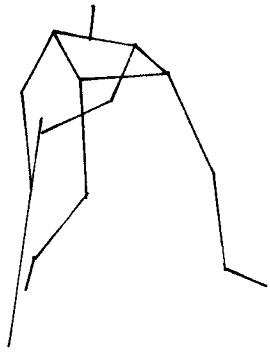
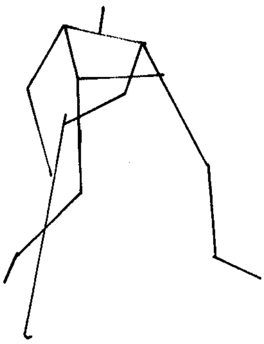
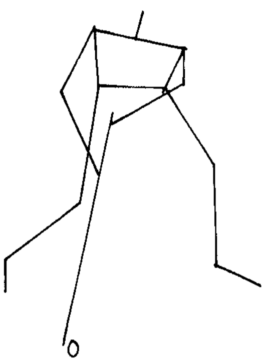
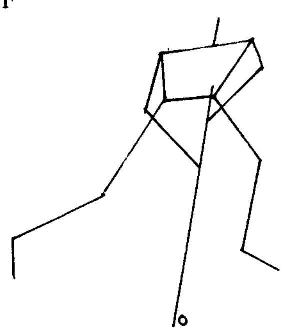
MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ISOMETRIC CONTRACTION OF THE VERTEBRAL COLUMN EXTENSOR MUSCLES Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales ISOMETRIC CONTRACTION OF THE KNEE EXTENSORS Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres
B 	Back-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis ARM ABDUCTION Deltoid, Supraspinatus
C 		AS ABOVE.

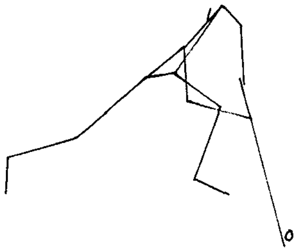
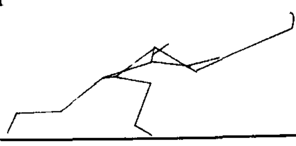
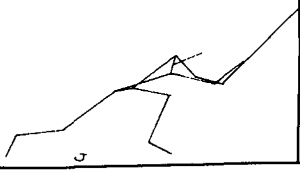
D 	Top of back-swing	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM EXTENSION Triceps Brachii Anconeus KNEE FLEXION Gracilis Gastrocnemius Sartorius Biceps Femoris Semitendinosus Semimembranosus
E 	Fore-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; THIGH ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus THIGH EXTENSION: Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus
F 		AS ABOVE
G 	Contact	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris
H 	Follow - through phase	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis

I 		AS ABOVE INCLUDING ACTIVITY FROM; VERTEBRAL COLUMN EXTENSION Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales
J 	Recovery	AS ABOVE
K 	Return to normal posture	AS ABOVE.

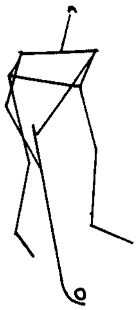
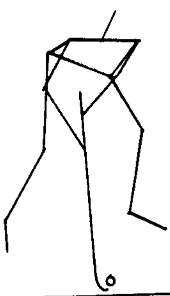
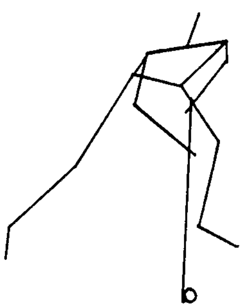
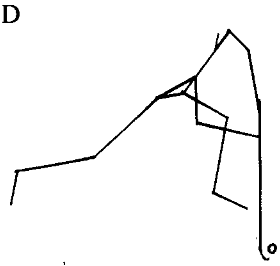
STATIONARY FOREHAND FLICK SHOT

MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus ARM ABDUCTION Deltoid, Supraspinatus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Back-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior

C 	Fore-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius THIGH ABDUCTION: Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus
D 		AS ABOVE.
E 		AS ABOVE.
F 		AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres

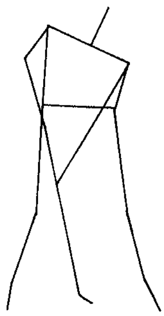
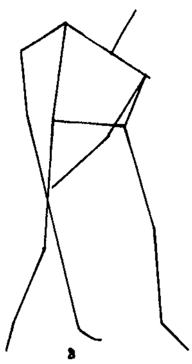
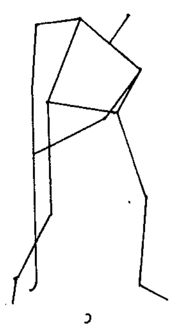
G 		AS ABOVE.
H 	Loss of contact	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus
I 	Follow-through phase	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres
J 	Recovery phase	AS ABOVE.

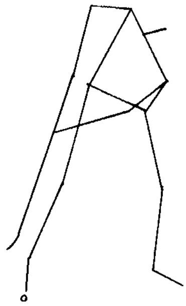
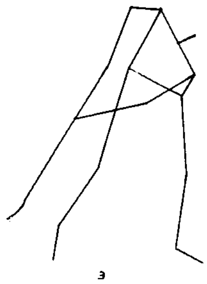
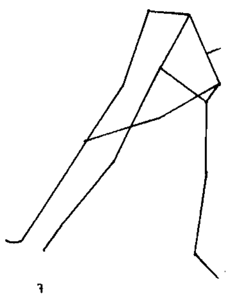
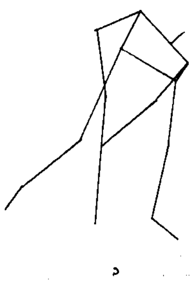
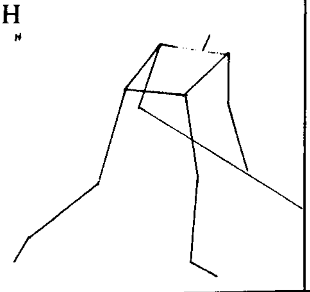
MOVING FOREHAND FLICK SHOT

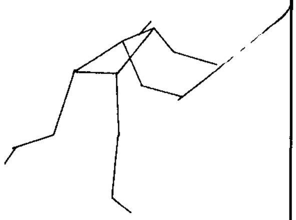
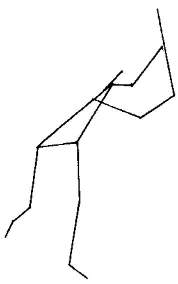
	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres ARM ABDUCTION Deltoid, Supraspinatus FOREARM EXTENSION Triceps Brachii, Anconeus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Fore-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris
C 		AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus HIP ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
D 		AS ABOVE.

E 	Loss of contact	AS ABOVE.
F 	Follow-through phase	AS ABOVE INCLUDING ACTIVITY FROM; HIP ADDUCTION Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis
G 		AS ABOVE.
H 	Recovery	AS ABOVE INCLUDING ACTIVITY FROM; HIP FLEXION Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius

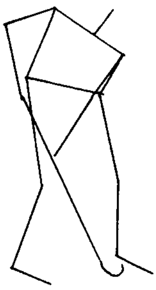
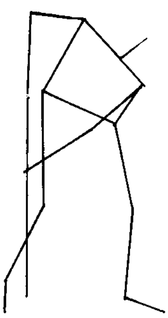
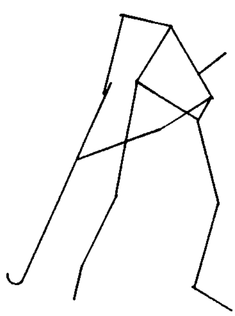
STATIONARY BACKHAND SLAP SHOT

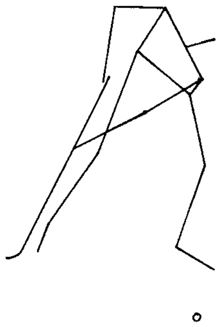
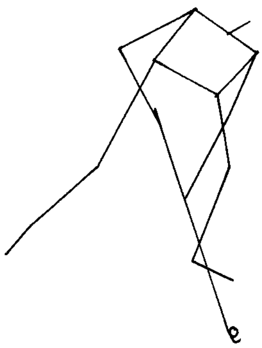
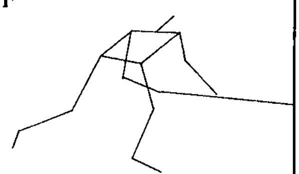
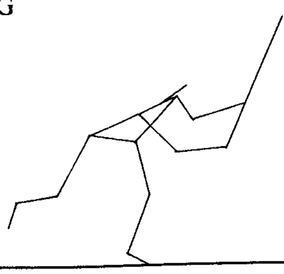
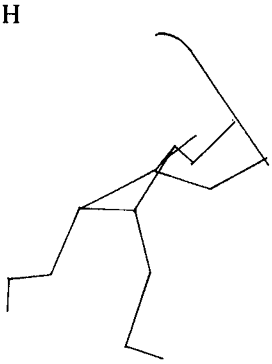
	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Back-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris
C 		AS ABOVE.

