THE EFFICACY OF VISUAL FEEDBACK TO ENHANCE SPORTING PERFORMANCE, WITH SPECIFIC REFERENCE TO FIELD HOCKEY.

By

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DEDICATION

I would like to dedicate this thesis to all those who have influenced me and been with me as I have travelled through life. Your love and encouragement has been invaluable especially during this chapter where distance has kept us apart and at the same time brought us closer together.

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ABSTRACT

The purpose of this thesis was to determine the efficacy of visual feedback for enhancing the sporting performance of field hockey players. To achieve this, the thesis was subdivided into two study areas, physical and skilled performance. The research questions for this thesis are:

1. What are the physical demands of the 'modern' female field hockey match? (Chapter 5)
2. Is the 5-m Multiple Shuttle Test (5-m MST) a reliable test for female hockey players? (Chapter 6)
3. Is the 5-m MST a valid test for determining fitness levels for female field hockey players? (Chapter 7)
4. Is a normative profile for field hockey performance established after half a season? (Chapter 8)
5. Can visual feedback be used to enhance skilled performance during competitive hockey matches? (Chapter 9)

Visual feedback of sport can be used to improve our understanding of both physical and skilled performance. However, the scientific efficacy of this technique is not fully understood. Therefore this thesis will aim to increase the data available on field hockey and enhance our knowledge and implementation of visual feedback.

The physical demands of the 'modern' female field hockey match were determined by quantifying the displacement of the players (n = 11) every 15 seconds during a match (n = 3). The results for each match and each half were analysed using ANOVA with repeated measures and a covariance for playing time to determine if any differences existed between the 3 matches and playing halves (1st and 2nd). The correlation between the measured displacement and the calculated displacement (video technique) was $r = 0.91$. The mean difference between measured and calculated displacement was 0.26 m with 95 % confidence intervals of –6.3 m to 5.8 m. The mean total displacement was 3901± 552 m (range 2832 to 4832 m) in 63.3 ± 9.5 min or 61 ± 6 m per minute of playing time. The displacement in match 1(4303 ± 596m for total displacement (TD) and 65 ± 8 m for displacement per min playing time (Dmin) was greater than match 2 (3672 ± 519 m (TD); 58 ± 4 m (Dmin) $P < 0.001$) and match 3 (3766 ± 598 m (TD); 59 ± 5 m (Dmin) $P < 0.05$). There were also significant decreases in displacement between the first and second half ($P = 0.01$ total displacement and $P = 0.009$ displacement per minute playing time). There were no significant differences in the mean displacement or the mean speed ($P = 0.33$ and $P = 0.31$ respectively) between the different matches or the 2 playing halves ($P = 0.19$ and $P = 0.20$ respectively). Mean heart rate was significantly higher for game 1 (176 ± 5 beats.min^{-1}) than the other 2 games (162 ± 5 beats.min^{-1} and 166 ± 4 beats.min^{-1}; games 2 and 3 respectively). The heart rate in the first half was significantly higher than the heart rate in the second half ($P = 0.03$). The amount of time spent standing was 1.5 ± 0.31%, walking 82.3 ± 2.12 % jogging 13.7 ± 1.59 %, cruising 1.86 ± 0.44 % and sprinting 0.69 ± 0.06 %. The mean amount of time spent in low intensity activities was 97.4 % and the % time spent in high intensity activities was 2.6 %. The subjective data indicated that the players perceived game 1 to be harder than games 2 or 3

(P < 0.05) and game 3 to be harder than game 2 (P < 0.05). The players also perceived that they ran further and sprinted more often in game 1 than in the other 2 games (P < 0.05). The preparation and the subjective feelings prior to the 3 matches were however, perceived to be the same (P = 0.67 and 0.09 respectively). In conclusion the average displacement that the players covered in a match was just less than 4 kilometres and the average displacement covered during each 15-second period was 15 m. All of this information needs to be recognised and implemented into a training programme if hockey players are to structure their training to be as effective as possible.

Reliability was determined by establishing the 'match-related fitness' of female hockey players (n=23), as measured by the 5-m MST, tested on 4 occasions within 4 weeks. The 5-m MST is a time-based test with distance covered as the outcome measures. The results for each testing session and each shuttle were analysed using ANOVA with repeated measures to determine the reliability of the shuttle test. The mean distance for each of the 6 shuttles decreased (121.2 ± 7.5 m; 114.5 ± 7.5 m; 112.2 ± 7.5 m; 109.9 ± 7.9 m; 108.4 ± 8.1 m; 108.7 ± 8.3 m; P<0.001) similarly for each of the 4 sessions (P = 0.99). The intraclass correlation coefficient (ICC) for these variables were R = 0.98 and R = 0.86 respectively. The total and peak distances covered during the tests were not significantly different (P =0.99 and P = 0.12 respectively). The delta distance and the fatigue index calculated post-test were significantly different (P = 0.001 and P = 0.006 respectively) between the 4 sessions. The ICC for these variables were both R = 0.74. Heart rate and RPE were not significantly different between the sessions (P = 0.42 and P = 0.095 respectively). The ICC for heart rate ranged from R = 0.65 to R = 0.97 and for RPE from R = 0.85 to R = 0.91. In conclusion the 5-m multiple shuttle run test reliably measures total and peak distances, heart rate and rating of perceived exertion response with sufficient reliability to track changes in fitness over a season. The delta distance and fatigue index are not as reliable and should be interpreted with caution.

The validity of the 5-m MST was determined with both indirect and direct measures of performance. The 5-m MST has 4 of the 9 major attributes associated with team sports and the nature of the test logically indicates that it is valid for the fitness of assessment of field hockey players.
Comparisons were made between the data collected from established fitness tests (20-m Multiple Shuttle Test [20-m MST] and the 40-m Sprint Test) and the 5-m MST. The strongest relationship existed between the 20-m MST and the total distance covered during the 5-m MST (r = 0.92). Moderate correlations existed between the peak distance and the 20-m MST (r = 0.83), peak distance and the 40-m sprint test (r = -0.77) and the total distance and the 40-m sprint test (r = -0.73). These data suggest that the 5-m MST has criterion validity for assessing speed endurance components for field hockey players. The ability of the 5-m MST to differentiate between different playing abilities, provincial and non-provincial, was examined. The provincial players covered a significantly greater total and peak distance (P = 0.001 and P = 0.04 respectively). It can therefore be concluded that the 5-m MST can clearly distinguish between the fitness levels of different playing abilities and

as a result has content validity. Direct validity was determined by comparing the values attained for the 5-m MST with the data from the time-motion study (displacement per minute, mean displacement and mean speed). The highest correlation was found between the total distance covered in the 5-m MST and the mean displacement, ($r = 0.74$). The peak and delta distances were moderate predictors of mean displacement ($r = 0.70$ and $r = 0.73$ respectively) and the total distance was significantly correlated with the displacement per minute playing time ($r = 0.63$). Although these relationships would be considered low to moderate predictors of performance in other circumstances the complete randomness that is associated with team sports and the numerous factors that influence the outcome of matches make any prediction of team sport performance a difficult task. Therefore, these can be considered significant relationships. It was therefore concluded that the 5-m MST had both indirect and direct validity for the fitness assessment of field hockey players.

The performance profiles of hockey were determined by quantifying match descriptors ($n = 12$) during league matches ($n = 10$). All data were analysed using Chi Square to determine if consistency within any of the match descriptors existed. If consistency existed then the level of consistency was established (Hughes et al., 2001). Intra-observer reliability was 100 % due to computer software used. There were significant differences observed between the circle entries, short corners, long corners, free hits and the goals (both from open play and short corners) conceded over the 10 matches ($P<0.01$). No statistically significant differences were observed in the number of goals scored, the numbers of goals scored from short corners and the different matches (P>0.05). Normative profiles were established for the % time spent in the attacking midfield area, % possession and % game time after only 1 match. The ratio of shots to goals was stable after 2 games. The % time spent in the defending midfield stabilised after 7 games. The number of goals from short corners and the ratio of shots: short corners both normalised after 8 games. The last match descriptor to reach a normal profile was the number of goals scored (9 matches). Comparison of the matches against the same opposition found significant differences in only 2 areas; the number of attacking short corners and the number of shots against. No other significant differences occurred (Table 8.4). The results between the 2 games however, were different. The first game was lost (2-5) but the second match was won (3-2). Qualitative analysis of the short corner defence formation was found to be similar by 3 independent observers. In conclusion many match descriptors do not have stable profiles after 10 matches and are therefore of little use when trying to predict performance. However, predictive comparisons can be made when the opponents are consistent. Qualitative information can also help to determine areas of consistent performance.

The efficacy of visual feedback to enhance skilled performance was determined by the qualitative analysis of hockey matches (n = 11). Post-match observations were made of opposing team's formations. Visual feedback clearly identified areas of strength and weakness within the opposition and the coach made the appropriate tactical changes to counteract or expose these areas. Successful results were observed during both club and provincial matches. Real-time analysis was also found to enhance attacking short corner performance. Defensive short corner performance was recorded during 1st half performance and analysed for weakness during the half-time interval. Where appropriate, changes were made by the coach for the 2nd half of the match. The results were observed during club-level and provincial-level performance through the modifications that were made to attacking short corners. However, goals were only scored at provincial level. This study shows that the use of visual feedback can enhance performance whether in tactical changes to team formation or during set pieces. Both of these areas can determine the success or failure of performance.

This thesis has established that visual feedback has efficacy for enhancing sporting performance with hockey players. The information gained from this work will enable coaches to build up a greater understanding of the sport in terms of both the physical and skilled elements and thus to develop more appropriate training interventions. In addition the evaluation of the physical requirements of hockey during competition has enabled the reliability and validity of a fitness test to be established.

LIST OF PUBLICATIONS

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CHAPTER 1
INTRODUCTION TO THESIS

1.1 INTRODUCTION

Team sports are enjoyed by millions of players and spectators all over the world. There are numerous theories about the characteristics of a winning team during a specific match or during a season. Most of these theories are purely subjective and have no scientific basis.

Team preparation in the past has also been a subjective process with coaches and managers often using the same training methods that their previous managers/coaches used. Many of these methods whether they were to develop skill or physical fitness, were not based on sound scientific principles. The application of sport science results in a more systematic approach to athletic preparation. This is based on a better understanding of the skilled requirements and physical demands of the sport event/activity.

Visual feedback is one of the most effective ways of objectively increasing our knowledge base of sporting performance. By recording sporting events and replaying the information back to athletes they are better equipped to understand how they performed. The more information that is recorded the greater the profile that can be established of a specific athlete or event. However, visual feedback is limited by the information that has been recorded on camera. The specific location and number of cameras influences the application of the information. One camera focusing on one player for the duration of a match can provide data on that specific player's movements (duration and intensity) and also can supply the coach with information regarding the player's skilled performance. However, in this specific case information on the team's performance as a whole is not possible.

Numerous studies have been published detailing how visual feedback has been used to develop our understanding of football, including the codes of Association Football and Rugby Union, (Reilly and Thomas, 1976; Withers et al., 1982; Docherty et al., 1988; Reilly et al., 1988; Reilly et al., 1993 and Reilly et al., 1997). Despite the popularity of field hockey there are not many studies on the game. Lothian and Farrally (1992 and 1994) have conducted the most recent studies on the physical demands of hockey. The rules of hockey have changed since then, changing the demands placed upon the players. As a result the literature on field hockey needs to be not only increased but also updated to be relevant to the modern game now being played.

1.2 MOTIVATION FOR THESIS

Visual feedback of sport can be used to improve our understanding of both physical and skilled performance. Data obtained from studies using visual feedback defines the physical and skilled demands of the sport more precisely and is used to better condition athletes during training for competition. The testing of athletes' physical performance is quantitative and takes the form of fitness assessments. This will be discussed later. The assessment of skilled performance is generally qualitative and is most frequently observed either in training or actual competitive situations.

The sport under investigation in this thesis is field hockey. It was chosen on the basis that the author is actively involved in the sport with 20 years of playing experience.

1.2.1 Physical Determinants of Performance.

There is an increasing trend for athletes from a variety of sports to consult with sports scientists about having their fitness evaluated at various stages in their season (off-season, pre-season and mid-season) or as part of their preparation towards a major competition. The coaches and players expect the sports scientists to give them a comprehensive assessment of their individual and team's present fitness level, how it compared with previous occasions and how it can be improved. It is important that the components of fitness being assessed by the test are well understood so that they can be related to changes in playing performance. The information from field based fitness tests can only be useful to the coach if the tests have a certain level of scientific integrity, they are reliable, sport specific and valid.

The Sports Science Institute of South Africa uses a variety of tests to assess the fitness levels of players from team sports characterised by short-duration high-intensity exercise with frequent rest periods. One of the tests used to determine repeated sprint performance (speed-endurance and agility) is the

5-m Multiple Shuttle Test. This specific test mimics several of the physiological demands of team sports and is frequently used to assess athletes and forms the basis of subsequent training programmes. However, there are no scientific data on its reliability or validity. Thus it is reasonable to question whether this test provides coaches with accurate information that can be used effectively to prepare the team for the season or competition.

To ascertain whether a test is truly valid, a thorough understanding of the physical requirements of the sport in question is essential. Such information can be attained from time-motion analysis. However, few sports have been studied in this depth and therefore, a gap exists in the literature. The explanation for the limited number of time-motion studies on different sports is due to a number of factors. For example, the complexity and expense of the equipment required to generate accurate data, the amount of time required to learn how to use the system and subsequently the time required to compile and analyse the data are all factors which make this type of research difficult.

The rules of modern sports are also changing to make the games more spectator 'friendly'. This means that most of the published literature is out of date with respect to the rule changes which have influenced the way the sports are now being played. Therefore any interpretation of these data must be done so with caution. In summary, a scientific approach to sport training and competition needs to be adopted by coaches and trainers for sports performance to continually improve. To contribute to this process tests which are used to assess fitness need to be validated. Furthermore, it is important to determine whether the fitness tests measure parameters which are relevant to the sport.

1.2.2 Skilled Determinants of Performance.

The application of visual feedback to enhance understanding of the skilled elements of sport has developed with improvements in technology. It is now common to see game statistics being displayed on television during a match. We have also become accustomed to watching slow-motion action replays. All of this has given the spectator a greater insight into the performance of players during the game. These technologies have proved themselves to be of such importance that officials (cricket and rugby union) are making use of video clips of the same event, repeatedly played in slow motion and from different camera angles to make decisions from controversial game situations.

Many studies utilizing visual or video feedback have been conducted on team sports (Reep and Benjamen, 1968; Hughes and Williams, 1988; Lewis and Hughes, 1988; Stanhope and Hughes, 1997; Jackson and Hughes, 2001 and Winkler, 2001). These studies have investigated the performance of two different categories of teams, successful and unsuccessful, and tried to identify the determinants of successful behaviour. This information can then be translated and applied to the coaching situation and the appropriate changes made during training sessions.

Traditionally, coaching interventions were based on subjective observations of performance. Recent studies have shown that such observations are not only unreliable but also inaccurate (Franks and Miller, 1986; Franks, 1993). Visual feedback enables an objective review of performance to be recorded and analysed. Using this information reliable feedback can then be given to the coach or athlete and more athlete-specific and valid training interventions can be developed and applied.

In summary the use of visual feedback is of importance for an objective understanding of skilled performance. A vast amount of information can be generated with this type of analysis. If the data are not interpreted appropriately the use of visual feedback can add confusion and even be detrimental to performance. It is therefore important to develop ways of understanding the determinants of successful hockey performance and learn what areas of the game can be manipulated to increase the success rate of the team.

1.3 AIMS OF THESIS.

The aims of this thesis were two-fold;

1. To understand how visual feedback, more specifically video replays can enhance our understanding of the physical characteristics of field hockey and thus how this can be assessed using reliable and valid techniques.

2. To understand how visual feedback can be utilized to enhance skilled performance in field hockey.

The first study was a time-motion study of field hockey during several league matches. The purpose of this study was to investigate the physical demands placed on players during a match (excluding energy demands and skill requirements) under the modern rules.

This study was followed by an assessment of the reliability of a repeated sprint shuttle test. Each subject performed 4 repeats of a 5-m multiple shuttle test within a 4-week period. The aim of this study was to assess the reliability of the test to determine whether this test could be used as part of a fitness assessment for hockey players.

The third study of the thesis was the validation of the aforementioned 5-m MST specifically for female club level field hockey players. This was done by using criteria outlined by the National Coaching Foundation (1995) in the United Kingdom and a more direct evaluation based on a comparison of the performance of each subject during the fitness test and the physical data established during the time-motion study. The comparison determined the accuracy of the 5-m MST in assessing the fitness of female field hockey players.

The second part of the thesis concentrated on the analysis of the skilled performance of field hockey players. The fourth study investigated 10 league hockey matches to determine if a normative profile of descriptive statistics existed. In addition, a qualitative analysis of skilled performance was conducted to establish if movement patterns could be determined.

The final study of the thesis was conducted to determine whether performance could be enhanced with the use of visual feedback. A qualitative analysis was performed on the opposing team's performance to determine possible areas of weakness. Once identified a strategy was developed to exploit the weaknesses and increase the rate of successful behaviours.

The research questions of these studies are summarised below:

Research Questions

1. What are the physical demands of the 'modern' female field hockey match?
2. Is the 5-m Multiple Shuttle Test (5-m MST) a reliable test for female hockey players?
3. Is the 5-m MST a valid test for determining fitness levels for female field hockey players?
4. Can a normative profile for match descriptors of field hockey performance be established after half a season?
5. Can visual feedback be used to enhance skilled performance during competitive hockey matches?

The answers to these questions should provide information to coaches, players and sport scientists alike, so that they may develop a greater understanding of the demands, both physical and skilled, of hockey. This information from this thesis has the potential to improve the quality of fitness testing and the subsequent interpretation of the results and can also be used to develop more team or player-specific training sessions to enhance the rate of performance of successful behaviours and ultimately winning behaviour in competitions. The overall goal of this information should be to maximise the physiological and skilled preparation and ultimately competitive performance of field hockey players.

A reader of this thesis unfamiliar with field hockey may find some of the hockey-specific terminology confusing. In accordance with this a glossary on field hockey terminology has been compiled in Appendix A.

CHAPTER 2

NOTATIONAL ANALYSIS

2.1 Introduction

Traditionally, coaching intervention has been based upon subjective observations of athletes. However studies have shown that such observations are not only unreliable but inaccurate (Hughes and Franks, 1997). International level coaches have been shown to remember only 42% of the key factors that lead to a successful performance in a match (Franks and Miller, 1986).

In the majority of team sports a single observer, i.e. coach, is not able to view and record all of the action occurring on all of the playing field. In addition, with the numerous events that take place during a game it is impossible to observe everything even in a small area. Sometimes, an event during a game only becomes important after the next event has occurred (Franks and Goodman, 1986). The sequential nature of the information from sports places undue stress on the memory system of the observer. Therefore, the information given to the players at, for example half time, is incomplete and highly dependent on the subjective memory capacity of that individual.

It is therefore apparent that some additional method of recording performance in an objective manner is required to improve the quantity and quality of information the coach is supplied with. The technology now available means that video recordings can be made during either competition, training or both. The results can be then analysed after the event and the data recorded on computer, and a database established for future comparisons.

Notational analysis evolved as a means of objectively recording data during sporting performance for an accurate statistical breakdown of performance parameters. The four main objectives of any notation system can be listed as follows (Hughes, 1988):

- Analysis of movement – velocity, acceleration, rate of work.
- Tactical evaluation
- Technical evaluation
- Statistical compilation

2.2 HISTORY OF NOTATIONAL ANALYSIS.

The basic notational analyses have been around for centuries in various unsophisticated forms. The earliest examples can be traced back to the ancient Egyptians and their use of hieroglyphics to record dance and the Romans who employed primitive notation to record gestures.

The most obvious form of notation is that of music. The earliest form of notating music has been traced back to the 11th century, although the form we would recognise today did not appear until the 18th century (Hughes and Franks, 1997). Dance notation is the next to emerge in the 15th century. The system was designed to record particular movement patterns rather than general movement. Modern movement notation therefore, can trace its early history back to the starting base of dance notation (Hughes and Franks, 1997).

2.3 THE DEVELOPMENT OF SPORT-SPECIFIC NOTATION SYSTEMS.

Messersmith and Corey (1931) published some of the earliest data on sports analysis. They recorded the distance covered by a basketball player during a match by using a scale model of a basketball court and a simple electrical circuit to trace and record the movements.

Commercial systems for analysing sports have been available since 1966 (Hughes and Franks, 1997), although there is limited literature on the subject. American Football was one of the first sports to recognise the value of sport analysis (Purdy, 1977); although computer analysis is prohibited in the actual stadium, hand notation is permitted and the information is later transferred to computer outside the stadium (Hughes and Franks, 1997).

Lawn tennis was one of the first racket sports to be credited with a notational system (Downey, 1973). This system has subsequently been used as the basis for other sports like badminton and squash. Sanderson and Way (1977) developed a notational system for squash that placed a large emphasis on documenting information on the pattern observed during play. The main limitation of this, and many other techniques, was the amount of time required to learn the recording technique. Processing the information after the event was also very time-consuming. The methodology described by Sanderson and Way (1977) required between 5 and 8 hours of training to become proficient with the technique and then up to another 40 hours to process all the information that had been generated during a match.

The majority of sport analysts, particularly of team sports, have concentrated on quantifying the skill related patterns, the number of passes that are required for a goal to be scored (Reep and Benjamin, 1968) and the success or failure of playing systems or patterns (Ali, 1988; Harris and Reilly, 1988; Pollard et al.,1988). Very little data are available on the physical requirements of these sports as determined by time-motion studies.

2.4 Time-Motion Analysis of Team Sport.

2.4.1 Soccer

The most well known time-motion study of sport came from Reilly and Thomas (1976). They used a combination of hand notation and an audio recorder and were able to determine the intensity and the extent to which the soccer players performed different activities (for example, walking, jogging, running and sprinting) during match play. Work rates and distances covered by players in different positions were also recorded. The quality and quantity of data collected by Reilly and Thomas (1976) have defined this study as the standard against which other similar research should be measured (Hughes and Franks, 1997).

Withers et al. (1982) also performed a detailed analysis on Australian soccer players. Players were videotaped whilst playing and then their different classifications of motion were calibrated after the match. Average stride length was used to determine the distances covered by each player. The results attained from this study were similar to those of Reilly and Thomas

(1976). Mayhew and Wenger (1985) used videotapes to record movements of midfield players during several matches. They established the amount of time spent in activities such as standing, walking, jogging, running and utility (backwards, sideways, shuffling or jumping movements). The ratio of high intensity to low intensity exercise was 1:7. Mayhew and Wenger (1985) therefore, suggested that training should be designed to improve the performance of the "aerobic" and "anaerobic alactacid" energy systems.

The analysis of the movement of soccer referees during matches has also been conducted by Catterall et al. (1993). Video cameras were used to follow the referees during the course of a match and their heart rates were continuously recorded during the matches. It was established that the mean distance covered by a referee during the course of a match was 9.44 km. The distance covered in the second half decreased while heart rate remained similar (average of 165 beats min^{-1}) throughout the match.

2.4.2 Rugby.

Docherty et al. (1988) used video recordings of club, representative or international matches to establish the time spent by rugby players (centres and props) in 6 different match activities; standing, walking, jogging, running, sprinting and non-running intense activity (tackling, pushing in the scrum, ruck or maul and actively competing for the ball). They found that the players spent 85% of the time in low-intensity activities. The rest of the time was broken down as follows: 6% running, 9% tackling, pushing and competing for the ball. The props spent more time engaged in non-running activities (rucks, mauls and scrums) than the other forwards. The rules of rugby have changed since the publication of this study. The game played now is much faster and there has been an increase in actual playing time, which means that data from Docherty et al. (1988) must be used with caution when relating to 'modern' rugby requirements.

McLean (1992) analysed the physical demands of international rugby. Video tapes of live international Five Nation Championships (1989 – 90) matches were examined to determine running speeds of the players in possession or in closest pursuit of the ball, the amount of playing time and the duration of the high-intensity work periods. McLean (1992) found the most frequently occurring work: rest ratios were 1:1-1.9 thus, indicating the large demand that the game of rugby places on the players' ability to perform high-intensity work.

In summary, the above studies project an image of team sports being dependent upon the endurance and sprint capabilities of each player. This is even more evident with modern sports. Subtle changes to the rules over the last few years have influenced the dynamics of the game. Soccer for example, changed the way the goalkeeper can handle the ball from a back pass and rugby modified the rulings regarding the ruck and maul. These alterations to the rules of the sports resulted in the development of a visually more attacking game. As a result of these changes to the laws governing the games, the physical demands on the players and their training regimes have also changed.

Notational analysis studies can also give an indication of training requirements for those specific sports. The types of movements, forwards, backwards and sideways and the speeds at which they are conducted can be ascertained. This information should be used in training programmes to enable players to mimic possible game demands and train the body to perform these movements more effectively and efficiently. The intensity of the exercise should also be noted for training sessions, otherwise players will be consistently training at incorrect workloads and that may affect their performance during matches.

For other sports to progress in the same way as soccer and rugby similar studies need to be conducted. This is especially true of field hockey, as the next section will reveal.

2.5 NOTATIONAL ANALYSIS OF FIELD HOCKEY (SKILLS ORIENTATED AND TIME-MOTION).

2.5.1 Skill Orientated Notational Systems.

Andrews (1985) conducted an analysis of attacking circle play using videotapes of international men's hockey. It was found that the most effective circle entries came from the right side of the field and as a direct result of this there was a higher proportion of successful shots from the left side of the goal.

Hughes and Cunliffe (1986) studied the effects that different playing surfaces had on patterns of play and individual playing profiles. The artificial surface was found to elicit a faster and more skilful game than grass.

Hughes and Billingham (1986) analysed the patterns of passing sequences. They found that more successful teams made greater use of the right-hand side of the pitch, forced more penalty corners, were tackled in possession fewer times and had a greater number of shots at goal.

Franks et al. (1987) studied the women's 1986 World Cup. They recorded:

- Goals scored and conceded
- Shots taken at goal
- Results of shots at goal
- Possession of the ball, where possession was lost or gained
- Types and numbers of passes made
- Success or failure at set plays (set plays included free hits, side-line, penalty corners and strokes).
- Goalkeeper performance.

It was found that 62% of the goals came from set pieces (penalty corners 42% and penalty strokes 11%) and the other 38% came from free play. On average 5 shots at goal were required for a goal to be scored. However, it was not always true that the teams with the most number of shots at goal scored the most goals. One shot at goal during free play would result in two shots from set pieces. It was concluded that successful teams must be capable of creating shooting opportunities from both set pieces and free play because an over-dependence on penalty corners would produce negative results.

2.5.2 Time-motion studies of field hockey.

Millers and Edwards (1983) used a similar technique to Withers et al. (1982) to analyse the time spent in different modes of locomotion by a defender during a game of hockey. They found the player spent about 17% of the match standing, 66% walking, 15% running and 2% sprinting.

Marshall (1986) used stopwatches to determine the amount of time international players spent sprinting during the 1986 Women's World Cup. The forwards spent the most time sprinting (116.4 s or 6% of game time) and the defensive players the least (43.4 s or 2% of game time). A follow-up study was performed 2 years later to determine if any changes had occurred. The same trend was observed between the different playing positions although less time was spent sprinting (4 and 2 % of game time for forwards and midfielders, respectively). These studies emphasise how little time is spent performing sprinting during field hockey.

Lothian and Farrally (1992) investigated the energy cost of field hockey matches using heart rate monitoring and video analysis. Twelve players from 4 different teams over 5 different matches were studied. The mean $VO_{2\ max.}$ for this study group was 49.8 ± 4.6 ml.kg^{-1}.min^{-1}. Heart rate methodology was used to calculate the energy expenditure as 3873 ± 436 kJ, while the video analysis calculations produced lower results (2846 ± 284 kJ). It was concluded that the real energy expenditure value was somewhere between these two estimates. Mean heart rates of 171 ± 7 beats.min^{-1} were recorded during the matches. This indicates that players are working at approximately 80% maximum heart rate; however, by looking at the movements of the players it can be seen that this gives a false impression of how hard the players are actually working at the time. Lothian and Farrally (1992) suggested that the rest periods between the high-intensity exercise bouts are not long enough to allow heart rate to recover to a low-intensity level. Heart rate therefore, cannot be used to indicate movement intensity but can be used to give an overall picture of the individual strain during a match.

The video analysis methodology related energy expenditure to speeds of movement, and thus categorised the activities as follows; standing 0 km.h^{-1}, walking 4 – 6 km.h^{-1}, jogging 8 – 10 km.h^{-1}, cruising 12 – 14 km.h^{-1} and sprinting above 14 km.h^{-1} (Lothian and Farrally 1992). Most of the time (78%) during the matches was spent in low-intensity activity, once again supporting the description of team sports as predominantly "aerobic". The work to rest ratio of 1:5.7 also supports this description. Lothian and Farrally (1994) found that the total time spent performing high-intensity activities (jogging backwards or sideways, cruising, cruising backwards or sideways, sprinting or hockey related activities) was between 18 and 29 % of the match. The mean duration of high-intensity work was 5 ± 1 s and low intensity lasted on average 18 ± 4s. The authors also tried to establish the relationship between maximal oxygen uptake and the volume of high-intensity work performed. A correlation of $r = 0.78$ was found between maximal oxygen uptake and the volume of high intensity work, suggesting a strong relationship between these two variables. This relationship only explained 60% of the variance, implying that other factors such as individual's physiological profile and game characteristics (tactics, opposition and environmental) contributed to the other 40% of the variance.

A summary of the above literature on the physical demands of field hockey suggests that players need to have a large endurance component and an ability to sprint whenever they are required to during a match, in addition to the basic skills required for the sport.

2.6 FUTURE DEVELOPMENTS FOR NOTATIONAL ANALYSIS AND TIME-MOTION STUDIES.

The future developments in notational analysis will be closely linked with the advancements in computer and video technology. The technological developments that have already occurred have improved the efficiency of notational analysis and the amount of information that can be collected in real time and post-event.

Hughes and Franks (1997) suggested that generic software and the improvements in voice-activated technology will, with the aid of computerised video feedback, enable both detailed objective analysis of competition and the immediate presentation of the most important events during play.

The continual generation of notational studies of sports will increase the size of the 'database' of information and will give a clearer understanding of the requirements of each sport. However, unless movement patterns that individuals make in relation to other team members (Franks and Goodman, 1986) and the opposition are taken into account, the information gained is always going to be subject to misinterpretation.

Whatever technique is used to obtain sporting information it is important that the notational system is accurate and generates results that are easy to understand and which will increase the insight into sports performance (Hughes and Franks, 1997).

Summary

The demands of modern sport cause coaches, trainers and sports scientists to search continually for new innovations to improve sporting performance. Notational analysis objectively records skill and/or physiological aspects of sports without influencing the outcome of the event. The results attained from the analyses can be used to enhance playing performance by changing factors related to either the skill or physical aspects of the game. Technology is continually improving, making collection and processing of data much faster than ever before. The cost of equipment is also reducing making it more viable for video analysis to be conducted.

It is therefore, reasonable to conceive that in the next few years coaches will have links to real-time playing statistics and information that can assist the coach with tactical or strategic decisions during the game. This type of advancement has the potential to have a major influence on the outcome of a match, especially in sports where continual substitutions are permitted (field hockey, ice hockey and basketball etc.).

The information gathered from notational analysis increases the understanding sports scientists have of team sports. This places the sports scientist in a position of being able to support the athlete and improve performance. This support can be maximised by implementing scientifically evaluated sport-specific fitness tests. The next Chapter introduces the concept of performance profiling using both notational analysis and physiological assessment of teams.

CHAPTER 3

PERFORMANCE PROFILING (PHYSIOLOGICAL AND SKILLED).