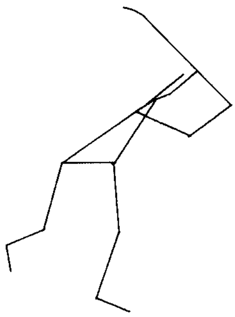
D 		AS ABOVE.
E 		AS ABOVE.
F 	Fore-swing phase	AS ABOVE INCLUDING ACTIVITY FROM; KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus HIP ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus
G 	Contact	AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
H 	Follow-through	AS ABOVE

I 		AS ABOVE INCLUDING ACTIVITY FROM; ACTIVE HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus ACTIVE KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis
J 	Recovery phase	AS ABOVE.

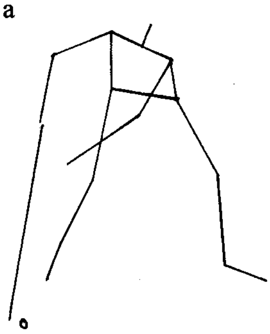
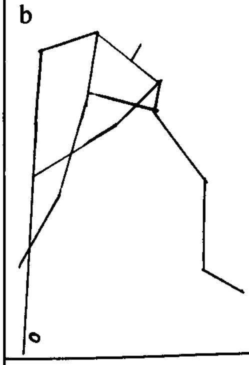
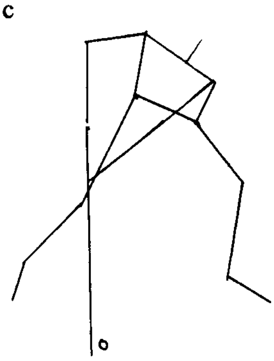
MOVING BACKHAND SLAP SHOT

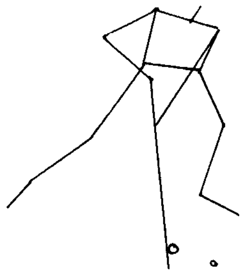
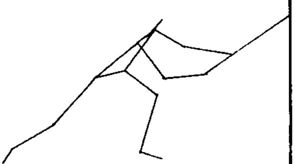
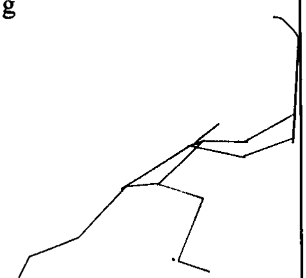
MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION Triceps Brachii, Anconeus KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION (ISOMETRIC CONTRACTION) Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Back-swing	AS ABOVE INCLUDING ACTIVITY FROM; THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
C 		AS ABOVE

D 	Fore-swing	AS ABOVE
E 	Contact	AS ABOVE INCLUDING ACTIVITY FROM; MEDIAL HIP ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
F 	Follow-through	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION; Pectoralis Major, Deltoid, Coracobrachialis HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus
G 		AS ABOVE INCLUDING ACTIVITY FROM; KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
H 	Recovery	AS ABOVE INCLUDING ACTIVITY FROM; FOREARM EXTENSION Triceps Brachii, Anconeus

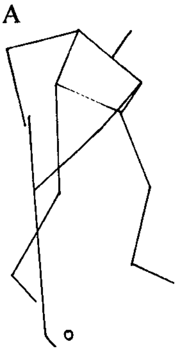
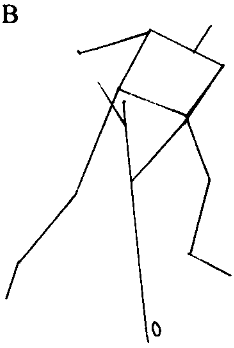
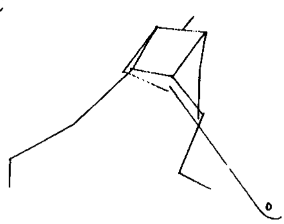
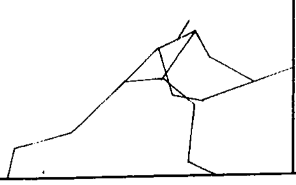
I 		AS ABOVE.

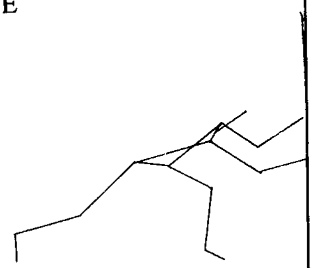
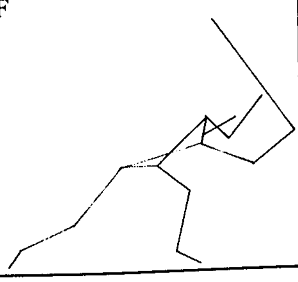
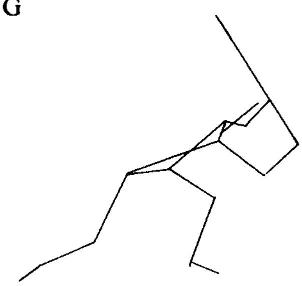
STATIONARY BACKHAND FLICK SHOT

MOVEMENT	PHASE	MUSCLES USED
a 	Starting position	VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores ARM ABDUCTION: Deltoid, Supraspinatus FOREARM FLEXION: Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres ARM ADDUCTION: Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis FOREARM EXTENSION: Triceps Brachii, Anconeus HIP EXTENSORS (ISOMETRIC CONTRACTION) Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus VERTEBRAL COLUMN EXTENSORS Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales KNEE EXTENSORS (ISOMETRIC CONTRACTION) Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris THIGH ABDUCTION: Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus ANKLE INVERSION: Tibialis Anterior, Extensor Hallucis Longus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior
b 	Fore-swing	AS ABOVE.
c 		AS ABOVE INCLUDING ACTIVITY FROM: PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior

d 		AS ABOVE INCLUDING ACTIVITY FROM: MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
e 	Loss of contact	AS ABOVE.
f 	Follow-through	AS ABOVE INCLUDING ACTIVITY FROM: SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis
g 	Recovery phase	AS ABOVE. INCLUDING ACTIVITY FROM: VERTEBRAL COLUMN EXTENSION: Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSION: Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSION: Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION: Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior THIGH ADDUCTION: Quadratus Femoris, Adductor Longus, Adductor Brevis, Adductor Magnus, Pectineus, Gracilis HIP FLEXION: Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis KNEE FLEXION: Gracilis Gastrocnemius Sartorius Biceps Femoris Semitendinosus Semimembranosus

MOVING BACKHAND FLICK SHOT

MOVEMENT	PHASE	MUSCLES USED
A 	Starting position	ARM ADDUCTION Pectoralis Major, Latissimus Dorsi, Infraspinatus, Teres Major, Teres Minor, Coracobrachialis ARM ABDUCTION Deltoid, Supraspinatus FOREARM FLEXION Biceps Brachii, Brachialis, Brachioradialis, Pronator Teres FOREARM EXTENSION Triceps Brachii, Anconeus VERTEBRAL COLUMN ROTATION Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores VERTEBRAL COLUMN EXTENSORS (ISOMETRIC CONTRACTION) Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus THIGH LATERAL ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus Femoris ISOMETRIC KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius DORSIFLEXION Tibialis Anterior, Extensor Hallucis Longus, Extensor Digitorum Longus, Peroneus Tertius
B 	Fore-swing	AS ABOVE INCLUDING ACTIVITY FROM; ANKLE INVERSION Tibialis Anterior, Extensor Hallucis Longus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior THIGH ABDUCTION Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus
C 	Lose of contact	AS ABOVE INCLUDING ACTIVITY FROM; PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior MEDIAL THIGH ROTATION Gluteus Medius, Gluteus Minimus, Adductor Longus, Adductor Brevis, Adductor Magnus
D 	Follow-through	AS ABOVE INCLUDING ACTIVITY FROM; SHOULDER FLEXION Pectoralis Major, Deltoid, Coracobrachialis

E 		AS ABOVE.
F 	End of follow through	AS ABOVE INCLUDING ACTIVITY; THIGH ABDUCTION: Gluteus Medius, Gluteus Minimus, Tensor Fasciae Latae, Piriformis, Obturator Internus, Superior Gemellus, Inferior Gemellus LATERAL THIGH ROTATION Psoas Major, Iliacus, Piriformis, Obturator Internus, Obturator Externus, Sartorius, Superior Gemellus, Inferior Gemellus, Quadratus
G 	Recovery	AS ABOVE INCLUDING ACTIVITY FROM; VERTEBRAL COLUMN EXTENSION Spinalis Thoracis, Spinalis Cervicis, Spinalis Capitis, Semispinalis Thoracis, Semispinalis Cervicis, Semispinalis Capitis, Multifidus, Rotatores, Interspinales HIP EXTENSION Gluteus Maximus, Adductor Magnus, Biceps Femoris, Semitendinosus, Semimembranosus KNEE EXTENSION Rectus Femoris, Vastus Lateralis, Vastus Medialis, Vastus Intermedius PLANTAR FLEXION Peroneus Longus, Peroneus Brevis, Gastrocnemius, Soleus, Plantaris, Popliteus, Flexor Hallucis Longus, Flexor Digitorum Longus, Tibialis Posterior HIP FLEXION Psoas Major, Iliacus, Tensor Fasciae Latae, Adductor Magnus, Adductor Longus, Rectus Femoris, Sartorius, Pectineus, Adductor Brevis, Gracilis KNEE FLEXION Gracilis, Gastrocnemius, Sartorius, Biceps Femoris, Semitendinosus, Semimembranosus

APPENDIX 3

ELECTROMYOGRAPHY SKIN IMPEDANCE LEVELS.

Table 1: Mean impedance levels (kΩ) for each muscle.

MUSCLE	IMPEDANCE LEVELS	
	MEAN	S.D.
Latissimus dorsi	11	6.9
Pectoralis major	17	13
Gluteus maximus	19.6	7.8
Rectus femoris	18	6.7
Semitendinosus	17.4	5.1
Adductor longus	11.2	6.3
Sartorius	15.4	9.5
Gastrocnemius	19.8	6.6

APPENDIX 4

Publication to date, originating from thesis.

Journal of Human Movement Studies, 1997, 32: 235-251

ANALYSIS OF ROLLER HOCKEY MATCH PLAY

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SUMMARY

Match analysis was used to determine time and motion characteristics of male Roller Hockey match play. Sixteen players were recorded continually on videotape during two Premiere League matches. Players were tracked across three static cameras, incorporating the entire pitch simultaneously. Their movements e.g. action type, duration, intensity and direction were recorded manually. Actions were divided into skating and hockey activities. Skating activity was categorised into rolling, pushing, sprinting, slide stopping, falling and stationary, and hockey activity consisted of tackling, passing, dribbling, collecting loose ball, stopping ball, travelling with ball and shooting.

The overall mean duration for a skating action was 3.1 seconds and the most frequent skating activity was rolling (71% match time). Hockey activity occurred for an average of 13% match time. The maximum time spent with the ball on a single occasion was 49.6 seconds. Travelling with the ball and tackling were the most frequent hockey activities with 4.4% and 4.3% match time respectively. The most common shot was the forehand flick shot. The ratio of high to low intensity activity was 22:77.

0306-7297/97/0600-0235 $21.00

INTRODUCTION

The majority of Roller Hockey literature consists of historical reviews of the sport (Hollander and Clark, 1975; Kelemen, 1980; Pout, 1993; Schulze, 1981 and Turner, 1978) and descriptive reviews (Andreson, 1993; Arnold, 1982; Blome, 1987; Clark, 1993; Dupertuis, 1984; Feineman, 1993; Greenwood, 1993; Hemphill, R, 1989; Hemphill, B, 1994; Herbst, 1985; Hoffecker, 1980; Hollander and Clark, 1975; Lucas, 1992; Mehlmon, 1982; Stewart, 1994 and Turner, 1978). Torti (1986) and Kirk and Laurinat (1986) have analysed the strategies and techniques of individual players. Less attention has been given to scientific research. Palmi-Guerrero (1994) performed a study on group cohesion in Roller Hockey and Galantini and Busso (1992) looked at the physical fitness of young Roller Hockey players. Blanco et al (1994) and Blanco et al (1996a) compared training and competition level of lactic acid and heart rate during Roller Hockey, and recorded changes in ventilation, oxygen uptake, energy cost, blood lactate and heart rate during maximal and progressive shuttle skating. Blanco et al (1996b) studied the energy cost of dribbling in Roller Hockey because, they state, dribbling the ball and passing are the most frequent skills in the practice of Roller Hockey.

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KEY WORDS:
hockey
match-analysis
roller-hockey
skating
time-motion

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Match Analysis has been used to gain the time and motion characteristics of many sports e.g. Football (Ali and Farrally, 1991; Mayhew and Wenger, 1985; Treadwell, 1988), Rugby (Docherty et al, 1988; Treadwell, 1988), Field Hockey (Andrews, 1985; Franks and Goodman, 1986; Lothian and Farrally, 1994; Macheath, 1987), Ice Hockey (Green et al, 1976; Montgomery and Vartzbedian, 1979), Squash (Hughes, 1995) and Netball (Borrie et al, 1995). No such analysis has been located in the sport of Roller Hockey.

Due to the limited scope of the Roller Hockey literature it was felt a time and motion study of all the actions that may occur in a Roller Hockey match would not only be of value to Roller Hockey players and coaches, but would allow comparisons with other interval, multi sprint sports. Such a match analysis would aid the development and application of appropriate training techniques for Roller Hockey.

Method

Procedure

This match analysis consisted of two Premiere League Roller Hockey matches (with a combined score of 11:8). Roller Hockey is a five a-side game, including the goalkeeper. During these two matches four players in each team were studied (excluding the goalkeeper) giving a total of 16 subjects. All subjects were male, injury free and regular members of the teams. Due to the large amount of data obtained from each player (i.e. an average of 1004.7 actions) it was felt sufficient to analyse the collective data from two Roller Hockey matches, together, and draw conclusions from these.

The matches were recorded using Sony 9100P video camcorders with fixed visual fields and full audio recording systems. Three static camcorders were located in an elevated spectators gallery on one side of the pitch. These positions allowed the entire pitch to be filmed simultaneously. Agreement to the filming of the matches was obtained from all players and officials.

Data Analysis

The two matches were analysed subsequently by an international Roller Hockey player. Each player was tracked during the entire match (including stoppage time) across the three cameras. If the analyser was unsure of any movement the video tape was rewound and observed as many times as necessary to obtain accurate data. Coded data from this manual analysis was entered into Microsoft Excel for statistical analysis.

Due to rolling substitutions players were categorised by position in order to standardise the time on the pitch and enable analysis of data across positions, and across players. The movement of each player during the matches was noted in terms of the activity type, duration, intensity and direction.

The *duration* of each action was determined using frame by frame analysis. The time recorded on the tape allowed the duration to be determined to a hundredth of a second.

The *intensity* of each action was a subjective measure determined by the analyser, based on experience and perceived exertion. Each action was rated, individually, as either high intensity or low intensity.

The *direction* of the action was divided into four categories, forwards, backwards, stationary and forwards + backwards (this refers to individual actions such as tackling that consist of both forwards and backwards movement).