3.1 INTRODUCTION

The understanding and influencing of sporting performance is the very essence of the coaching process (Hughes and Franks, 1997) and the directive for researchers in the field of sports performance (Hopkins et al., 1999). An assumption was that by testing the physiological profiles of athletes, sports scientists could predict their performance in competition, especially with sports such as running and cycling (Duggan and Tebbutt, 1990; Coyle, 1995). Team-sport athletes have also been tested under the same premise. This has proven on many occasions to be a false assumption. The reasons for poor predictive results of physiological tests for performance in team sports are manifold and include using testing procedures that are not specific to the sport, the underestimation of external influences such as the playing conditions, the opposition, the officials and the exclusion of skills required for the sport in question.

The increased awareness of the benefits sports science has to enhance sporting performance has and will continue to demand changes in the way athletes are profiled. The gradual transition from laboratory tests to more field-based tests has improved the validity of the resulting profiles. The improvements in technology have also had an influence, with computer-aided testing procedures now being commonplace. For example, heart rate monitors can transfer data directly into electronic spreadsheets for immediate analysis. The field of notational analysis has also been transformed with technological advancements (Hughes and Franks, 1997). Computers are powerful enough to store numerous databases and small enough to be transported to the field of play. This allows for immediate profiling of team sports during live competition.

3.2 Physiological Profile

Many team sports require repeated short bursts of maximal or near maximal effort (power) lasting 5 – 10 seconds, over a period of time anywhere from 70 – 120 minutes. Such sports include, rugby (Docherty et al., 1988 and McLean, 1992), soccer (Mayhew and Wenger, 1985; Davis and Brewer, 1993 and Tumilty, 1993), basketball (McInnes et al., 1995), volleyball (Künstlinger et al., 1987 and Smith et al., 1992) and field hockey (Reilly and Borrie, 1992).

In general these sports are characterised by high intensity, intermittent periods of exercise interspersed with randomised periods of recovery. There are a variety of factors such as skill, opposition tactics, environmental conditions, importance of the game and the spectators that influence the outcome of a match, making the formulation of a precise game plan difficult (Hawley and Burke, 1998). As a consequence there is no definitive training formula for all team sport players.

Fundamental to working with team sport players is a knowledge of the physiological demands of the sport itself (BASES, 1997). The scarcity of scientific studies dedicated to team sports (Hawley and Burke, 1998) limits the input that sports scientists can have especially when trying to infer match performance from a fitness assessment. Field hockey is a prime example of such a sport, where the literature on the 'modern' game (since 1994) is virtually non-existent. The following review will examine the development of the sport of field hockey. The review will address the scientific studies on field hockey with the goal of identifying the information that can be applied to improve performance.

3.3 History of Field Hockey

Field hockey has been a popular team game for centuries. Although the origins of hockey can be traced back to Asia in 2000 BC, a formalised set of rules were not developed and agreed upon until 1886 (Reilly and Borrie, 1992). Since then the rules of the game have changed at an accelerated rate over the last 10 – 15 years. The introduction of synthetic pitches, modifications in stick design and materials, more aerodynamic hockey balls and substantial rule changes have transformed the game into the fast moving physically and technically demanding sport that is now being played.

Hockey has been described as a fast moving invasive field sport played on a pitch 90 m long by 55 m wide (Reilly and Borrie, 1992). The duration of a match is 70 minutes (35 minutes each half), with a 5 - 10 minutes half time break (FIH, 1998). A squad of 16 players can play for a team during a match, but only a maximum of 11 players can be on the field at any one time.

3.4 Physical Demands of Field Hockey

The intensity of the game varies according to the level of expertise of the players (National Sports Medicine Institute [NMSI], 1998). Elite competition has been described by Reilly and Borrie (1992), as "aerobically" demanding with frequent though brief "anaerobic" efforts superimposed. The physiological demands of field hockey are made all the greater by the asymmetry associated with being able to use only one face of the stick. Hockey players therefore, have to pay greater attention to their body position, both in relation to the ball and their opponent, than other team sport players (Reilly and Borrie, 1992). There is an increase in energy cost while dribbling a ball compared to running at the same speeds. For example, Reilly and Seaton (1990) found the net physiological cost of dribbling a hockey ball was 15 – 16 $kJ.min^{-1}$ higher than running at the same speeds without a ball. In addition, heart rates were 20 – 30 beats per minute higher, while dribbling a hockey ball compared to running at the same speeds.

3.5 Estimated Energy Demands

According to Reilly and Borrie (1992) the exercise intensity of hockey can be determined by time-motion studies of match play. Once the work-rate profiles have been determined relative contributions of the "anaerobic" and "aerobic" energy systems can be estimated. Bowers and Fox (1988) stated that field hockey requires 60% energy from the adenine triphosphate – creatine phosphate (ATP-CP) and lactic acid (LA) system, 20% from the lactic acid –

oxygen or aerobic (LA-O_2) and the final 20% from the aerobic system. These figures were contradicted by Aggiss (1985) who suggested that the proportion should be 70% of the energy supplied by the aerobic system and only 30% by the anaerobic system, although he did concede that there is no scientific evidence to support this. Reilly and Borrie (1992) also supported the viewpoint of Aggiss (1985) especially when examining at top league club matches and higher levels of proficiency.

What has been established is the fact that the rest and recovery periods during matches constitutes less than 20% of total game time, including stoppages for injuries and the half time break (Cibich, 1991). Cibich (1991) also found that players spend approximately 50% or more of the total match time at and above 85% of their maximal heart rate. This suggests that the players are exercising at maximal or near maximal effort for over half of the game, and that the recovery periods are insufficient to allow heart rate to decrease to lower levels (Lothian and Farrally, 1992). From these data it is reasonable to conclude that competitive hockey matches place great demands on the "anaerobic" as well as the "aerobic" system (Boyle et al., 1994).

Various studies have documented the physiological characteristics of male and female field hockey players. These studies are summarized in Tables 3.1, 3.2 and 3.3 that show the "aerobic", "anaerobic" and anthropometric data, respectively.

It is understood that the terms “aerobic” and “anaerobic” are not technically correct because the terminology is based on a pre-supposed mechanism that is under much debate. It would be better to use terms such as “short duration, high intensity exercise” or “continuous submaximal exercise” as descriptors rather than mechanistic terms such as “anaerobic” or “ aerobic”. Nevertheless the terms “aerobic” and “anaerobic” have been used extensively in the literature, and will therefore be used in this context in the following discussion.

Tables 3.1, 3.2 and 3.3 describe the physical profile of field hockey players as examined under scientific conditions, either laboratory (treadmill) or field based (20 m MST). These data, as discussed in Chapter 2, do not necessarily reflect the physical demands of field hockey or the actual fitness characteristics demanded during a match. Only when fitness data are compared to physical match performance can relevant evaluations be made.

Table 3.1: "Aerobic" capacity of male (M) and female (F) field hockey players.

Reference	Sex	$VO_{2\,max}$ ($ml.kg^{-1}.min^{-1}$)	Test Mode	Population
Maksud et al., 1976	F	42.9	Treadmill	College
Zeldis et al., 1978	F	51.7	Treadmill	College & USA National
Rate & Pyke, 1978	F	50.1	Treadmill	Australian Provincial
Withers & Roberts, 1981	F	50.2	Treadmill	Australian Provincial
Reilly et al., 1985	F	54.5	Treadmill	Welsh squad
Ready & van der Merwe, 1986	F	59.3	Progressive treadmill test	Canadian 1984 Olympic squad
Reilly & Bretherton, 1986	F	43.2	Graded cycle test (PWC_{170})	English Elite & County Players
Cheetham & Williams, 1987	F	52.2	Treadmill	English county
NCF, 1995	F	55.7	20m MST	British national squad
Melanson et al., 1997	F	57.1	Not stated	USA 1996 Olympic squad
Withers et al., 1977	M	64.1	Treadmill	Australian Provincial
Kansal et al., 1980	M	48.3	Cycle	Indian college & national
Roberts & Morton, 1981	M	60.7	Treadmill	Australian provincial & national
Hargreaves, 1983	M	62.2	Treadmill	Great Britain squad
Scott et al., 1988	M	53.3	Cooper 12 minute run	South African Provincial/National
Boyle et al., 1994	M	61.8	Treadmill	Great Britain players
NCF, 1995	M	59.6	20m MST	British squad

Table 3.2: "Anaerobic" power and capacity of male (M) and female (F) hockey players.

Reference	Sex	"Anaerobic" power/capacity	Test Mode	Population
Verma et al., 1979	F	59.5 ($kg.m.s^{-1}$)	Stair run	Indian national
Ready & van der Merwe, 1986	F	910(W) (power)	Modified Stair run	1984 Canadian Olympic squad
Reilly & Bretherton, 1986	F	79.3 ($kg.m.s^{-1}$)	Stair run	English elite & county
Bhanot & Sidhu, 1981	M	90.1 ($kg.m.s^{-1}$)	Stair run	Indian national
Scott et al., 1988	M	9.1 ($W.kg^{-1}$)	Wingate	South African provincial & national

Table 3.3: Anthropometric characteristics of male (M) and female (F) field hockey players.

Reference	Sex	Body Fat	Test Mode	Population
Bale & McNaught-Davis, (1983)	F	23 %	Sum of skinfolds	English provincial
Reilly et al., 1985	F	26 %	Not stated	Welsh squad
Ready & van der Merwe, 1986	F	16 %	Hydrostatic weighing	1984 Canadian Olympic squad
Reilly & Bretherton, 1986	F	23 %	Sum of 4 skinfolds	English elite and national
Proulx & Sexsmith, 1988	F	13 %	Sum of skinfolds	Canadian university students
Withers et al., 1987	F	20 %	Hydrostatic weighing	South Australian
Sparling et al., 1998	F	17 %	Sum of 7 skinfolds	1996 USA Olympic squad
Kansal et al., 1980	M	15 %	Sum of skinfolds	Indian national & university
Scott, 1991	M	11%	Sum of skinfolds	South African national & provincial

3.6 PERFORMANCE PROFILES.

Performance analysis through the direct study of sporting performance has enabled sports scientists, coaches and athletes to better understand the demands of their sport and thus improve coaching methods (McGarry and Franks, 1997; Olsen and Larsen, 1997 and Hughes and Bell, 1998). This can be in the form of physical performance (time motion studies) or skill related (including tactical and strategic information). Chapter 2 discussed some examples of these studies.

A priority in performance analysis is to identify those elements that distinguish successful sporting performance from non-successful (McGarry and Franks, 1997). Individuals and teams frequently elicit stereotypical patterns of play and these are idiosyncratic models of performance (Potter and Hughes, 2001). Major international tournaments (World Cups, Grand Slam tennis, Olympics, European Cup etc.) are frequently used to identify the key components of success. Typically performances of individuals or teams that reach the semi finals are compared and contrasted with those teams that do not pass the first round. It is from this analysis that the profile of successful performance is established.

One of the earliest direct studies on performance in soccer was that conducted by Reep and Benjamen (1968). They found that goals tended to be scored from passing sequences that involve a small number of passes. Eighty percent of goals were scored from a sequence of three or less passes, thus it was suggested that the 'long ball' game would lead to greater success than possession-dominated soccer. Examples of other soccer performance profile studies include the study of Hughes et al. (1988), who found that successful teams had significantly more touches of the ball per possession than unsuccessful teams during the 1986 World Cup finals. These authors also found that there were significant differences in the playing patterns of the successful and unsuccessful teams. The successful teams used the centre of the pitch significantly more than the unsuccessful teams. Lewis and Hughes (1988) in their study concluded that successful teams passed the ball more times when attacking especially out of defence and in the final attacking area of the field than unsuccessful teams. The findings of Winkler (2001) supported this work. He also found that successful teams create more goal-scoring opportunities and have more shots at goal than unsuccessful teams. Successful teams were also better equipped to break down their opposition's offensive play and thus prevent 'good' shots from being taken at goal. Stanhope (2000) found evidence to suggest that countries with a similar geographic location played a similar pattern of soccer in the 1994 World Cup. However, there was a great deal of variation in the styles adopted by the unsuccessful teams that no one pattern could be identified (Stanhope, 2000).

Models to describe or predict rugby performance are also possible according to Treadwell (1991) and will be independent of factors such as the weather, the referee or coaching styles of the different teams. In a study of Five Nations Rugby over 2 years, Hughes and Williams (1988) found no significant differences in the playing patterns of the successful and unsuccessful teams, but they did establish that 3 teams played a similar style that was different to the teams from the other 2 nations. Stanhope and Hughes (1997) also concluded that successful and unsuccessful teams in the 1991 World Cup played similar games. There were, however, differences in the rucking and kicking abilities between the two different levels of the teams. The successful teams could kick more strategically in the field, putting their opposition under greater pressure than the unsuccessful teams (Stanhope and Hughes, 1997). Further analysis of the 1991 World Cup revealed that the forwards of the more successful teams were able to dominate the line-outs and the 'driving phases' of the game such as rucking and mauling (Hughes and White, 1997).

The determinants of success and failure have also been examined in women's rugby. Jackson and Hughes (2001) investigated 2 seasons of women's international rugby from the Six Nations Championship and the Canada Rugby Cup. They discovered that successful teams had a higher average number of passes per possession rate, made a greater number of tackles per player, generally put more players into ruck and maul situations and won more line-out ball than unsuccessful teams. The work rate, determined by the number of times each team reached a breakdown in play and secured possession, of the successful teams was also greater. Kicking was found to elicit a negative effect on the result, the greater the number of times the ball was kicked by a specific team, the greater the probability that that team would loose the match. This was primarily due to a lack of accuracy and gave the advantage to the opposition players for them to counterattack.

Individual sports have also been studied for determinants of success. The majority of the work has been performed on racket sports and more specifically with squash. Simply stating that the number of winning and losing shots discriminates between success and failure in racket sports is of little value according to McGarry and Franks (1996). Therefore some additional information is required. This additional information takes the form of establishing invariant behaviour patterns within the sport (McGarry and Franks, 1997). Invariant behaviour occurs when consistent responses are given to a certain stimulus, for example repeatedly playing a deep lob after a drop shot in squash. The opposite of invariant behaviour is variant behaviour and this is simply defined as an inconsistent response to the same stimulus. Once these invariant behaviours are understood, performance profiles of players can be developed. The initial work of McGarry and Franks (1994) found a player – player interaction. This meant that performance against the same opponent would be invariant; however, when a different opponent was played variant behaviour was displayed. Additional work later revealed that the level of analysis had a greater effect than previously thought. A greater level of invariance was found in playing performance when the preceding shot details were considered (McGarry and Franks, 1996). This work demonstrates that consistent and inconsistent shot responses are found in squash match play. It would therefore be reasonable to suggest that athletic behaviours flux between periods of variant and invariant behaviour throughout the time course of the game (McGarry and Franks, 1996). The level of flux is dependent upon the degree of disturbance that is introduced. This very simply means that if player A plays a shot that is unexpected by the opponent that behavioural state becomes unstable. The duration of the instability depends upon the shot response of the opponent, for example if the opponent's shot is out then the instability ends and an alternative state begins (a new rally to begin with a serve). If the shot response by the opponent keeps the ball in play then the period of instability is over and the previous steady behavioural state is resumed (McGarry and Franks, 1996). It is this disturbance, the shot by player A, sometimes called a perturbation that elicits the critical response, which in squash ends a rally or in soccer results a goal being scored. That according to McGarry and Franks (1996) needs to be investigated further to enable an accurate prediction of sport performance from past events to be possible.

Notational analysis is frequently used to enable sports scientists, coaches and athletes to understand the components of their particular sports. There has been debate as to whether notational analysis can be classified as research (O'Donoghue, 2001). Doubt has arisen over the reliability (Hayes, 1997) of the data due to the unique nature of sporting competition. The work of Hughes et al. (2001b) found that there was very little statistical basis to determine the number of matches that needed to be analysed for a stable performance profile to exist. If a normative or stable profile does not exist then comparisons between other data are not possible. It would be reasonable to suggest that by increasing the size of the database the more accurate the means would become (Potter and Hughes, 2001). However, Hughes et al. (2001b) argued that as a database increases it may lose its sensitivity to changes.

The analysis method developed by Hughes et al (2001b) was to determine the number of games required for a normative profile to exist. This required that the cumulative mean be examined over a number matches. According to this method the first point at which the cumulative mean consistently lay within a set of 'limits of error' was recorded as a normative or consistent profile. If the cumulative mean did not lie between the limits of error then additional matches would need to be analysed. The limits of error are defined as a percentage deviation (± 1%; ± 5%; ± 10%) of the overall data mean about the overall mean.