Preliminary analysis of the video tapes revealed that a successful Roller Hockey player must develop a high level of skill in two integrated areas, skating and hockey. These two skills may be subdivided to incorporate all the actions that a player may perform in a Roller Hockey match. The actions observed during this study were divided into these two areas, skating activity and hockey activity. *Skating activity* consisted of rolling, pushing, sprinting, slide stopping, falling and stationary. *Hockey activity* may be performed in unison with skating activities and consisted of tackling, passing, stopping the ball, collecting lose ball, dribbling, travelling with the ball and shooting.

Rolling is an eight wheel glide in either direction and includes cruising. Cruising is defined by Marino (1977) in ice hockey, as one or two forward utility strides with minimal effort, used to maintain speed or to adjust position on the rink with almost no forward lean. In Roller Hockey cruising includes the gentle application of the toe stop when going backwards.

Pushing defines both a forward and backward propulsive movement. Marino and Wease (1979) describe pushing in ice hockey, as bi-phasic, with each stride consisting of alternate periods of single support (the gliding/ recovery period) and double support (the propulsive period).

Sprinting is defined as running on the skates, with the legs linear, and for the first few strides includes running or pushing off the toe stops.

Slide stopping is an action adopted by Roller Hockey players to stop in a fast and effective manner, whilst being ready to sprint in another direction. The action itself is similar to a snow plough stop in skiing, and is divided further into left (with left side forward), and right (with right side forward) slide stops.

Falling includes the getting back to the feet and any time spent on the floor.

Stationary involves no skating movement, however a hockey movement may be performed.

Tackling incorporates tackling another player or being tackled. This often includes body contact, lunging for the ball and blocking the ball or a player with the body.

Passing the ball may be done whilst stationary and on the move. *Stopping the ball* includes receiving a pass and intercepting the ball. *Collecting loose ball* is defined as an unchallenged, often low intensity activity. *Dribbling* the ball is a deliberate, challenging movement of the ball in order to maintain possession, as opposed to *travelling with the ball* which is classed as a passive rolling with the ball. *Shooting* consists of four standard Roller Hockey shots, the *forehand flick shot*, the *backhand flick shot*, the *forehand slap shot* and the *backhand slap shot*.

RESULTS

The duration of a Premiere League Roller Hockey match is 25 minutes each way (every time the whistle is blown the clock is stopped and started when play resumes). This study reports an average match time of 61 minutes 26 seconds (mean stoppage time is 11 minutes and 26 seconds).

TABLE 1: Roller Hockey : Analysis of *hockey* activity (excluding shooting) for all positions (n=16).

ACTIVITY CATEGORY	MEAN FREQUENCY ±S.D.	MEAN TOTAL TIME (S) ±S.D.	MEAN DURATION (S)	MEAN % MATCH TIME
TACKLING	96.57 ±9.58	158.28 ±29.13	1.64	4.29
PASSING	68.19 ±12.83	71.49 ±34.89	1.05	1.94
COLLECTING LOOSE BALL	20.06 ±3.42	20.92 ±6.27	1.04	0.57
STOPPING THE BALL	66.38 ±12.90	48.20 ±11.08	0.73	1.31
DRIBBLING	6.63 ±3.68	11.74 ±6.69	1.77	0.32
TRAVELLING WITH BALL	87.81 ±27.40	160.69 ±40.67	1.83	4.36
ALL HOCKEY ACTIVITY Excluding Shooting	345.64	471.32	1.34	12.79

TABLE 2: Roller Hockey: Analysis of *shooting* activity for all positions (n=16).

SHOTS	TOTAL NUMBER OF SHOTS IN MATCH	TOTAL TIME SPENT SHOOTING IN MATCH (S)	MEAN DURATION A OF SHOT (S)	PERCENTAGE OF MATCH SPENT SHOOTING FOR EACH POSITION
FOREHAND FLICK SHOT	91	79.60	0.87	0.13
BACKHAND FLICK SHOT	21	17.34	0.83	0.03
FOREHAND SLAP SHOT	86	101.68	1.18	0.17
BACKHAND SLAP SHOT	47	41.36	0.88	0.07
TOTAL SHOOTING	245	239.98	0.94	0.40

The mean number of individual actions performed by each position in a Roller Hockey match was 1004.7, and the mean duration of each of these actions was 3.7 seconds. The maximum time spent with the ball on a single occasion was 49.6 seconds.

In Tables 1 to 5 the mean totals refer to the mean of the totals gained from all positions. The mean duration refers to the overall mean duration of that action for all the positions.

The time and motion analysis for hockey activity (excluding shooting) during the two matches for all sixteen positions is shown in Table 1. For all positions the most frequent hockey activities were travelling with the ball and tackling, equivalent to 4.4% and 4.3% of match time, respectively. Table 1 indicates that for all positions the mean total time spent performing hockey related activities (excluding shooting) was 12.8% of the match, and the mean duration for a hockey activity excluding shooting was 1.34 seconds.

Table 2 indicates the time and frequency of all shooting activities in a Roller Hockey match. The most common shot is the forehand flick shot, and the forehand slap shot is the longest shot to execute. The overall percentage of the match spent performing hockey activities including shooting is 13.2%.

The time and motion analysis for skating activity is shown in Table 3. For all positions the most frequent skating activity is Rolling; it is equivalent to 71% of match time, and has the longest mean duration (7.6 seconds). Sprinting occurs for only 4% of match time. The overall mean duration for a skating activity was 3.1 seconds. The combined skating and hockey, time and motion activities for a match is displayed in Figure 1.

Table 4 shows the results for the intensity analysis. 22% of the match was classed as high intensity activity and 77% was classed as low intensity activity. The total time spent performing high intensity activity ranges from 192.2 to 865.6 seconds, while much longer times (934.2 to 2370.5 seconds) were spent performing low intensity activity.

The direction of movement analysis (Table 5 and Figure 2) shows 70% of the motion during a Roller Hockey match is forwards, with backward motion occurring for only 7% of the match time.

TABLE 3: Roller Hockey: Analysis of *skating* activity for all positions (n=16).

ACTIVITY CATEGORY	MEAN FREQUENCY ±S.D.	MEAN TOTAL TIME (S) ±S.D.	MEAN DURATION (S)	MEAN % MATCH TIME
ROLLING	345.88 ±43.55	2625.00 ±223.91	7.59	71.22
PUSHING	221.38 ±24.14	526.38 ±66.66	2.38	14.28
SPRINTING	95.50 ±32.05	147.60 ±40.58	1.55	4.00
FALLING	4.69 ±2.13	18.75 ±9.54	4.00	0.51
STATIONARY	13.44 ±4.33	47.21 ±18.92	3.51	1.28
SLIDE STOP RIGHT	57.94 ±14.81	70.63 ±17.04	1.22	1.92
SLIDE STOP LEFT	37.00 ±13.39	52.72 ±23.04	1.42	1.43
ALL SKATING ACTIVITY	775.83	3488.29	3.10	94.64

DISCUSSION

Observation shows that Roller Hockey is a fast moving sport, involving many different skating and hockey movements.

Table 1 shows that passing and stopping the ball occurs a similar number of times. Dribbling has a long duration, however it occurs infrequently and therefore occupies only 0.3% of match time. In contrast Blanco et al (1996b) state that dribbling and passing are the most frequent skills in Roller Hockey (presuming they are referring to hockey activity). In this study Table 1 shows travelling with the ball and tackling as the most frequent hockey activities. This finding may be explained because, firstly, travelling with the ball and dribbling have been defined in this study as two separate movements (one passive and one challenging, respectively), however Blanco et al (1996b) may not have separated these categories. An amalgamation of these two categories in this study would make travelling with the ball/dribbling the most frequent hockey activity in accordance with Blanco et al (1996b). Secondly, the results of this study show a low frequency of dribbling and higher frequencies of passing and stopping. This may indicate a certain style of play, more team orientated than individual, with more passing. However, Blanco et al (1996b) state that dribbling is as frequent as passing. This may suggest that Spanish match play is of a different style to English match play, a much more skilful, individual game, hence higher frequencies of dribbling.

The most common shot is the forehand flick shot (Table 2). The quickest shot is the backhand flick shot, and the longest duration shot is the forehand slap shot. This is interesting as the most practised shot in training sessions in this country is probably the forehand slap shot. For coaches and players there is a compromise here, the forehand slap shot is probably the fastest through the air and the most powerful shot, however due to it taking the longest time to set up (Table 2) it may be the easiest to intercept. Perhaps more training time should be devoted to the other faster shots.

Table 3 shows rolling to be the most common skating activity (71% of match time) followed by pushing (14% of match time) and sprinting (4% of match time). Observation of the video recordings revealed that sprinting lasted typically only for 4 or 5 strides, before the player went into pushing or rolling.

TABLE 4: Roller Hockey: Analysis of *intensity* for all positions (n=16).

INTENSITY	MEAN TOTAL TIME (S) ±S.D.	MEAN DURATION (S) ±S.D.	MEAN % MATCH TIME
HIGH	829.00 ±141.71	1.49 ±0.46	22.49
LOW	2822.00 ±286.71	7.15 ±2.17	76.56
ALL ACTIVITIES	3686	4.32	99.05

TABLE 5: Roller Hockey: Analysis of the *direction* of motion for all positions (n=16).

DIRECTION	MEAN TOTAL TIME (S) ±S.D.	MEAN % MATCH TIME
FORWARDS	2575.68 ±134.92	69.88
BACKWARDS	264.07 ±57.83	7.16
FORWARDS AND BACKWARDS	367.68 ±118.63	9.98
STATIONARY	44.15 ±23.50	1.20
OTHER ACTIVITIES	434.42 ±77.10	11.79
ALL ACTIVITIES	3686.00	100.00

Note: Other Activities, includes actions where no direction was determined i.e. tackling, passing, receiving the ball, falling and slide stopping, these were obtained by subtraction.

In Table 4, 22% of match time is spent at high intensity (mean duration, 1.49 seconds). High intensity activity may consist of sprinting, pushing, falling, slide stopping, tackling, passing, dribbling, stopping the ball, shooting and travelling with the ball, however each action was categorised for intensity individually. 77% of match time was spent at low intensity (mean duration, 7.15 seconds). Low intensity activity may incorporate rolling, pushing, falling, stationary, tackling, passing, collecting loose ball, stopping the ball, shooting and travelling with the ball. Results support the observation that Roller Hockey is an interval nature sport, with periods of lower intensity activity providing the opportunity for recovery from the higher intensity activity.

Lothian and Farrally (1994) report similar findings to this study with regard to intensity, with 17.5 to 29.2% and 71.8 to 83.6% of a field hockey match spent at high and low intensities, respectively. This result is interesting, however any similarities between match intensity and the physical demands of field hockey and Roller Hockey may be premature. Field hockey players spend only 3.6% of the match in contact with the ball (Lothian and Farrally 1994), while in this study 13% of a Roller Hockey match is spent in contact with the ball. Further analysis in this study indicates that the majority of ball contact is associated with the high intensity classification. This may indicate that there is a difference in the intensity play style between field hockey and Roller Hockey.

Comparison of these results with other sports indicates the relatively dynamic nature of Roller Hockey. Docherty et al (1988) reported 15% of a rugby match spent at high intensity and 85% at low intensity. In football Mayhew and Wenger (1985) reported 12% of match play spent in activities that were primarily anaerobic in nature (high intensity) and 88% primarily aerobic (low intensity). Reilly and Thomas (1976, cited in Treadwell, 1988) reported 1.7% of a football match spent in contact with the ball, Treadwell (1988) reported football players to spent an average of 1.5% of a match in contact with the ball and rugby union three-quarter players 1.9%.

In Roller Hockey a relatively low percentage of match time is spent stationary (Table 3; 1.3% of match time), Docherty et al (1988) reported 38% of a rugby match is spent standing and Ali and Farrally (1991) reported 7% of a football match spent standing still. This may be because players in a Roller Hockey match are on wheels that roll with little assistance.

FIGURE 1: Combined *skating* and *hockey*, time and motion activity during a Roller Hockey match.

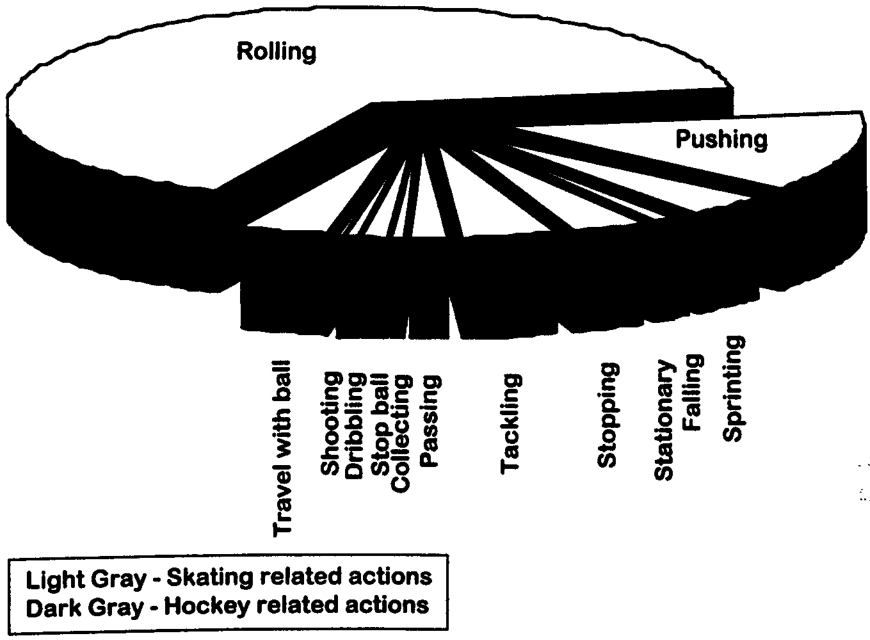
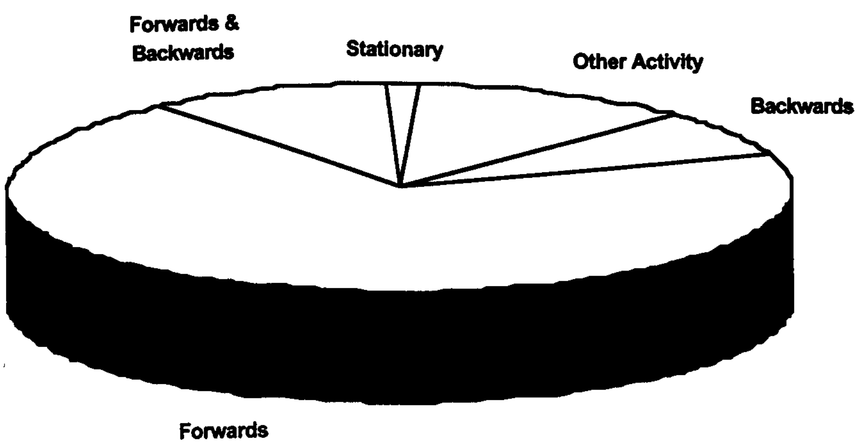


FIGURE 2: Percentage of time spent travelling in each *direction.*



The results of this study have certain implications for the training of both hockey and skating skills. Firstly, for hockey training the results highlight the importance of quick and precise ball contact (mean duration 1.2 seconds), hence the relative importance of passing and stopping training over dribbling training. Additional shooting training in the faster shots may be also of benefit.

For skating training the results show sprinting during a match situation to last typically for only four or five strides before changing to pushing, which results in a substantial decrease in acceleration. The proportions of the match spent travelling forwards (70%) and backwards (7%) gives an indication of the levels of replication necessary in the training environment.

This study provides comprehensive data on the movement activity during Roller Hockey match play. The large amount of high intensity activity and the large number of actions being performed in quick succession indicate that Roller Hockey is a fast, dynamic sport. Although the findings in this study have coaching implications it should be recognised that the results within the study are themselves likely to be a reflection of the pre-match training that the teams of this study had experienced. To maximise the benefits of match analysis for players, and ultimately match performance, it may be worth considering routine monitoring of critical indicators of match play so that the efficacy and suitability of training can be optimised.

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PLAYER POSITION, MATCH HALF AND SCORE EFFECTS ON THE TIME AND MOTION CHARACTERISTICS OF ROLLER HOCKEY MATCH PLAY

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SUMMARY

Match analysis determined the effect of position, half and score on the time and motion of male Roller Hockey match play. Using three static cameras, sixteen players were video recorded continually during two Premiere league matches. To analyse a) Position: players were classed as forwards or defenders, b) Half: the data was divided into halves c) Score: players were classed as either winners, or losers, of that half. The duration (in hundredths of a second) of players movements were recorded manually in terms of the action type, intensity, and direction.