This is summarised by the following equations;

Let n = the variable number of matches

$N_{(E)}$ = value of n to reach limits of error

$N_{(T)}$ = total number of matches

Cumulative mean = (Sum of the frequencies of 'n') / n

Limits of error (10%) = Mean $N_{(T)} \pm$ (Mean $N_{(T)}$ x 0.1)

Limits of error (5%) = Mean $N_{(T)} \pm$ (Mean $N_{(T)}$ x 0.05)

Limits of error (1%) = Mean $N_{(T)} \pm$ (Mean $N_{(T)}$ x 0.01)

These values are then graphically represented and $N_{(E)}$ can be determined from the graph if sufficient matches have been analysed. If $N_{(E)}$ does not exist then addition data must be collected for that variable. If a normative profile has been established for a variety of variables then comparisons can be made and templates for successful or unsuccessful performance can be established

(Hughes et al., 2001b.) This is a relatively simple technique that estimates the minimum number of matches that are required for a specific variable and can be applied to any sport (Hughes, 2001b).

In summary the profiling of athletes is important for establishing what factors are associated with successful sporting behaviour. However, as discussed above, unless the data are obtained using reliable and valid testing procedures, the results are difficult to interpret. The next Chapter discusses reliability and validity with specific reference to physical fitness testing.

CHAPTER 4

RELIABILITY AND VALIDITY

4.1 INTRODUCTION

The assessment of athletes has expanded rapidly over the last 10 – 20 years. Coaches, athletes and sports scientists alike now realise that the most consistent method of preparation for competition comes from a systematic scientific approach (Hawley and Burke, 1998 and Reilly, 1996). In a number of countries such as Australia, the former East Germany and the United States of America, this method of preparing athletes for competition has resulted in the establishment of national or regional sports institutes. At these institutes the athletes undergo a battery of medical and physiological tests and as a consequence, receive the most up-to-date sports-specific scientific feedback to enhance their current training programmes and improve their athletic performance (Hawley and Burke, 1998).

A prerequisite for the successful performance of any physical activity is the possession of skills specific to the activity and the appropriate physical fitness (Wilsmore and Curtis, 1992 and Reilly, 1996). Physical fitness can be defined as a set of attributes (health and skill related) that combine together to determine a person's ability to perform a specific physical activity or task. The health components are cardiovascular fitness, flexibility, muscular endurance and strength. The fitness components related to skill are agility, balance, co-ordination, power, reaction time and speed (Kent, 1994). Fitness for a player participating in a team sport is said to be a sport-specific multivariate combination of the aforementioned components (Reilly, 1996). A whole variety of tests therefore, have to be conducted to establish a fitness profile for the athlete/sport.

Most tests used to determine athletic fitness have concentrated on measuring general aerobic power and capacity, and have neglected the specific requirements of each athlete's sport. In accordance with this, Winkler (1993) suggested that laboratory-based endurance and submaximal tests, which measure linear movement only, must make way for tests designed to test the specific physiological requirements of the athlete's preferred sporting discipline.

Field based fitness tests offer the coach and athlete accessible means for assessing specific fitness components that are relevant to their sport. A few of these tests such as the 20-m Multiple Shuttle Test developed by Lèger and Lambert (1982) to predict VO_{2max} are able to indirectly estimate a physiological measure of fitness. Most field tests determine performance of certain sport-related tasks (National Coaching Foundation [NCF], 1995). Consequently coaches have developed their own fitness tests that although sport specific, may not have been scientifically designed and tested (NCF, 1995). As a result the reliability of the data collected during these fitness evaluations may be questionable.

For any fitness test to be deemed relevant, it must measure components of fitness that are specific to the sport in question. The information that it provides must also be objective, reliable and valid.

4.2 SPECIFICITY AND OBJECTIVITY.

4.2.1 Specificity

Specificity is a principle that states a person must be tested specifically for that characteristic of physical fitness. This principle applies to muscle groups, movement patterns, velocities and contraction types.

4.2.2 Objectivity

Objectivity is the quality of the test being free from bias and not influenced by the views of the experimenter. Objectivity can also be considered to be the aspect of measurement related to the extent to which two observers can independently attain the same score.

4.3 RELIABILITY.

Reliability is defined as "*a characteristic of a measurement or experimental procedure, which produces similar results on two or more separate occasions*" without any change in fitness (Kent, 1994). The test will only be reliable if the intrinsic variation of the test is less than the variation in the subjects' fitness between testing sessions. Hopkins et al. (1999) stated that even using the most reliable tests with the best athletes, there will still be a variation in performance of 3%.

Reliability is an important consideration when deciding upon the usefulness of a test to detect subtle changes in physical performance after a period of physiological, psychological or nutritional intervention (Schabort et al., 1997; NCF, 1995).

4.4 VALIDITY.

Validity is defined as "*the extent to which a test, measurement or other method of investigation possess the property of actually doing what it has been designed to do*" (Kent, 1994 p 470). When a fitness test is described as valid, it is assumed that the results of the test allow conclusions to be made about the fitness status of the individual.

The NCF (1995) stated that it is a reasonably complex task to validate tests and that may be one of the main explanations why many team sport field tests have not been scientifically validated. There are three methods by which validity can be established:

- Logical or face validity
- Criterion validity
- Construct validity

4.4.1 Logical Validity

Logical validity is determined if the primary fitness components responsible for performance are known and there is a high level of confidence that the test in question measures those components. Logically this would lead to the conclusion that the test possesses some form of validity.

4.4.2 Criterion Validity

If assumptions from logical validity were evaluated against an established testing procedure and there was a strong correlation between the data from the new test and the established one, then the new test would have criterion validity.

4.4.3 Construct Validity

Construct validity is ascertained if the test is able to discriminate different fitness levels between different levels of groups of performers.

However, the logical, criterion and construct categories of validity appear to only provide an indirect indication of the validity of the test. They do not examine the specific demands of the sport in terms of equating scores achieved in the fitness test with actual physical performances during a match.

4.4.4 Validity of a Team Sport Fitness Test.

For a fitness test to be valid for team sports it must directly measure an aspect or aspects of actual sporting performance. A cycling test, for example, is not a valid test for team sport participants because of the mode of exercise and thus the muscle groups utilised are different. Tests that are unidirectional are also of limited value because team sports have been documented as having frequent changes in activity (Reilly and Thomas, 1976). It is apparent that field tests are more appropriate when it comes to assessing the physical fitness of team sport athletes as they allow for greater flexibility in their design.

4.4.5 Validity of the 20-m multistage shuttle test.

One of the most commonly used tests to assess fitness levels of team and racket sport players is the 20-m multistage shuttle test (20-m MST). The data obtained from studies on the test show it is significantly correlated with laboratory determined values of $VO_{2\,max.}$ (van Mechlen et al., 1986 ; Paliczka et al., 1987; Lèger et al., 1988 ; Ramsbottom et al., 1988 and Mahoney, 1992).

The test was developed by Lèger and Lambert (1982) to determine the maximal uptake ($VO_{2\,max.}$) of school children, healthy adults and athletes (Lèger et al., 1988). The test was modified by Lèger et al. (1988) and again by Ramsbottom et al. (1998). Ramsbottom et al. (1988) developed normative data for active adult sportsmen and women.

Various studies have been performed using the 20-m MST to predict relative $VO_{2\,max.}$ A consistent finding from a variety of studies has been the consistent and significant under-prediction of $VO_{2\,max.}$ (Ahmaidi et al., 1992 ; Sproule et al., 1993 ; Berthoin et al., 1994 ; Grant et al., 1995 and St. Clair Gibson et al., 1998).

The lower values of $VO_{2\,max.}$ may be explained by the biomechanical processes involved when the athlete has to rapidly change direction (Ahmaidi et al., 1992). The multistage shuttle test requires continual speeding up, slowing down and direction changes requiring a significant contribution from the anaerobic energy systems. The further the player progresses in the test the higher the demand placed upon the anaerobic system (Grant et al, 1995). Grant et al. (1995) suggested that subjects with low anaerobic capacities may well under-perform in the test relative to their aerobic power.

The majority of the work that has evaluated the 20-m MST, has used heterogeneous groups of subjects that were either pre-adolescent (<14 years) or had a variety of sporting backgrounds, training levels and ability. One of the few studies that has used highly trained athletes (team squash players and club endurance runners) (St Clair Gibson et al., 1998) had the lowest correlation value (r = 0.67 for the combined group) compared to other studies with correlation values ranging from 0.76 to 0.92. St Clair Gibson et al. (1998) concluded that the 20-m MST was less accurate in predicting $VO_{2\,max}$ in a trained group of athletes with higher maximal oxygen uptake values and a smaller spread of values.

Despite this under-prediction of $VO_{2\,max.}$ observed with highly trained athletes, the nature of the test itself is not fully representative of the demands of team sports (Table 4.1). Team sports are dynamic and involve rapid changes in intensity, direction and recovery, in addition to basic ball skills, whereas the shuttle test of Léger and Lambert (1982) has predetermined intensities and distances and does not allow for periods of recovery.

Table 4.1: Basic Comparison of Team Sport Attributes with the 20-m MST.

Attribute	**Team Sports**	**20-m MST**
Frequent instances where subject has to rapidly accelerate, decelerate and change direction	✓	✓
Variation in distances covered	✓	X
Recovery periods of varied length	✓	X
Variation in the length of the work bouts	✓	X
Repeated bouts of maximal effort	✓	X
Extensive Submaximal Work.	✓	✓
Work to rest ratios that mimic actual match demands	✓	X
Randomised movement patterns (angles of movement anywhere from 1 to 360^0)	✓	X
Requires adoption of low body position that places extra demands on body	✓	X

The 20-m MST is an incremental speed protocol with athletes only reaching high intensity work rates during the final stages of the test (Stage 20 equates to a speed of 18 $km.h^{-1}$ (Léger et al., 1988)). Running speeds of faster than 18 $km.h^{-1}$ have been reported in time-motion studies (Ohashi et al., 1988; Van Gool et al., 1988 and McLean, 1992). Players frequently reach the maximal or near maximal speeds, for short periods of time (5-7 seconds) throughout a match (Dawson et al., 1993 and Fitzsimons et al., 1993). Therefore, tests that only measure players' high intensity performance during the final stages of the protocol do not accurately reflect actual physical game requirements.

From this basic comparison of team sport requirements and attributes of the 20-m MST (Table 4.1) it can be demonstrated that there is a need for a scientifically repeatable and valid measure that can more accurately determine team sport fitness.

Such a test should, according to the literature, include the following points for it to be representative of the physiological requirements of the sport (without introducing the influence of technical skill):

- Frequent instances where the subject has to rapidly accelerate, decelerate and change direction (McInnes et al., 1995)
- Recovery periods of varied length
- Variations in the length of the work bouts
- Repeated bouts of maximal effort rather than one-off sprints (Dawson et al, 1993)
- Work to rest ratios that mimic actual match demands (McLean, 1992)

A compromise has to be made when designing and implementing field fitness tests. The tests must be simple to use, and designed so that many athletes can be tested simultaneously. Futhermore, field fitness tests should not require expensive or extensive amounts of equipment, but must maintain a certain level of precision (BASES, 1997).

A test that appears to fulfil most of the above criteria is the "repeated sprint ability test" that is used for testing team sport athletes by the South African Sports Science Institute. This test is a 5-m high-intensity multiple shuttle test

(5-m MST). The purpose of this test is to measure the speed, agility and endurance of team sport players (Hawley and Burke, 1998). At present there are no scientific data for this test that relate to its repeatability and overall validity.

The last four chapters have introduced the literature pertaining to how visual feedback has been developed and used to aid our understanding of sporting performance. This information needs to be interpreted and disseminated to coaches, athletes and sports scientists in such a way that it can be used in a practical environment to enhance training techniques and ultimately competitive performance. The rest of this thesis is focused on establishing relationships between visual feedback and performance, of either a physical or skilled nature. The next chapter is the start of the empirical work and investigates the physical demands, through a time-motion study placed upon field hockey players during competition. With this data we are able to evaluate the fitness requirements of field hockey players and design valid testing programmes, this will be discussed in Chapters 6 and 7. Chapters 8 and 9 will discuss how visual feedback can be used to aid our understanding of skilled performance.

CHAPTER 5

A TIME-MOTION STUDY OF FEMALE FIELD HOCKEY PLAYERS.

5.1 INTRODUCTION.

Published time-motion studies of team sports have mainly focused on soccer (Reilly and Thomas, 1976; Withers et al., 1982; Mayhew and Wenger, 1985 and Catterall et al., 1993). The results from these studies have increased sports scientists' and coaches' understanding of the physical requirements of the game and have resulted in a more scientific approach to training.

The physical demands of field hockey are very similar to soccer. Hockey has also been described as soccer with a stick (Moore, 1988). Player participation in hockey has ranked third in the world in terms of numbers, behind soccer and ahead of high profile sports such as rugby and cricket (Moore, 1988). Data from the Sydney Olympic Games 2000 show that hockey was the second most popular sport in the games (Federation of International Hockey (FIH), 2001). Despite the popularity of the sport there are little data about the physical requirements of the sport. This may be attributed to the fact that field hockey lacks the comprehensive television coverage that has aided many post-event studies, in other sports such as soccer and rugby. The amateur status of the sport may also have an impact on the resources that are allocated to researching hockey.

Several changes in rules, equipment and playing surface have occurred in field hockey over the last two decades that have changed the physical requirements of the game considerably. The major alterations to the rules have included changes to the obstruction rulings, the introduction of continuous substitution of players and the removal of the 'off-side' rule.

Furthermore, previous field hockey studies have only measured the time spent at different activity intensities (Lothian and Farrally, 1992 and 1994). Since these papers were published, additional rules have changed. The nature of the game has thus altered and therefore there is a demand for studies into the 'modern' game of hockey. Therefore, the aim of this study was to quantify the displacements covered by field hockey players during club league matches played under modern (1999) rules.

5.2 METHODS.

The last three matches of a female Western Province Grand Challenge squad during the 1999 season, were recorded using two hand-held video cameras. Each camera was located adjacent to the 25-yard line. The camera was positioned in the stand at a height of (7.31 m) and distance (12.8 m) from the field (figure 5.1). The camera panned between the baseline and the halfway line to ensure that as many of the field players i.e. not the goalkeeper were recorded by the camera during the match at all times.

Three of the players (1 attacking and 2 midfield) randomly selected initially, wore heart rate monitors during all three of the matches. Only three heart rate monitors were used due to concern with 'cross-talk' from additional monitors.

The heart rate monitors were set to record heart rates every 15 seconds (Polar Vantage XL, Polar Electro, Finland).

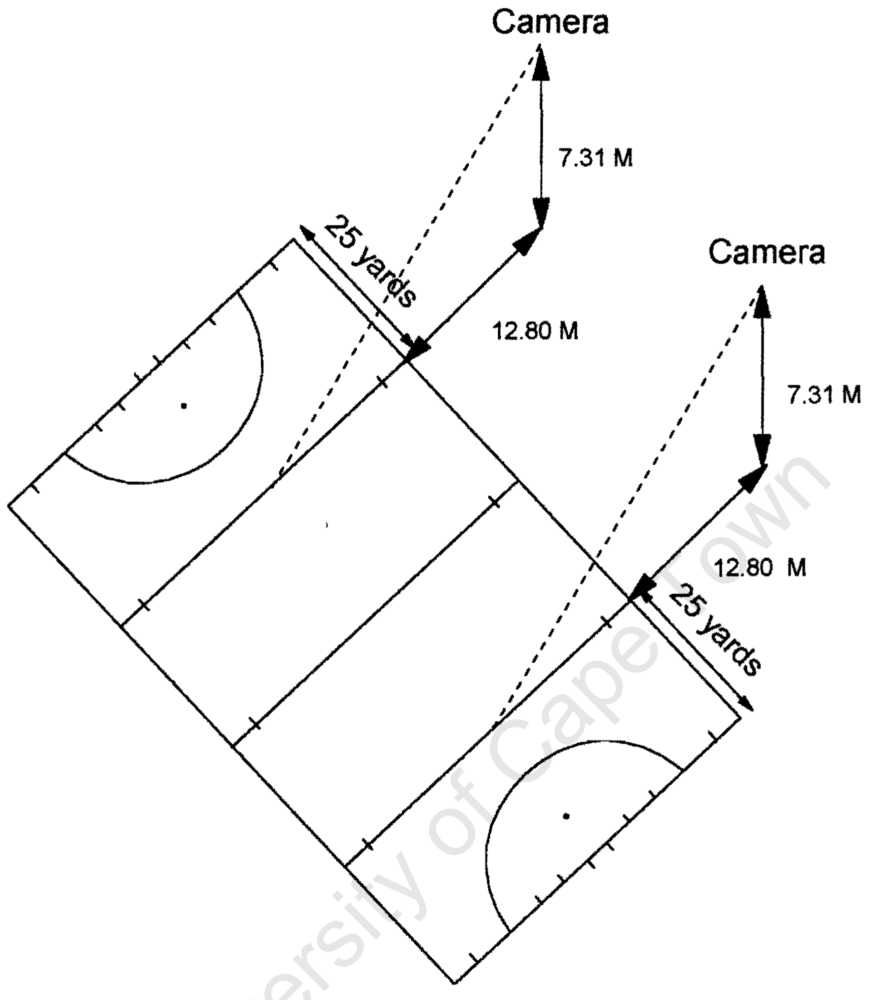

Figure 5.1 Diagrammatic Layout of Camera Location in relation to Hockey Pitch.