A two sample t test revealed position has a minor effect on action type (higher percentages of dribbling by forwards), but no effect on the intensity or direction of movement. Score has no effect on intensity and direction, but significantly higher percentages of backhand slap shots were performed by losers. Match half has the greatest influence on match play, action type (higher percentages of sprinting in the first halves, and rolling in the second halves), intensity (higher percentages of low intensity activity in the second halves) and direction (higher percentages of 'forwards+backwards' skating in the second halves). Results negate the segregation of forwards and defenders in training and highlight the need for stamina in match play.

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INTRODUCTION

Few scientific studies have been reported in Roller Hockey although it has been an Olympic demonstration sport. Identified studies were included in the basic time and motion analysis of Roller Hockey match play (Kingman and Dyson, 1997).

In other sports, research has provided additional information on match play by investigating factors that influence the time and motion of players. For example, in football, Ali and Farrally (1991) reported a significant position effect for the time spent in various match play activities among attackers, defenders and midfielders. Treadwell (1988) and Docherty et al (1988) both reported a position effect in rugby. Green et al (1979) found significant differences between the time and motion of forwards and defensemen in ice hockey. For women's field hockey Lothian and Farrally (1994) reported only one position effect; midfielders were involved in significantly more changes in activity ($P<0.05$).

In some sports players activities have also been shown to differ

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significantly between the first half and the second half, for example, Saltin (1973, cited in Ali and Farrally, 1991) reported footballers speed and distance decreased significantly in the second half. Ali and Farrally (1991) and Lothian and Farrally (1994) reported a significant difference between the time spent at high intensity activity for the first and second half, in football and women's field hockey, respectively.

Other factors that may influence the time and motion of match play are the score and the standard of players. Lothian and Farrally (1994) reported no score effect in Women's field hockey. In rugby, Agar (1978 - 1979, cited in Docherty et al, 1988) found considerable differences in match play activities for players at different levels of competition, however, Docherty et al (1988) found no differences among club level and representative level rugby players.

The aim of this study is to investigate how a player's position in a match, the match half and the match score influence the time and motion of Roller Hockey match play. In any sport factors that influence activities in a match should be reflected in training, and in Roller Hockey this may aid the development of Roller Hockey specific training programs.

METHOD

Procedure

Two Premiere League Roller Hockey matches were analysed (with a combined score of 11:8). Roller Hockey is a five a-side game, including the goalkeeper. During these two matches, four players in each team were studied (excluding the goalkeeper), giving a total of 16 subjects. All subjects were male, injury free and regular members of the teams. Due to the large amount of data obtained from each player (i.e. an average of 1004.7 actions), it was felt sufficient to analyse the collective data from two Roller Hockey matches, and draw conclusions from these.

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Due to rolling substitutions, players were categorised by position, in order to standardise the time on the pitch and enable analysis of data across positions, and across players. Players *positions* were recorded as either forwards or defenders, depending on the position they occupied for the majority of that half. All the teams analysed defended in a box formation or a diamond formation (Figure 1), making position identification reasonably easy.

To analyse the effect of the *score* on activity during match play, players were classed as either winners or losers of that half, there were no draws. To analyse the effect of the *half* on players activities, the data was divided into the first and the second half.

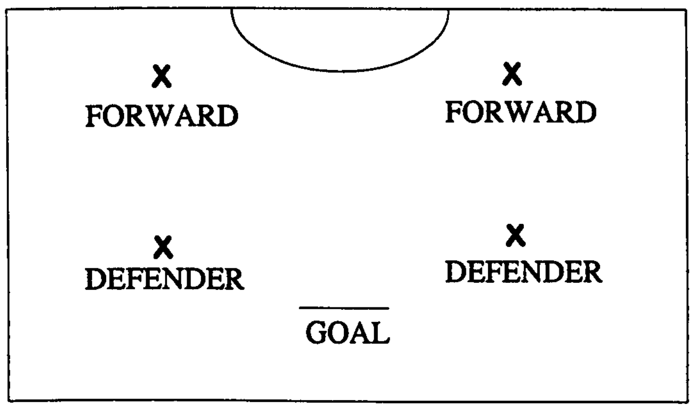
The duration of all the activities was determined using frame by frame analysis. The time recorded on the tape allowed the duration to be determined to a hundredth of a second. The duration of the movements of each player during the matches was noted in terms of the intensity of activity, the direction and the action type.

The *intensity* of each action was a subjective measure determined by the analyser, based on experience and perceived exertion. Each action was rated, individually, as either high intensity or low intensity.

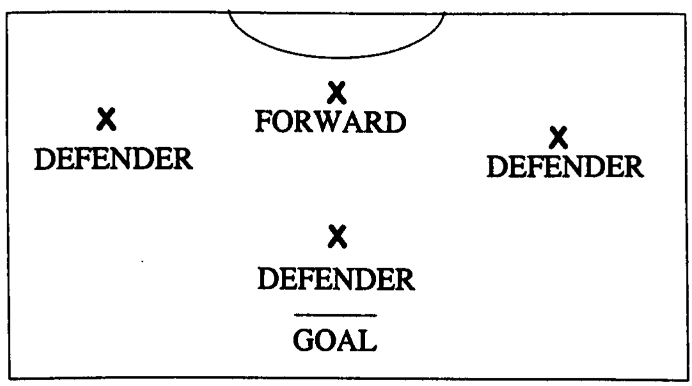
The *direction* of the action was divided into four categories, forwards, backwards, stationary and forwards + backwards (this refers to individual actions such as tackling that consist of both forwards and backwards movement).

The *action type* was categorised by preliminary analysis of the video tapes, this enabled the identification of all the actions performed by a Roller Hockey player in a match situation. These actions were divided into two areas, skating activity and hockey activity. *Skating activity* consisted of

FIGURE 1: Defensive formations in Roller Hockey.



Box Formation Defence



Diamond Formation Defence

rolling, pushing, sprinting, slide stopping, falling and stationary. *Hockey activity* may be performed in unison with skating activities and consisted of tackling, passing, stopping the ball, collecting lose ball, dribbling, travelling with the ball and shooting.

Rolling is an eight wheel glide in either direction and includes cruising. Cruising is defined by Marino (1977), in ice hockey, as one or two forward utility strides with minimal effort, used to maintain speed or to adjust position on the rink with almost no forward lean. In Roller Hockey cruising includes the gentle application of the toe stop when going backwards.

Pushing defines both a forward and backward propulsive movement. Marino and Wease (1979) describe pushing in ice hockey as bi-phasic, with each stride consisting of alternate periods of single support (the gliding/recovery period) and double support (the propulsive period).

Sprinting is defined as running on the skates, with the legs linear, and for the first few strides includes running on, or pushing off, the toe stops.

Slide stopping is an action adopted by Roller Hockey players to stop in a fast and effective manner, while being ready to sprint in another direction. The action itself is similar to a snow plough stop in skiing, and is divided further into left (with left side forward) and right (with right side forward) slide stops.

Falling includes the getting back to the feet and any time spent on the floor.

Stationary involves no skating movement, however a hockey movement may be performed.

Tackling incorporates tackling another player or being tackled. This often includes body contact, lunging for the ball, and blocking the ball or a player with the body.

Passing the ball may be done whilst stationary and on the move. *Stopping the ball* includes receiving a pass and intercepting the ball. *Collecting loose ball* is defined as an unchallenged, often low intensity activity. *Dribbling* the ball is a deliberate, challenging movement of the ball in order to maintain possession, as opposed to *travelling with the ball* which is classed as a passive rolling with the ball. *Shooting* consists of four standard Roller Hockey shots, the *forehand flick shot*, the *backhand flick shot*, the *forehand slap shot* and the *backhand slap shot*.

Results

The results of this study analyse the effect of three factors; position, half and score on;

- the actions performed in a Roller Hockey match (Tables 1A, 1B, and 1C).
- the intensity of activity in a match (Tables 2A, and 2B).
- the direction of movement (Table 3).