After each match all the players were asked to complete a basic questionnaire to assess their perceptions of effort and activities during the match on a scale of 1 to 5, with 5 being the hardest. The following questions were asked;

- How difficult did you feel the match was?
- How did you feel before the match?
- Did you have to run more than usual?
- Did you have to sprint more than usual?
- How was your pre-match preparation?

In addition the following questions were asked and a yes/no response was given;

- Did you suffer any form of injury?
- Did it reduce the amount of running that you could do?

The videotapes of the matches were manually analysed using a stopwatch and a scale diagram of the hockey field. Each player's initial position was marked on the diagram and then every 15 seconds throughout the match a new position was recorded. This analysis only allowed for the horizontal displacement of the players to be measured not their distance. In some cases the horizontal displacement may have been slightly less than the actual distance covered, particularly if a player ran back towards the starting point of the 15 second time period. However, due to the quantity of data collected this discrepancy was considered to be minor. The analysis was performed for each player individually and for each of the three matches.

The new position of each player was given a time code so that the displacement between each 15-second marker could be measured. This distance between the 2 positions was measured with a ruler and recorded as the displacement. The player's speed could be calculated between each marker because the time between each point was known. Total displacement, mean displacement per minute of playing time (total displacement / number of minutes played), mean displacement per 15 s (total displacement / number of 15 second displacements) and mean speed per 15 s (mean displacement / 15 s) could also be determined for each player. The amount of time that each player spent playing (game time – time substituted) was also recorded. All of the measurements recorded for the players had to be normalised for playing time because of the continual substitution ruling, which meant that players were given breaks during the match and allowed to return at any time.

The technique for analysing displacement was validated by having a subject run around the same hockey field, with the video cameras set up in the same position as they were for the matches. The subject dropped markers at 15-second time intervals (n = 40) and the distance between the markers was then measured using a measuring wheel. The difference between this measured displacement and the displacement calculated using the transcription from the videotape were compared to calculate the measurement error. The intra-observer reliability was also determined by repeating the video analysis technique for determining displacement three times and comparing the mean error in measurement (11.5 %).

Movement intensity was determined using similar parameters to those of Lothian and Farrally (1992). The different categories are as follows; standing 0 $km.h^{-1}$, walking 0.1 – 6 $km.h^{-1}$, jogging 6.1 – 10 $km.h^{-1}$, cruising 10.1 – 14 $km.h^{-1}$ and sprinting above 14 $km.h^{-1}$. The % time spent in those activities was then calculated.

5.3 STATISTICAL ANALYSIS.

The means and standard deviations for each factor and normalised factor were calculated for all of the players and over the three different matches.

A two-way analysis of variance with repeated measures and a covariance for playing time (to correct for differences in playing time) was used to determine differences between displacement and speed during each half in each of the three matches. A Scheffe's post-hoc test was used to identify specific difference when the main effect was significant ($P<0.05$).

The heart rate data were analysed with an analysis of variance with repeated measures. A Scheffe's post-hoc test was used to identify specific differences when the main effect was significant ($P<0.05$).

The subjective data were analysed using a Kruskal-Wallis ANOVA to determine if there were any significant differences between the responses and the three matches. A Spearman's Rank order correlation was calculated to determine the relationship between the subjective responses of the subjects and their running data.

The limits of agreement between the measured displacement and the calculated displacement were assessed with a Bland Altman plot (Bland and Altman, 1986).

5.4 RESULTS.

The correlation between the measured displacement and displacement determined by video analysis was r = 0.91. This is shown in Figure 5.2.

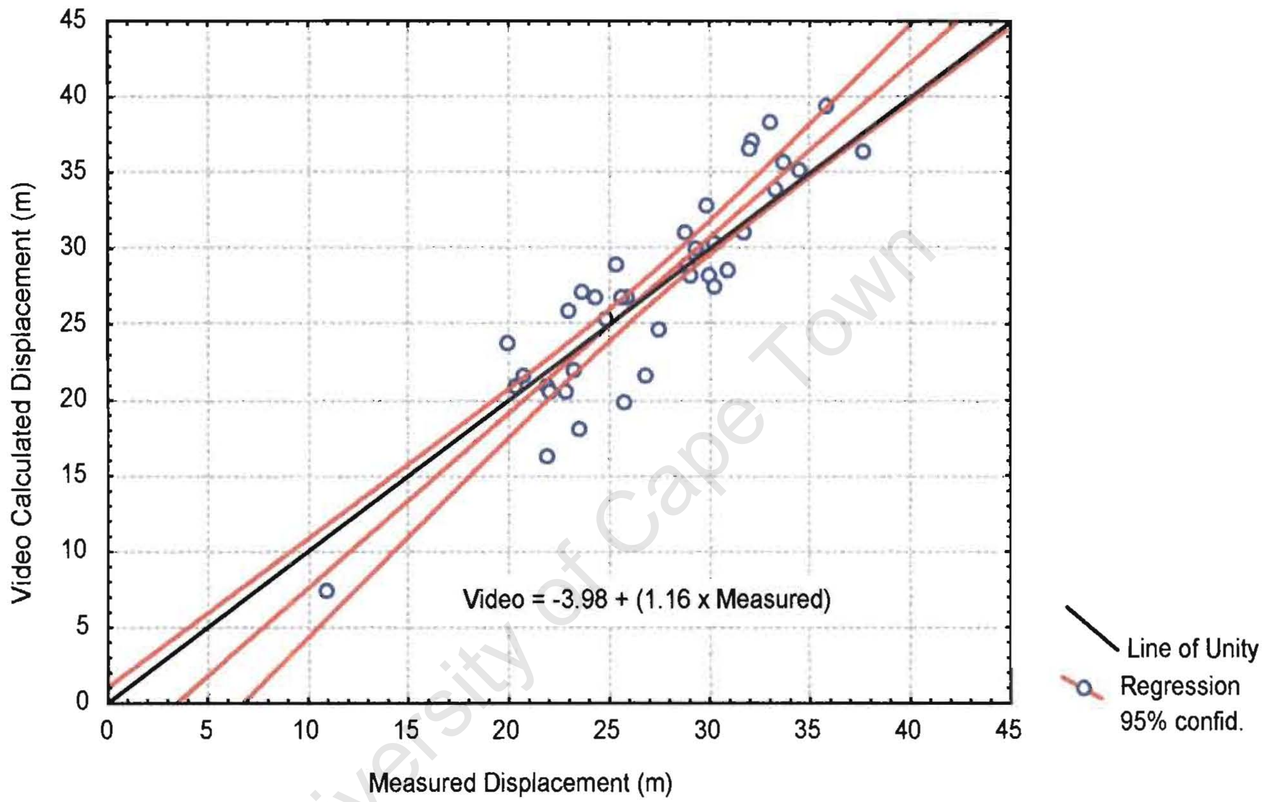

Figure 5.2: The relationship between the Measured Displacement and the Displacement determined by Video Analysis.

The 95% limits of agreement between the displacement determined by video analysis and the measured displacement are shown in Figure 5.3. The mean difference is 0.26 m with a 95% confidence of -6.3 m to 5.8 m. The magnitude of the displacement error had no effect on the calculation of the displacement measured by video analysis.

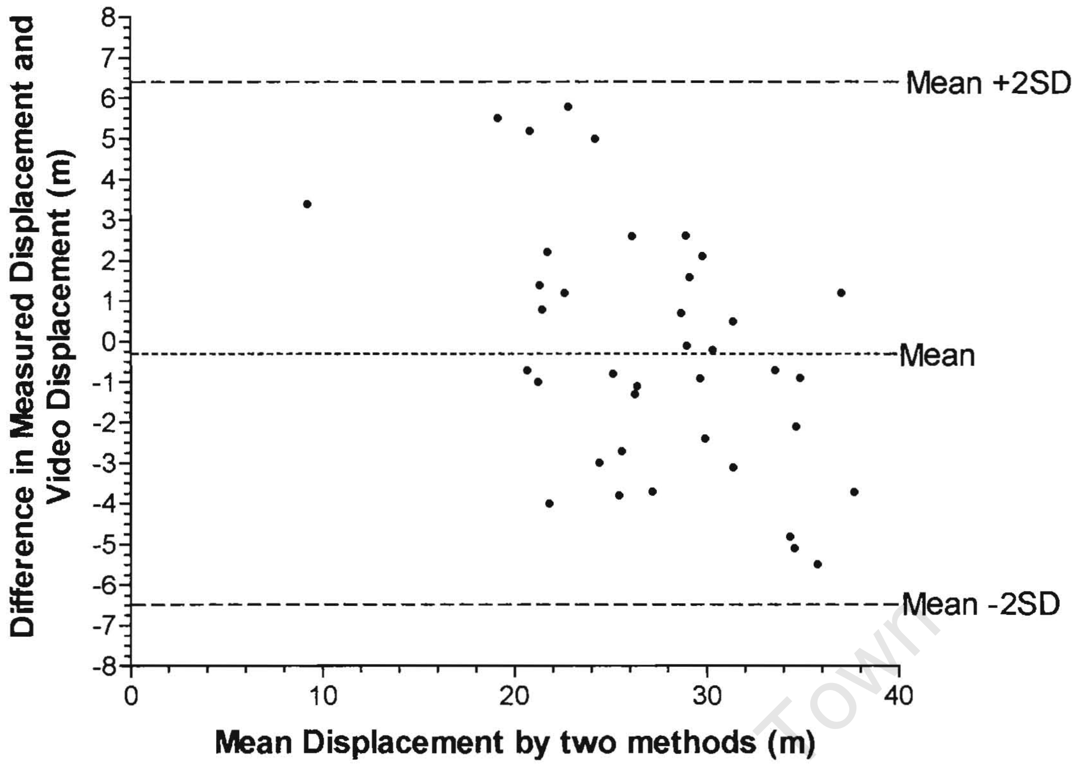

Figure 5.3: Differences between Actual Measured Displacement (m) and Displacement determined using a Video Technique (m).

The scores of the three matches were; Game 1 lost 1-0, Game 2 won 7-0 and Game 3 won 4-0. The team analysed in this study finished 3rd in the league, their opponents in game 1 finished 1st, in game 2 finished 8th and game 3 finished 4th. The weather conditions for the 3 games were similar according to the players.

The raw data representing the movement profile of a central midfield player (number 14, game 1, 1st Half) are shown in Figures 5.4a. The analysed data representing the displacement for each 15-second period throughout the game are shown in Figure 5.4b.

The subjects (n = 11) that participated in this study were aged 24.4 ± 2.2 years; height 167.2 ± 7.4 cm, body mass 62.4 ± 7.9 kg and body fat 24.2 ± 3.0 %. The mean predicted $VO_{2max.}$ value was 42.7 ± 7.1 $ml.kg^{-1}.min^{-1}$ (20-m Multiple Shuttle Test, Ramsbottom et al., 1988).

The mean ± standard deviation data collected during the 3 matches is represented in Table 5.1 and the group results are summarised in tables 5.2, 5.3, 5.4 and 5.5. The mean total displacement covered during the matches was 3901 ± 552 m (range 2832 to 4832 m) in 63.4 ± 9.5 minutes of playing time. This equates to a mean displacement of 61 ± 6 m per minute of actual playing time.

There were significant differences between the total displacements recorded for each of the 3 matches (P = 0.02) and between the two halves of the match (P = 0.01) (Figure 5.5). The total displacement in match 1(2303 ± 596 m) was greater than match 2 (3672 ± 519 m) (P = 0.0002) and match 3 (3766 ± 598 m) (P = 0.001) (Figure 5.5). No significant differences were found between match 2 and 3. Significant differences were also observed between the displacement per unit time and the matches (P=0.005). In match 1 the players covered significantly more distance (65 ± 8.4 m) (Table 5.1) than in the other 2 matches (58 ± 3.7 game 2 and 59 ± 4.6 m game 3) (P=0.005 match 1 vs. 2 and P=0.046 match 1 vs. 3) per minute playing time. No significant differences were observed between matches 2 and 3.

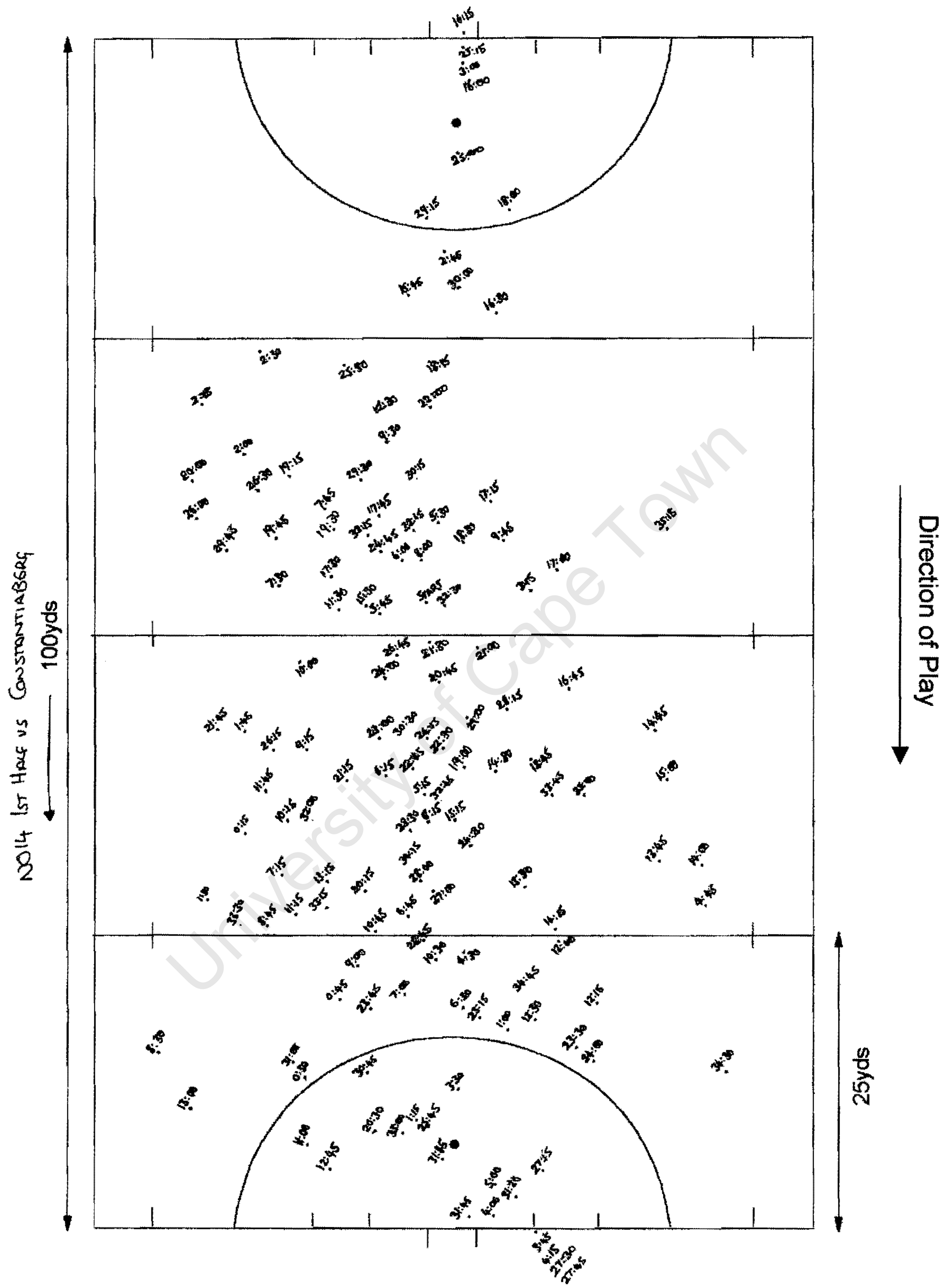

Figure 5.4a: Movement Profile for Player 14 during 1st Half of Game 1.

Table 5.1 Summary of the mean data ± standard deviations recorded during the 3 matches and further divided into 1st half and 2nd half (n = 11).

	Match 1		Match 2		Match 3	
	1st	2nd	1st	2nd	1st	2nd
Total Displacement (m) *	2126 ±377	2177 ±219	1925 ±321	1747 ±198	1932 ±316	1834 ±282
Displacement per unit playing time ($m.min^{-1}$) **	65 ± 8	64 ± 4	60 ± 4	56 ± 6	61 ± 5	58 ± 4
Mean Displacement (m)	15 ± 3	16 ± 1	15 ± 1	14 ± 1	15 ± 1	15 ± 1
Mean Speed ($m.s^{-1}$)	1.01 ± 0.2	1.04 ± 0.1	0.98 ± 0.1	0.92 ± 0.1	1.01 ± 0.1	0.96 ± 0.1

* Match 1 vs. Match 2 (P = 0.0002).
Match 1 vs. Match 3 (P = 0.001)

** Match 1 vs. Match 2 (P = 0.005)
Match 1 vs. Match 3 (P = 0.046)

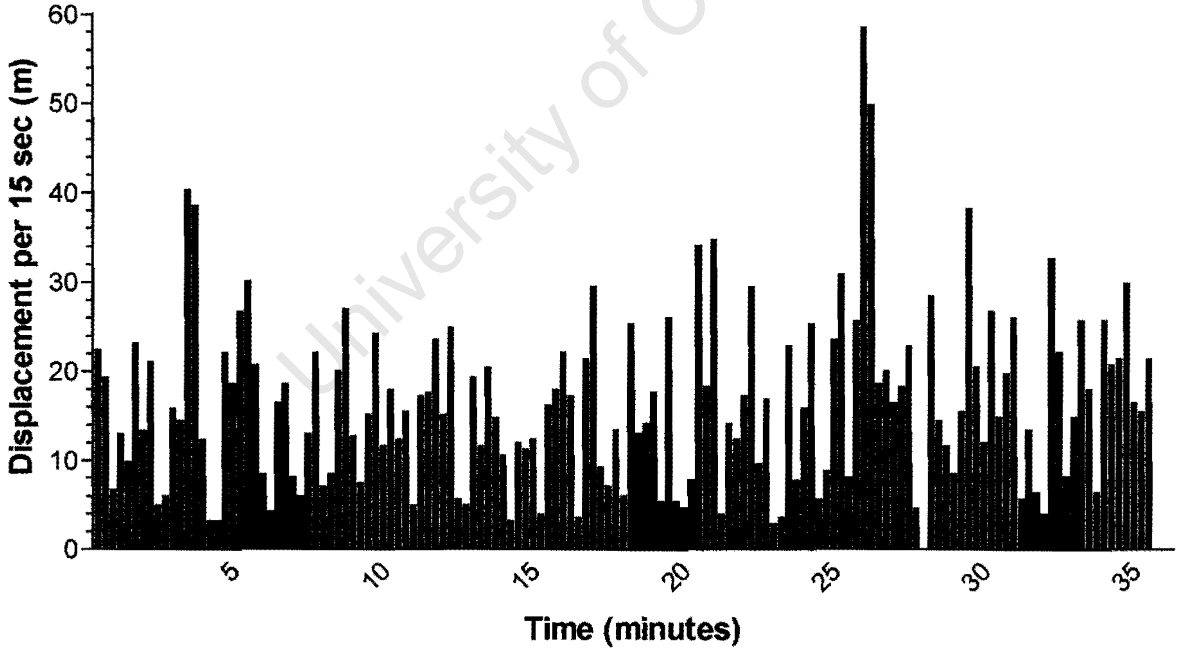

Figure 5.4b : Player 14 Movement Profile 1st Half Game 1.

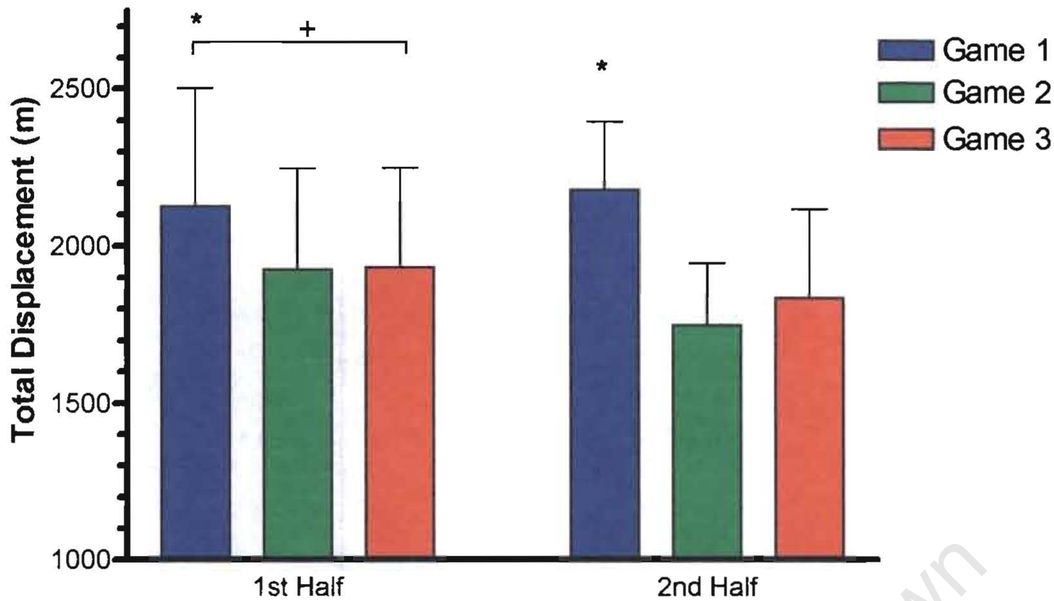

Figure 5.5 : The Mean Total Displacement (m) covered during the 3 League Matches

* represents significant difference between Game 1 and Game 2 and 3.
\+ represents significant difference between the 1st Half and the 2nd Half.

When all the matches were combined the players covered significantly greater displacement during the first half, 1994 ± 340 m when compared to the second, 1919 ± 295 m (P = 0.01). The same significant decrease in displacement between the different halves was observed with the displacement per minute playing time 62 ± 6 m and 59 ± 6 m (1st and 2nd half respectively) (P = 0.009).

There were no significant differences in the mean displacement per 15 s between the three matches (P = 0.33) and the mean speed and the matches (P = 0.31) (Table 5.1). The mean displacement or the mean speed did not differ between half 1 and half 2 (P = 0.19 and P = 0.20 for displacement and speed respectively).

Table 5.2: Summary of Group Data for Playing time Displacement Covered per Half and per Minute, Mean Displacement and Mean Speeds during Game 1.

Player	Half of Match	Playing Time (min)	Total Displacement covered per half (m)	Displacement per minute ($m.min^{-1}$)	Mean Displacement (m) SD (Range)	Mean Speed ($m.s^{-1}$) SD (Range)
2	1st	35.0	2163	62	15.2 ± 10.5 (0.0 – 55.0)	1.02 ± 0.70 (0.0 – 3.66)
	2nd	35.0	2036	58	14.3 ± 8.7 (0.0 – 41.0)	0.96 ± 0.60 (0.0 – 2.73)
3	1st	35.0	1914	55	13.5 ± 8.2 (0.0 – 42.7)	0.90 ± 0.60 (0.0 – 2.85)
	2nd	28.5 +	1739	61	15.0 ± 8.2 (0.0 – 44.5)	1.00 ± 0.57 (0.0 – 2.96)
4	1st	31.3	2388	76	18.8 ± 10.4 (0.0 – 49.7)	1.25 ± 0.69 (0.0 – 3.31)
	2nd	35.0	2444	70	17.2 ± 11.2 (1.1 – 53.2)	1.15 ± 0.75 (0.1 – 3.55)
5	1st	20.0 *	1438	72	18.0 ± 11.1 (0.0 – 45.5)	1.20 ± 0.74 (0.0 – 3.03)
	2nd	3.3 *	189	58	14.5 ± 7.7 (7.0 – 35.4)	0.97 ± 0.51 (0.5 – 2.36)
6	1st	35.0	2148	61	15.1 ± 9.5 (0.0 – 56.7)	1.00 ± 0.64 (0.0 – 3.78)
	2nd	35.0	2269	65	16.0 ± 10.0 (0.0 – 45.2)	1.07 ± 0.69 (0.0 – 3.01)
7	1st	35.0	2508	72	17.7 ± 10.6 (0.0 – 55.7)	1.18 ± 0.71 (0.0 – 3.71)
	2nd	35.0	2365	68	16.7 ± 11.1 (0.0 – 61.3)	1.11 ± 0.74 (0.0 – 4.08)
8	1st	35.0	2311	66	16.3 ± 10.6 (0.0 – 59.5)	1.09 ± 0.71 (0.0 – 3.97)
	2nd	35.0	2438	70	17.2 ± 10.3 (0.0 – 50.0)	1.15 ± 0.69 (0.0 – 3.34)
9	1st	35.0	2486	71	17.5 ± 11.0 (0.0 – 54.3)	1.17 ± 0.73 (0.0 – 3.62)
	2nd	35.0	2133	61	15.0 ± 9.9 (0.0 – 42.0)	1.00 ± 0.66 (0.0 – 2.80)
11	1st	35.0	1738	50	12.2 ± 8.7 (0.0 – 51.1)	0.82 ± 0.58 (0.0 – 3.41)
	2nd	35.0	2102	60	14.8 ± 10.9 (0.0 – 55.0)	0.99 ± 0.72 (0.0 – 3.66)
13	1st	18.0	1306	73	17.6 ± 10.9 (0.0 – 55.3)	1.17 ± 0.72 (0.0 – 3.69)
	2nd	32.8	2016	66	16.3 ± 11.7 (1.4 – 47.6)	1.08 ± 0.78 (0.1 – 3.17)
14	1st	35.0	2293	66	16.2 ± 9.8 (0.0 – 58.5)	1.08 ± 0.65 (0.0 – 3.90)
	2nd	35.0	2231	64	15.7 ± 9.6 (0.0 – 50.8)	1.05 ± 0.64 (0.0 – 3.38)

*Indicates player suffered injury in Game 1 which affected performance and all subsequent data. + Indicates player sent off.

Table 5.3: Summary of Group Data for Playing time Displacement Covered per Half and per Minute, Mean Displacement and Mean Speeds during Game 2.

Player	Half of Match	Playing Time (min)	Total Displacement covered per half (m)	Displacement per minute ($m.min^{-1}$)	Mean Displacement (m) SD (Range)	Mean Speed ($m.s^{-1}$) SD (Range)
2	1st	31.8	1855	58	14.7 ± 9.5 (0.0 – 45.2)	0.98 ± 0.64 (0.0 – 3.01)
	2nd	35.0	1970	56	14.1 ± 8.5 (1.8 – 40.3)	0.94 ± 0.57 (0.1 – 2.68)
3	1st	28.0	1573	56	14.0 ± 8.9 (0.0 – 37.8)	0.94 ± 0.60 (0.0 – 2.52)
	2nd	35.0	1541	44	11.0 ± 7.2 (0.0 – 39.0)	0.73 ± 0.48 (0.0 – 2.60)
4	1st	21.8	1440	66	16.6 ± 11.0 (2.8 – 53.6)	1.10 ± 0.73 (0.2 – 3.57)
	2nd	35.0	1998	57	14.3 ± 9.7 (1.1 – 57.4)	0.95 ± 0.65 (0.1 – 3.83)
5	1st	35.0	2283	63	15.9 ± 10.9 (0.0 – 43.4)	1.06 ± 0.73 (0.0 – 2.89)
	2nd	31.8	2032	64	16.0 ± 10.9 (0.0 – 63.0)	1.07 ± 0.73 (0.0 – 4.20)
6	1st	35.0	2178	61	15.1 ± 10.1 (0.0 – 52.2)	1.00 ± 0.67 (0.0 – 3.48)
	2nd	31.0	1847	60	14.9 ± 9.1 (0.7 – 43.4)	0.99 ± 0.61 (0.1 – 2.89)
7	1st	35.0	2196	61	15.3 ± 9.4 (0.7 – 49.7)	1.02 ± 0.62 (0.1 – 3.31)
	2nd	30.3	1747	58	14.3 ± 9.3 (0.0 – 52.9)	0.96 ± 0.64 (0.0 – 3.52)
8	1st	35.0	1964	56	13.6 ± 10.4 (0.0 – 56.0)	0.91 ± 0.69 (0.0 – 3.73)
	2nd	30.5	1566	51	12.7 ± 9.0 (0.0 – 41.7)	0.85 ± 0.60 (0.0 – 2.78)
9	1st	35.0	2149	61	14.9 ± 10.2 (0.7 – 43.4)	0.99 ± 0.68 (0.1 – 2.89)
	2nd	25.5	1573	62	15.3 ± 10.8 (1.4 – 47.6)	1.00 ± 0.72 (0.1 – 3.17)
11	1st	35.0	2024	58	14.1 ± 8.6 (0.7 – 47.3)	0.94 ± 0.57 (0.1 – 3.15)
	2nd	29.8	1478	50	12.3 ± 8.2 (1.1 – 40.3)	0.82 ± 0.55 (0.1 – 2.68)
13	1st	26.0	1382	53	13.0 ± 9.5 (1.1 – 38.0)	0.88 ± 0.63 (0.1 – 2.50)
	2nd	30.5	1654	53	13.4 ± 9.4 (1.8 – 45.5)	0.89 ± 0.62 (0.1 – 3.03)
14	1st	35.0	2136	61	14.8 ± 9.1 (1.4 – 48.3)	0.99 ± 0.61 (0.1 – 3.22)
	2nd	32.0	1809	57	14.1 ± 8.4 (1.8 – 49.7)	0.94 ± 0.56 (0.1 – 3.31)

Table 5.4: Summary of Group Data for Playing time, Displacement Covered per Half and per Minute, Mean Displacement and Mean Speeds during Game 3.