Results of the study are presented primarily in terms of the percentage of a match half spent performing each activity, as this is considered to give the most valuable representation of the time and motion characteristics of match play. Any significant differences in the frequency, and the mean duration, of activities (although factors of the percentage of a match half) are also presented, as both provide additional information on match performance. To preserve the integrity of the data all tabular data was derived from the raw data sets obtained from video analysis.

Results overall indicated that the position played, the match half and the match score have different influences on the time and motion of Roller Hockey match play.

Position Effect

The effect of a Roller Hockey player's position on the actions performed in a match is shown in Table's 1A, 1B, and 1C. Forwards perform a significantly higher percentage of dribbling (Table 1A, $P=0.008$) in a match, with significantly longer mean durations (Table 1C, $P=0.003$). Table 1B shows forwards make a significantly higher frequency of tackles, forehand flick shots, backhand flick shots and slide stops right ($P=0.003$, $P=0.042$, $P=0.004$, and $P=0.010$, respectively), but Table 1A shows that none of these amount to a significantly greater percentage of a half. Table 1C shows forwards display a significantly longer mean duration for backhand flick shots. Table 2A, 2B and 3 show that a Roller Hockey player's position has no effect on the intensity of activity or the direction of movement in a match.

TABLE 1A: **The effect of position, half, and score on the percentage of a half spent performing Roller Hockey actions.**

ROLLER HOCKEY ACTION	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
Tackling	4.46 ±0.39	4.10 ±0.41	4.01 ±0.39	4.57 ±0.40	4.55 ±0.37	4.04 ±0.42
Passing	1.63 ±0.32	2.29 ±0.61	2.17 ±0.44	1.71 ±0.50	1.91 ±0.49	1.97 ±0.41
Collecting loose ball	0.61 ±0.11	0.51 ±0.05	0.66 ±0.05	0.48 ±0.11	0.63 ±0.11	0.51 ±0.06
Stopping ball	1.34 ±0.15	1.27 ±0.15	1.35 ±0.15	1.27 ±0.15	1.43 ±0.13	1.19 ±0.16
Dribbling	0.47* ±0.10	0.15* ±0.04	0.32 ±0.11	0.31 ±0.07	0.25 ±0.06	0.39 ±0.11
Shot - Forehand Flick	0.19 ±0.04	0.21 ±0.05	0.16 ±0.04	0.16 ±0.03	0.16 ±0.03	0.16 ±0.04
Shot - Backhand Flick	0.06 ±0.01	0.12 ±0.11	0.09 ±0.05	0.05 ±0.02	0.12 ±0.05	0.03 ±0.01
Shot - Forehand Slap	0.18 ±0.04	0.28 ±0.07	0.24 ±0.05	0.22 ±0.06	0.30 ±0.07	0.17 ±0.04
Shot - Backhand Slap	0.12 ±0.04	0.12 ±0.03	0.16 ±0.05	0.09 ±0.02	0.07* ±0.02	0.16* ±0.04
Travelling with ball	4.83 ±0.47	3.83 ±0.63	3.93 ±0.48	4.78 ±0.63	4.10 ±0.61	4.62 ±0.50
Rolling	68.89 ±1.89	73.62 ±3.71	66.82* ±2.86	75.40* ±3.21	72.88 ±3.59	69.33 ±1.88
Pushing	14.76 ±0.69	13.50 ±1.21	14.87 ±0.79	13.47 ±0.86	14.42 ±0.94	13.92 ±0.98
Sprinting	4.35 ±0.72	3.38 ±0.54	5.18* ±0.65	2.62* ±0.43	3.45 ±0.51	4.34 ±0.77
Falling	0.46 ±0.13	0.33 ±0.12	0.26 ±0.13	0.54 ±0.13	0.47 ±0.14	0.33 ±0.11
Stationary	1.25 ±0.30	1.09 ±0.26	1.40 ±0.28	0.95 ±0.23	1.08 ±0.24	1.27 ±0.33
Slide Stop Right	2.09 ±0.21	1.49 ±0.26	2.06 ±0.24	1.56 ±0.22	1.81 ±0.23	1.81 ±0.26
Slide Stop Left	1.05 ±0.19	1.63 ±0.43	1.58 ±0.32	1.06 ±0.31	1.20 ±0.29	1.44 ±0.35

*** represents significant differences, where P≤0.05.**

TABLE 1B: **The effect of position, half, and score on the frequency of Roller Hockey actions performed in a half.**

ROLLER HOCKEY ACTION	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
Tackling	52.76* ±1.79	43.20* ±2.42	46.69 ±2.19	49.88 ±2.58	50.81 ±2.35	45.75 ±2.33
Passing	34.47 ±3.00	33.67 ±3.59	36.81 ±3.09	31.38 ±3.32	36.81 ±2.89	31.38 ±3.50
Collecting loose ball	10.47 ±1.00	9.53 ±0.83	11.56* ±0.80	8.50* ±0.91	9.85 ±1.03	10.31 ±0.84
Stopping ball	35.53 ±2.95	30.53 ±3.41	32.38 ±3.29	34.00 ±3.16	35.88 ±2.51	30.50 ±3.69
Dribbling	4.24 ±1.06	2.27 ±0.59	2.94 ±0.65	3.69 ±1.13	3.75 ±1.16	2.88 ±0.56
Shot - Forehand Flick	4.00* ±0.44	2.58* ±0.51	2.85 ±0.37	3.86 ±0.57	3.40 ±0.51	3.33 ±0.50
Shot - Backhand Flick	1.67* ±0.20	1.00* ±0.00	1.67 ±0.33	1.57 ±0.20	1.75 ±0.25	1.56 ±0.24
Shot - Forehand Slap	2.83 ±0.69	3.56 ±1.03	4.18 ±0.99	2.86 ±0.70	5.00 ±1.36	2.91 ±0.76
Shot - Backhand Slap	2.93 ±0.44	2.67 ±0.61	2.56 ±0.58	3.09 ±0.44	2.71 ±0.64	2.92 ±0.43
Travelling with ball	45.47 ±5.25	42.13 ±8.51	41.06 ±5.90	46.75 ±7.68	39.25 ±5.23	48.56 ±8.04
Rolling	183.35 ±10.61	161.13 ±11.47	185.88 ±11.20	160.00 ±40.56	175.81 ±9.34	170.06 ±13.07
Pushing	116.53 ±3.45	104.07 ±8.24	115.50 ±6.15	105.88 ±5.92	116.50 ±6.65	104.88 ±5.41
Sprinting	53.35 ±10.58	41.40 ±8.07	64.06* ±9.55	31.44* ±6.09	41.56 ±6.89	53.94 ±11.67
Falling	2.53 ±0.56	2.13 ±0.50	1.44* ±0.53	3.25* ±0.54	3.19* ±0.60	1.50* ±0.35
Stationary	6.35 ±1.15	7.13 ±1.40	8.13 ±1.25	5.31 ±0.88	5.75 ±0.88	7.59 ±1.53
Slide Stop Right	35.29* ±3.43	21.80* ±3.49	33.38 ±3.81	24.56 ±3.59	31.19 ±3.71	26.75 ±3.94
Slide Stop Left	16.06 ±3.07	21.27 ±4.62	23.31* ±3.83	13.69* ±2.79	16.75 ±3.67	20.25 ±4.05

*** represents significant differences, where P≤0.05.**

TABLE 1c: The effect of position, half, and score on the mean duration (in seconds) of Roller Hockey actions performed in a half.

ROLLER HOCKEY ACTION	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
Tackling	1.55 ±1.07	1.75 ±0.17	1.56 ±0.11	1.72 ±0.16	1.68 ±0.15	1.60 ±0.13
Passing	0.83 ±0.13	1.29 ±0.33	1.11 ±0.22	0.99 ±0.27	1.01 ±0.28	1.08 ±0.21
Collecting loose ball	1.24 ±0.36	1.06 ±0.12	1.09 ±0.08	1.22 ±0.39	1.39 ±0.38	0.92 ±0.11
Stopping ball	0.68 ±0.06	0.80 ±0.08	0.80 ±0.07	0.67 ±0.07	0.75 ±0.06	0.72 ±0.08
Dribbling	2.08* ±0.28	0.93* ±0.20	1.59 ±0.32	1.49 ±0.26	1.03* ±0.20	2.05* ±0.31
Shot - Forehand Flick	0.93 ±0.15	0.96 ±0.14	1.00 ±0.18	0.89 ±0.10	0.86 ±0.09	1.04 ±0.19
Shot - Backhand Flick	0.58* ±0.10	0.18* ±0.10	0.53 ±0.14	0.49 ±0.13	0.60 ±0.17	0.46 ±0.11
Shot - Forehand Slap	1.28 ±0.26	1.24 ±0.25	1.31 ±0.30	1.22 ±0.22	1.44 ±0.29	1.10 ±0.22
Shot - Backhand Slap	0.93 ±0.13	1.06 ±0.16	1.15* ±0.15	0.77* ±0.10	0.78 ±0.12	1.08 ±0.13
Travelling with ball	2.04 ±0.10	2.54 ±0.71	1.87 ±0.09	2.68 ±0.65	1.89 ±0.10	2.66 ±0.65
Rolling	7.24 ±0.39	9.27 ±1.04	7.06 ±0.78	9.33 ±0.87	7.92 ±0.53	8.47 ±0.11
Pushing	2.36 ±0.12	2.42 ±0.12	2.41* ±0.12	1.37* ±0.11	2.34 ±0.14	2.44 ±0.11
Sprinting	1.71 ±0.13	1.66 ±0.15	1.71 ±0.14	1.66 ±0.11	1.69 ±0.16	1.68 ±0.11
Falling	2.79 ±0.76	1.91 ±0.51	2.03 ±0.66	2.73 ±0.37	1.93 ±0.32	2.83 ±0.88
Stationary	3.29 ±0.36	2.62 ±0.54	3.14 ±0.45	2.80 ±0.35	3.18 ±0.50	2.76 ±0.40
Slide Stop Right	1.10 ±0.04	1.56 ±0.43	1.16 ±0.29	1.47 ±0.40	1.12 ±0.11	1.51 ±0.39
Slide Stop Left	1.34 ±0.22	1.74 ±0.57	1.53 ±0.41	1.53 ±0.42	1.57 ±0.41	1.49 ±0.42

* represents significant differences, where $P \leq 0.05$.

TABLE 2A: The effect of position, half, and score on the percentage of a half spent performing high and low intensity activities.

INTENSITY	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
High	24.67 ±3.07	20.38 ±2.22	24.37 ±2.12	20.36 ±1.71	20.60 ±1.37	24.13 ±2.38
Low	74.53 ±8.91	82.53 ±2.22	74.90* ±2.14	82.84* ±3.19	78.34* ±1.49	79.40* ±3.92

* represents significant differences, where P≤0.05.

TABLE 2 B: The effect of posotion, half, and score on the mean duration (in seconds) of high and low intensity activities in a half.

INTENSITY	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
High	1.57 ±0.14	1.44 ±0.09	1.58 ±0.15	1.40 ±0.05	1.40 ±0.09	1.58 ±0.13
Low	6.52 ±0.34	7.77 ±0.85	5.99* ±0.37	8.31* ±0.68	6.93 ±0.40	7.38 ±0.80

* represents significant differences, where P≤0.05.

TABLE 3: The effect of postion, half, and score on the percentage of a half spent travelling in different directions.

DIRECTION	POSITION		HALF		SCORE	
	Forwards mean±s.e.	Defenders mean±s.e.	First mean±s.e.	Second mean±s.e.	Winners mean±s.e.	Losers mean±s.e.
Forwards	70.93 ±1.96	68.68 ±4.63	72.01 ±1.38	67.74 ±2.20	66.17 ±4.49	64.97 ±2.29
Backwards	6.31 ±0.50	8.13 ±1.10	7.79 ±0.79	6.54 ±0.77	7.29 ±0.90	6.36 ±0.77
Stationary	1.21 ±0.37	1.18 ±0.28	1.51 ±0.40	0.89 ±0.20	0.92 ±0.23	1.41 ±0.40
Forwards + Backwards	8.50 ±1.06	11.65 ±2.24	7.53* ±0.97	12.42* ±2.06	10.27 ±1.35	9.19 ±1.90

* represents significant differences, where $P \leq 0.05$.

Half Effect

The effect of the match half on the actions performed is shown in Table 1A, 1B and 1C. Table 1A shows significantly higher percentages of sprinting in the first halves (P=0.003) and rolling in the second halves (P=0.055). Sprinting occurs significantly more frequently in the first halves (Table 1B, P=0.007). Table 1B also shows significantly higher frequencies of collecting loose balls (P=0.017) and slide stopping left (P=0.051) in the first halves, and higher frequencies of falling in the second halves (P=0.023), however these have no effect on the overall percentages of a match (Table 1A). Table 1C shows significantly longer mean duration's for backhand slap shots (P=0.044) and pushing (P=0.00001) in the first halves, but again this has no effect on the overall percentage of a match (Table 1A).

The effect of the match half on the intensity of activity is shown in Table 2A and 2B. Table 2A shows a significantly higher percentage of the second halves is spent at low intensity (P=0.048), and low intensity activity displays a significantly longer mean duration in the second halves (Table 2B, P=0.005).

The effect of the match half on the direction of movement is shown in Table 3. A significantly greater percentage of the second halves is spent travelling forwards + backwards (P=0.04).

Score Effect

The effect of score on the time and motion of a match is shown in Table 1A, 1B and 1C. Table 1A indicates that losers spend a significantly greater percentage of a half shooting backhand slap shots (P=0.053). Table 1B shows a higher frequency of falls by winners (P=0.021) and Table 1C shows losers have a significantly higher mean duration for dribbling (P=0.009). For both intensity and direction no significant score effects are evident (Table's 2A, 2B and 3).

Discussion

The findings of this study show, firstly, that the position a player occupies for a match only effects the percentage of a half spent dribbling. Dribbling accounts for a mean of only 0.3% of a match (Table 1A). The work rate intensity and the direction of movement is shown to be unaffected by position.

In Roller Hockey some have argued that there is no difference between the activity of forwards and defenders, and that players should be able to play all positions. The findings of this study would generally support this, and recommend that forward and defending players are trained together, equally, in all aspects of Roller Hockey, including fitness. These findings however, do emphasis the importance of dribbling for forward players.

Ali and Farrally (1991), reported a significant position effect for the time footballers spent walking, jogging and standing still among attackers, defenders, and midfielders (P<0.05).

Secondly, the findings of this study show that the match half effects the percentage of a match spent rolling and sprinting. These two actions combined account for a mean of 75% of a match, suggesting that the match half is the most significant influence on Roller Hockey match play. Sprinting is probably the most intense activity in Roller Hockey and significantly smaller percentages of the second halves are spent sprinting; this suggests that fatigue may be a factor in match play. This suggestion is supported by the results shown for the intensity of activity in the first and second halves, a significantly greater percentage of the second halves is spent performing low intensity activity. These findings stress the importance of stamina in match play. The reduction of time spent sprinting and the increase in rolling in the second half opens the match to exploitation by fitter opposition.

The implications of these results suggest that the training of Roller Hockey skills should be conducted around fitness training, encouraging the players to perform high intensity activity when they are already tired, in order to simulate the fatigue likely to occur in the second half. To minimise the frequency of falling skating ability should also be monitored during training when players are fatigued.

Thirdly, the findings of this study show that match score only effects the percentage of a half spent performing the backhand slap shot, and has no effect on the work rate intensity or the direction of movement during a match. The backhand slap shot accounts for a mean of only 0.1% of a match, it maybe suggested that this is negligible, if so this study then supports the findings of Lothian and Farrally (1994) who found no score effect in women's field hockey.

To conclude, this study found a minor position effect for the type of action performed, but no position effect for the intensity and direction of movement in Roller Hockey match play, supporting the argument that differences among the positions in a Roller Hockey match do not exist and players are simply players, as opposed to forwards or defenders. There was a minor score effect in shooting. Match half had the greatest influence on Roller Hockey match play with results indicating less dynamic play in the second half, and therefore raising the possibility that fatigue in the second half should be an important consideration to all coaches.

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