Player	Half of Match	Playing Time (min)	Total Displacement covered per half (m)	Displacement per minute ($m.min^{-1}$)	Mean Displacement (m) SD (Range)	Mean Speed ($m.s^{-1}$) SD (Range)
2	1st	35.0	2027	58	14.5 ± 9.4 (2.5 – 44.1)	0.97 ± 0.62 (0.2 – 2.94)
	2nd	28.0	1631	58	14.6 ± 11.1 (1.4 – 53.6)	0.97 ± 0.74 (0.1 – 3.57)
3	1st	35.0	1961	56	14.0 ± 10.0 (0.0 – 48.3)	0.93 ± 0.66 (0.0 – 3.22)
	2nd	35.0	1830	52	13.1 ± 8.2 (0.0 – 39.9)	0.87 ± 0.55 (0.0 – 2.66)
4	1st	25.0	1750	70	17.2 ± 11.3 (1.8 – 53.2)	1.14 ± 0.75 (0.1 – 3.55)
	2nd	26.0	1454	56	14.0 ± 10.4 (1.1 – 47.3)	0.93 ± 0.70 (0.1 – 3.15)
5	1st	35.0	2241	65	16.0 ± 11.0 (0.0 – 49.7)	1.07 ± 0.73 (0.0 – 3.31)
	2nd	35.0	2296	66	16.4 ± 10.3 (0.0 – 47.3)	1.09 ± 0.69 (0.0 – 3.15)
6	1st	35.0	1998	57	14.3 ± 9.4 (1.8 – 60.6)	0.95 ± 0.63 (0.1 – 4.04)
	2nd	30.8	1941	63	15.8 ± 9.7 (1.1 – 73.9)	1.05 ± 0.65 (0.1 – 4.92)
7	1st	30.0	1916	64	16.0 ± 11.1 (0.0 – 58.1)	1.06 ± 0.74 (0.0 – 3.87)
	2nd	35.0	2201	63	15.7 ± 10.6 (0.0 – 66.2)	1.05 ± 0.71 (0.0 – 4.41)
8	1st	35.0	2130	61	15.2 ± 10.5 (0.0 – 45.5)	1.02 ± 0.70 (0.0 – 3.03)
	2nd	35.0	2041	58	14.6 ± 10.0 (0.0 – 62.0)	0.97 ± 0.67 (0.0 – 4.13)
9	1st	35.0	2255	64	16.1 ± 9.2 (0.0 – 40.3)	1.07 ± 0.61 (0.0 – 2.68)
	2nd	35.0	1837	53	13.1 ± 9.8 (0.0 – 49.7)	0.88 ± 0.65 (0.0 – 3.31)
11	1st	23.8	1337	56	14.2 ± 8.6 (3.5 – 43.8)	0.95 ± 0.57 (0.2 – 2.92)
	2nd	29.5	1649	56	14.0 ± 9.9 (0.0 – 42.4)	0.93 ± 0.66 (0.0 – 2.82)
13	1st	25.3	1411	56	14.0 ± 9.8 (2.1 – 60.9)	0.93 ± 0.65 (0.1 – 4.06)
	2nd	25.3	1420	56	14.1 ± 10.1 (1.1 – 60.2)	0.94 ± 0.67 (0.1 – 4.01)
14	1st	35.0	2228	64	15.9 ± 9.2 (1.1 – 52.5)	1.06 ± 0.61 (0.1 – 3.50)
	2nd	34.0	1870	55	13.8 ± 8.7 (0.0 – 45.9)	0.92 ± 0.58 (0.0 – 3.06)

Table 5.5 : Summary of Mean Playing Time, Total Displacement Covered per Half and per Minute, Mean Displacement, Mean Speed during the three Games.

Player	Mean Playing Time per half (min)	Mean Total Displacement covered per half (m) (± SD)	Displacement per minute ($m.min^{-1}$)	Mean Displacement (m) (SD) (Range)	Mean Speed ($m.s^{-1}$) (SD) (Range)
2	33.3 ± 2.6	1947 ± 184	59 ± 2	14.6 ± 0.4 (0.9 – 46.5)	0.97 ± 0.03 (0.06 – 3.10)
3	32.8 ± 3.2	1760 ± 175	54 ± 6	13.4 ± 1.4 (0.0 – 42.0)	0.90 ± 0.09 (0.01 – 2.80)
4	29.0 ± 5.1	1912 ± 442	66 ± 8	16.3 ± 1.9 (1.3 – 52.4)	1.09 ± 0.12 (0.15 – 3.49)
5	26.6 ± 11.7 *	1747 ± 829	65 ± 4	16.1 ± 1.1 (1.2 – 47.4)	1.08 ± 0.07 (0.00 – 3.16)
6	33.6 ± 1.9	2064 ± 160	61 ± 3	15.2 ± 0.6 (0.6 – 55.3)	1.01 ± 0.04 (0.04 – 3.69)
7	33.4 ± 2.3	2155 ± 281	64 ± 5	15.9 ± 1.1 (0.1 – 57.3)	1.06 ± 0.08 (0.01 – 3.82)
8	34.2 ± 1.7	2075 ± 304	60 ± 7	14.9 ± 1.6 (0.0 – 52.4)	1.00 ± 0.11 (0.00 – 3.50)
9	33.4 ± 3.5	2072 ± 322	62 ± 6	15.3 ± 1.4 (0.4 – 46.2)	1.02 ± 0.10 (0.02 – 3.08)
11	31.4 ± 4.2	1721 ± 300	55 ± 4	13.6 ± 1.1 (.09 – 46.6)	0.91 ± 0.07 (0.06 – 3.11)
13	26.3 ± 4.7	1532 ± 264	60 ± 8	13.0 ± 1.9 (1.2 – 51.1)	0.87 ± 0.13 (0.08 – 3.41)
14	34.4 ± 1.1	2094 ± 205	61 ± 4	15.1 ± 1.0 (0.7 – 50.9)	1.01 ± 0.07 (0.05 – 3.40)
Mean	31.7 min ± 5.7	1916 ± 385	61± 6	14.9 ±1.6	0.99 ± .011

* Indicates player suffered injury in Game 1 which affected performance and all subsequent data.

The mean heart rate recorded for game 1(176 ± 5 beats.min^{-1}) was significantly higher than games 2 (162 ± 5 beats.min^{-1}) and 3 (166 ± 4 beats.min^{-1}) (P = 0.008 and P = 0.04 respectively). The heart rate was higher in the first half of all three matches (171 ± 7 beats.min^{-1} vs. 165 ± 9 beats.min^{-1}) compared to the 2nd half (P=0.03) (Figure 5.6).

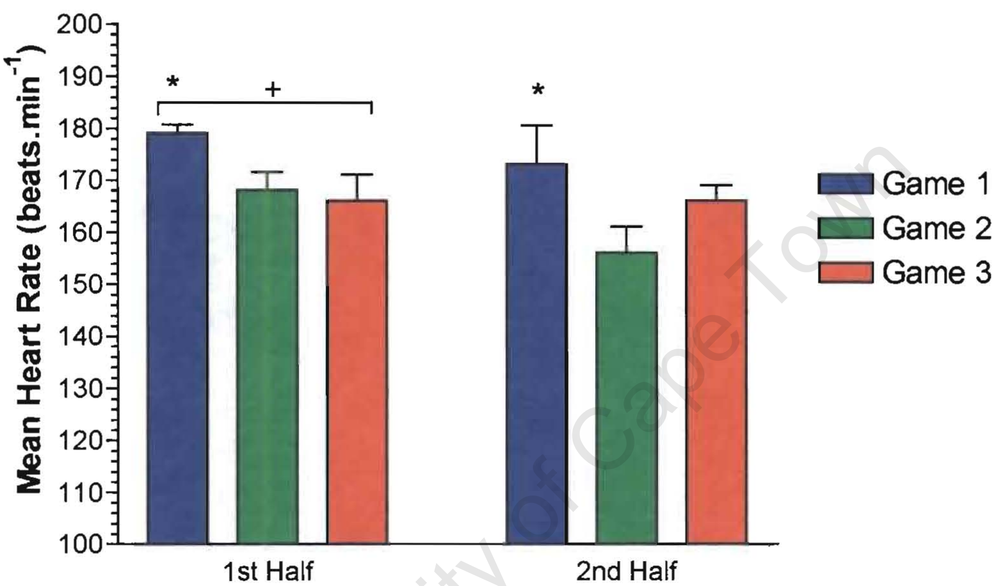

Figure 5.6: Mean Heart Rate (beats.min^{-1}) recorded for 3 players during the 3 League Games.

* represents significant difference between Game 1 and Game 2 and 3 (P<0.05).
\+ represents significant difference between the 1st Half and the 2nd Half (P<0.05).

The amount of time spent standing was 1.5 ± 0.31%, walking 82.3 ± 2.12 % jogging 13.7 ± 1.59 %, cruising 1.86 ± 0.44 % and sprinting 0.69 ± 0.06 % (Figure 5.7). The mean amount of time spent in low-intensity activities was 97.4 % and the % time spent in high-intensity activities was 2.6 %. There were no significant differences between the % time spent in the different movement categories and the 3 different matches. This is summarised in Figure 5.7.

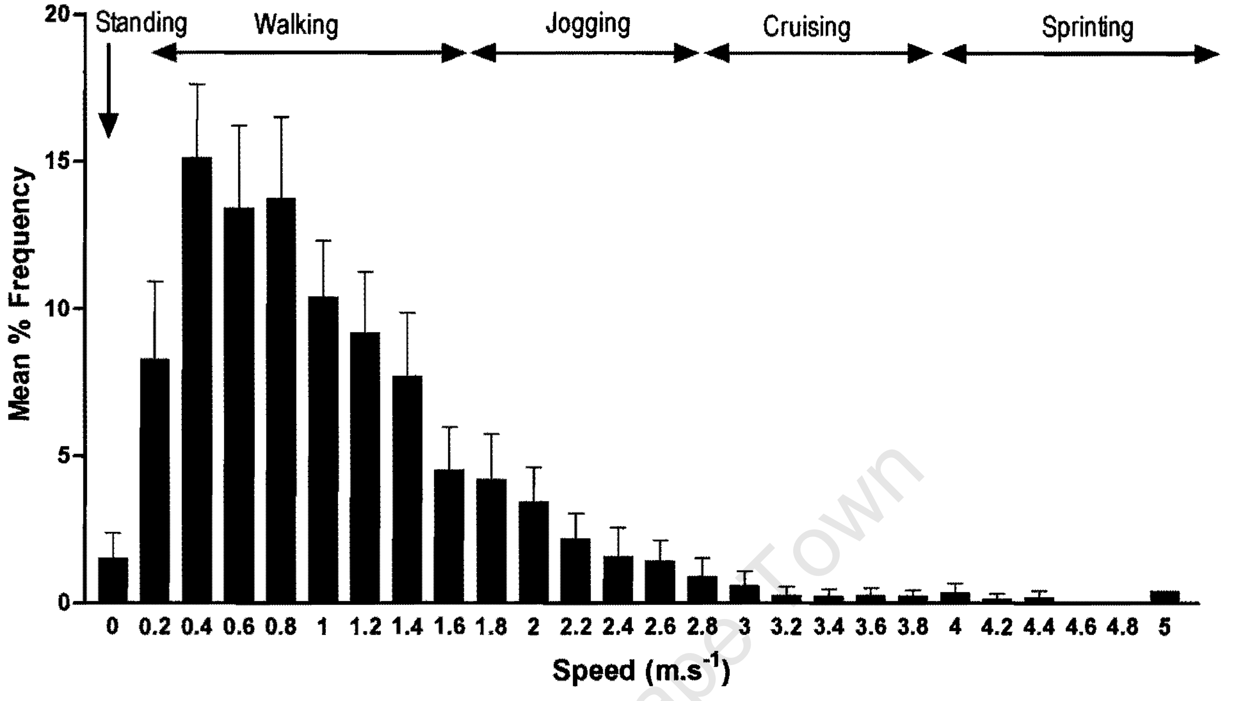

Figure 5.7: % Mean time spent at different speeds during hockey matches.

The mean subjective data are shown in Table 5.6. There was a significant difference in the subjective perception of difficulty between the matches (P = 0.0001). Match 1 (4.5 ± 0.5) was perceived to be harder than game 2 (1.8 ± 1.0) and game 3 (2.8 ± 1.0) in terms of game difficulty. Game 3 was perceived to be more difficult than game 2 (P = 0.04). The preparation before the games and the subjective feeling immediately prior to the games were not significantly different for the three games (P = 0.67 and P = 0.09 respectively). (Table 5.6).

The players perceived that they had to run a greater distance in game 1 (3.5 ± 1.1) than game 2 (2.4 ± 1.0) ($P = 0.04$) and game 3 (2.3 ± 0.9) ($P = 0.02$). This perception is also reflected in the physical data recorded during the three games (Figure 5.5).

There was a significant difference observed between the perceived quantity of sprinting and the different matches ($P = 0.013$). The players also perceived that they sprinted significantly further in game 1 than in the other two games.

Table 5.6: Mean Subjective Data recorded from the players (n = 11) after each match.

	Game 1	**Game 2**	**Game 3**
Game Difficulty *	4.5 ± 0.5	1.8 ± 1.0	2.8 ± 1.0
Pre Game Feelings	3.3 ± 0.9	3.7 ± 0.9	2.9 ± 0.7
Quantity of Running **	3.5 ± 1.1	2.4 ± 1.0	2.3 ± 0.9
Quantity of Sprinting ***	3.6 ± 1.1	2.5 ± 1.0	2.5 ± 0.8
Pre Game Preparation	3.6 ± 0.7	3.5 ± 0.7	3.4 ± 0.8

* Game 1 vs. Game 2
Game 1 vs. Game 3
Game 2 vs. Game 3.

** Game 1 vs. Game 2
Game 1 vs. Game 3

*** Game 1 vs. Game 2

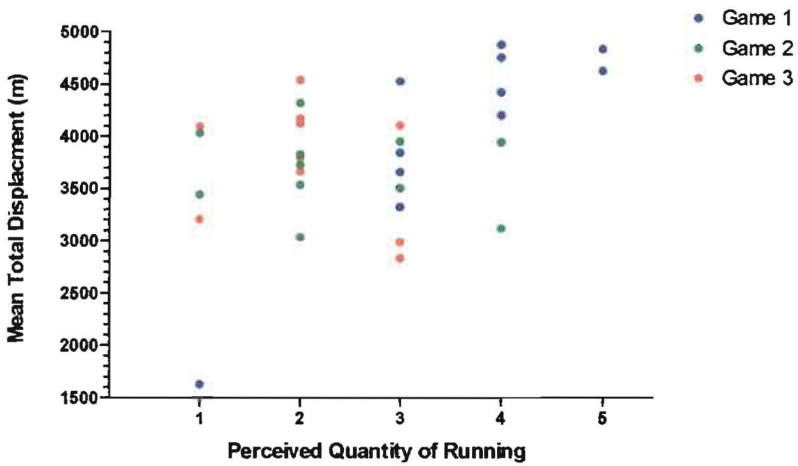

Figure 5.8a: Comparison of the Perceived Quantity of Running and the Mean Total Displacment covered (m) for the 3 different Games.

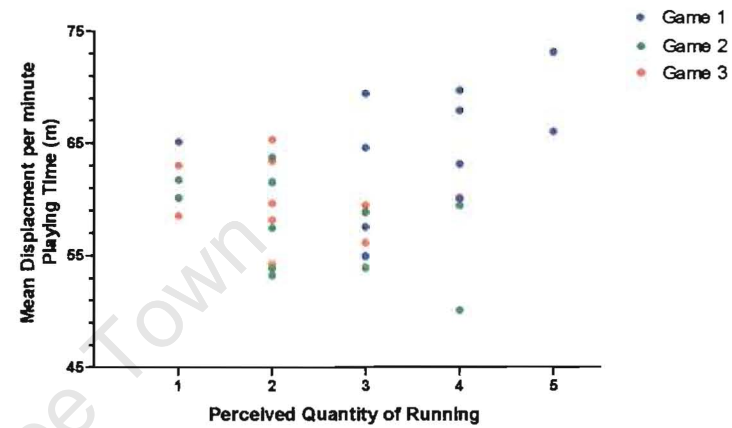

Figure 5.8b: Comparison of the Perceived Quantity of Running and the Mean Displacment per minute Playing Time ($m.min^{-1}$) for the 3 different Games.

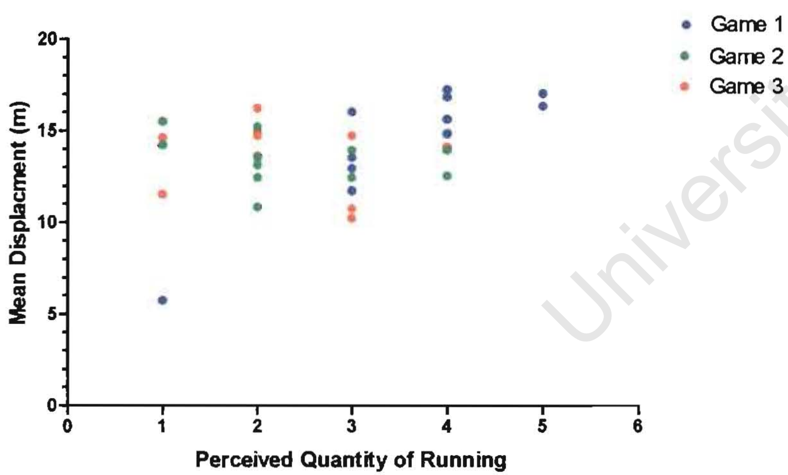

Figure 5.8c: Comparison of the Perceived Quantity of Running and the Mean Displacment covered (m) for the 3 different Games.

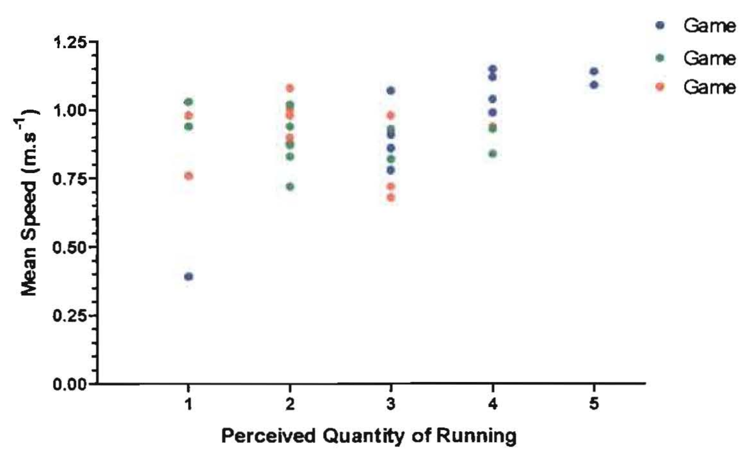

Figure 5.8d: Comparison of the Perceived Quantity of Running and the Mean Speed ($m.s^{-1}$) for the 3 different Games.

There was a trend for the mean subjective responses to reflect the mean physical data collected during the matches (Tables 5.7, 5.8 and Figures 5.8)

Table 5.7: A Summary of the Comparisons between Mean Subjective Responses and Mean Physical Data (Values for Player 5 game 1 not included as player was injured) (n=11).

		Mean Total Displacement (m)		Mean Displacement per minute ($m.min^{-1}$)		Mean Displacement per 15 s (m)		Mean Speed ($m.s^{-1}$)	
		N		n		N		N	
Game Difficulty	1	6	3739 ± 483	6	58 ± 4	6	13.8 ± 1.8	6	0.92 ± 0.12
	2	7	3971 ± 337	7	60 ± 4	7	14.1 ± 1.3	7	0.95 ± 0.09
	3	5	3350 ± 353	5	56 ± 5	5	12.3 ± 1.2	5	0.82 ± 0.08
	4	9	3868 ± 567	9	61 ± 5	9	13.7 ± 2.0	9	0.92 ± 0.09
	5	5	4609 ± 271	6	66 ± 5	5	16.3 ± 1.0	5	1.09 ± 0.06
Quantity of Running	1	4	3690 ± 437	5	62 ± 3	5	12.3 ± 4.0	5	0.82 ± 0.26
	2	10	3870 ± 432	10	59 ± 4	10	13.8 ± 1.6	10	0.92 ± 0.10
	3	9	3633 ± 539	9	59 ± 5	9	12.9 ± 1.9	9	0.86 ± 0.13
	4	7	4176 ± 593	7	62 ± 6	7	15.0 ± 1.7	7	1.00 ± 0.11
	5	2	4725 ± 151	2	70 ± 5	2	16.7 ± 0.5	2	1.12 ± 0.04
Quantity of Sprinting	1	2	4059 ± 47	3	61 ± 3	3	11.5 ± 5.0	3	0.77 ± 0.33
	2	10	3743 ± 481	10	60 ± 4	10	13.6 ± 1.8	10	0.91 ± 0.12
	3	11	3734 ± 485	11	58 ± 4	11	13.3 ± 1.7	11	0.89 ± 0.11
	4	6	4277 ± 556	6	65 ± 5	6	15.1 ± 2.0	6	1.01 ± 0.13
	5	3	4188 ± 936	3	63 ± 12	3	15.3 ± 2.4	3	1.02 ± 0.16

n - denotes number of subjects with the subjective score

Table 5.7 reflects the mean displacement data against the specific subjective response score. For example, the mean total displacement value that was perceived to rate 3 on the subjective questionnaire was 3350 ± 353 m. The Spearman's rank order correlation for the subjective data and the physical data showed that there were only significant correlations (R = 0.9) between total displacement and quantity of running and the mean speed and the quantity of running (Table 5.8)

Table 5.8 Spearman's rank order correlations for mean subjective responses and mean physical data (values for player 5 game 1 not included as player was injured) (n = 11).

	Mean Total Displacement (m)	**Mean Displacement per minute ($m.min^{-1}$)**	**Mean Displacement (m)**	**Mean Speed ($m.s^{-1}$)**
	R =	R =	R =	R =
Game Difficulty	0.50	0.70	0.20	0.36
Quantity of Running	**0.90 ***	0.53	0.60	**0.90 ***
Quantity of Sprinting	0.50	0.50	0.60	0.60

* Denotes significant correlation (P< 0.05)

5.5 DISCUSSION

The purpose of this study was to quantify the movement of top club level field hockey players covered during competition under modern rules (1999), thus adding to and updating the database of time-motion studies of hockey. The scarcity of studies dedicated to enhancing the understanding of team sports in general, but field hockey specifically, limits the influence that sports science can have on improving performance (Hawley and Burke, 1998).

The main finding of this study was that female field hockey players covered on average 3914 ± 552 m (range 3064 to 4210 m) in 63.3 ± 9.5 minutes of playing time (less than 70 minutes because of the continuous substitution ruling) or an average of 61 ± 6 m per minute. The distances reported in the literature for field hockey players are much higher (5610 m, Wein, 1981) than those found in this study. However, comparisons between the data are not possible because the standards of the matches are different (club vs. International), the matches were played under a different set of rules and this study measured female players whereas the other study reported on male players. In addition the methodology in this study was not able to measure the distance covered by each player. Therefore, zig-zag or runs that involved backwards and forwards movements would not be accurately reflected in the data. In addition the repeatability of the measurement technique needs to be improved, as a measurement error of 11.5% found in this study is too high for this to be considered a precise technique.

Female soccer players covered 8471 $\pm$ 2200 m (Davis and Brewer, 1993) during league matches. It is unclear whether the greater distance of the soccer players was due to the difference in size of the playing field, the rules governing the two sports or other factors. There are, however, similarities between mean heart rates between the 2 different sports with soccer players averaging 175 $\pm$ 10 beats.min^{-1} (Davis and Brewer, 1993) and hockey players averaging 168 $\pm$ 5 beats.min^{-1} in this study and 171 $\pm$ 7 beats.min^{-1} (Lothian and Farrally, 1994).

The mean displacement 14.9 $\pm$ 1.6 m per 15 seconds with values ranging from 0.0 m to 66 m. The mean speed observed was 0.99 $\pm$ 0.11 m.s^{-1} and ranged from 0.0 to 4.92 m.s^{-1}. These values indicate that most of the game is spent in low-intensity exercise (Figure 5.7). This is further illustrated by the amount of time spent during low intensity activities (standing, walking and jogging), 97.4 %, which shows that the majority of the 15-second intervals were spent at speeds ranging from 0.2 to 1.4 $m.s^{-1}$. This relatively low average intensity is a common finding to any time-motion analysis of team sports (Reilly and Thomas, 1976; Mayhew and Wenger, 1985; Docherty et al., 1988; McInnes et al., 1995 and Lothian and Farrally, 1994). The amount of time spent at differing exercise intensities performing discrete movements (standing, walking, running and sprinting) was not determined during this study because displacements were recorded every 15 seconds.

There were significant differences between the three games in terms of total displacement, displacement per minute playing time, heart rate and subjective responses, with the exception of the pre-match data. The opponents for game 1 were the eventual league winners and so it is logical to assume this was the hardest of the 3 matches. The subjective data confirmed that the players had to work harder in this game than in the other 2 games, which were against lesser opposition (i.e. the other 2 teams finished below the team being investigated in this study in the final league standings). These findings are supported by studies on soccer (Ekblom, 1986 and Bangsbo et al, 1991) that have documented differences in the distances covered between matches. The distance the players cover in a match is determined by several factors including the quality of the opponents, tactics employed during the game (by either team) and the importance of the match. Bangsbo et al., (1991) suggested that the players are not fully utilising their physical capacity during each match because there was a large intra-individual variation in the distance covered between matches. This suggestion is supported by data in this study, where against lesser opposition the subjects did not appear to extend themselves fully yet still won both matches.

The subjective ratings of the pre-match preparation were the same for each of the three matches. Therefore, the different results for the matches could not be due, according to the players, to different preparation or in pre-match psychological factors.

The mean total displacement and mean displacement per minute playing time were found to vary by 4% between the 1st half and the 2nd half. These data are similar to that found by Bangsbo et al. (1991). Their study established that a 5% decrease in fitness performance occurred during the second half of the match when compared to the first. The data for game 1 in this study suggests that the decrease in performance is not a fatigue response because there is actually an increase in physical performance during the 2nd half of the match. This finding suggests that factors other than fatigue affected second half performance in the other two matches. The subjective ratings of pre match preparation were the same for each of the three games. Therefore, it may be suggested that a change in playing tactics caused the change in physical performance during the 2nd half of the match.

In summary, the data from this study have quantified the movements that occur during the modern game of field hockey played by female club level players. The data from this study show that field hockey is played at a relatively low intensity and is randomly interspersed with periods of high intensity effort. The average displacement that the players covered in a match was just less than 4 kilometres and the average displacement covered during each 15-second period was 15 m. This indicated that training sessions should be comprised of low-intensity effort and be frequently interspersed with periods of high intensity activity. All of this information needs to be recognised and implemented into a training programme if hockey players are to structure their training as effectively as possible.

This time-motion study has quantified the movements that occur during the 'modern' game of field hockey. It is now possible using this information to evaluate the performance parameters of fitness tests with actual match data. Without this direct comparison it is not possible to accurately determine the extent of the usefulness of data that are generated during these tests. The next chapter discusses the reliability of the 5-m Multiple Shuttle Test for the assessment of the fitness of field hockey players.

CHAPTER 6

RELIABILITY OF A 5-M MULTIPLE SHUTTLE TEST

6.1 INTRODUCTION

Fitness testing of athletes participating in team sports is becoming more commonplace with the increased awareness of the benefits attained from a scientific approach to training.

Squads of team sport players are regularly having their fitness levels evaluated either as part of their regular season or during the build up to a major championship or competition. With regular assessments comes the demand for reliable testing procedures that can detect small changes in fitness levels. This was discussed in detail in Chapter 4.

A maximal shuttle test adopted by the Welsh Rugby Union and modified by the Sports Science Institute of South Africa is used to determine players' 'match-related fitness' (Pendleton, 1997). The test is designed to assess short duration, high-intensity work that is frequently cited as a characteristic of team sports (Reilly and Borrie, 1992; Dawson et al., 1993 and Fitzsimons et al., 1993).

A reliability study using the shuttle test protocol (n =15 rugby players and boxers) showed that the test was reproducible (mean R = 0.89 $\pm$ 0.03) for the 6 sprints (Pendleton, 1997). A modified version of this test requires that the subject touch the ground by the beacon with his/her hand rather than the foot as described in the original protocol (Pendleton, 1997). This subtle change to the protocol places different physical demands on the subject's acceleration and deceleration and anecdotal observations suggest that the test is more sport-specific for field hockey than the original test. The reliability of the modified protocol had not been evaluated. Accordingly, the aim of this study was to establish whether the modified version of the 5-m Multiple Shuttle test is a reliable test for assessing fitness and physical performance in female field hockey players. The validity of this test will be established in the next chapter.

6.2 METHODS

Subjects

Female field hockey players (n=30) volunteered to participate in the study. Six subjects withdrew from the study through illness or injury and another subject was not able to complete all six shuttles during test one so her data were excluded. The remaining subjects (n=23; aged 22.8 ± 3.7 years (mean ± standard deviation), height 165.9 ± 4.1 cm, mass 63.0 ± 8.9 kg and body fat 24.5 ± 4.8 %) completed 4 repeats of the 5-m multiple shuttle test within a 4 week period during which their physical training remained consistent. The minimum period between the tests was 2 days and the maximum was 7 days. All subjects played for a club in the Western Cape Grand Challenge hockey league and some of the subjects had played at provincial level (U 21 years or senior) or above (n = 11). Testing occurred on a rubberised indoor surface at the Sports Science Institute of South Africa.

Before testing, all subjects completed an informed consent form, medical questionnaire, an outline of their hockey training and history, and training records (the latter being completed each time before a testing session). The study was approved by the Ethics and Research Committee of the Faculty of Health Sciences of the University of Cape Town.

6.2.1 Experimental Design

All tests were administered at the same time of day (within ± 2 hours) and the subjects attended the laboratory with instructions to abstain from caffeine intake for 3 hours prior to testing and to perform the same intensity and duration of training the day before and on the day of testing before each session. Body weight, height and body fat (sum of 4 skin-folds; triceps, biceps, subscapula and supra-iliac as described by Durnin and Womersley, 1974) were measured at the first session.

Each subject was allowed 10 minutes to complete her own specific warm-up and 2 submaximal repeats of the modified 5-m Multiple Shuttle test (5-m MST). Subjects were then fitted with a heart rate transmitter and recorder (Polar Vantage XL, Polar Electro, Finland) to assess heart rate changes every 5 seconds of the test.

Six beacons were placed 5 m apart in a straight line to cover a total distance of 25 m. Subjects were instructed to perform maximally throughout the whole test. Each subject started the test in line with the first beacon (A), and upon an auditory signal sprinted 5 m to a second beacon B, touched the ground adjacent to the beacon with their hand and returned back to A touching down on the ground adjacent to the beacon with the hand again.

The subject then sprinted 10 m to the third beacon C, and back to A etc. until an exercise period of 30 seconds had elapsed. The distance covered by each subject was recorded to the nearest 2.5 m during each 30-second shuttle. Thereafter there was a 35-second recovery during which the subjects walked back to beacon A and indicated their rating of perceived exertion (RPE) on the Borg Scale (Borg, 1973). This 30-second shuttle, followed by 35-second rest period was performed 6 times. This protocol was defined as one test. The requisite 4 tests were performed within a 4 week period. Subjects were only given feedback on their performance in the test after they had completed 4 tests.

The data recorded during the tests were further categorised (Pendleton, 1997 and NCF, 1995):

Peak distance - the greatest distance covered during a 30 second shuttle.

Total distance - the total distance covered during the 6 x 30 second shuttles.

Delta distance - the difference between the longest and shortest shuttle distance.

Fatigue Index calculated according to the equation below:

$$\frac{\left[\frac{(\text{Shuttle 1} + \text{Shuttle 2})}{2} - \frac{(\text{Shuttle 5} + \text{Shuttle 6})}{2}\right]}{\frac{(\text{Shuttle 1} + \text{Shuttle 2})}{2}} \times 100$$

Where:

Shuttle 1 and 2 are the longest 2 sprints.

Shuttle 5 and 6 are the shortest 2 sprints.

6.3 STATISTICAL ANALYSES.

Data are expressed as mean ± standard deviation. A two-way (shuttle x test) analysis of variance with repeated measures (ANOVA) was used to determine differences in distances covered during each sprint. A Scheffe's post-hoc test was used to identify specific differences when the main effect was significant ($P < 0.05$). ANOVA was also performed for the total and peak distances covered during the shuttles and for the delta distance and fatigue index calculated post-test.

The coefficient of variation was calculated for all variables (distance covered for each shuttle, total, peak and delta distances, fatigue index and the heart rates and RPE recorded during each shuttle). The 95 % confidence intervals were calculated for all of the data.

An intraclass correlation coefficient was also determined for the total, peak and delta distances, the fatigue index values, mean heart rate and RPE. The intraclass correlation coefficient defined the repeated measures data on the same variable. The 95% confidence intervals were determined for each ICC using the programme of Hopkins (2002). As a general rule the intraclass correlation coefficient above $R= 0.90$ is defined as high and shows a consistency of measurements across trials (Vincent, 1995)

6.4 RESULTS

There were no significant differences in the peak and total distance and between the 4 tests (P=0.12 and P=0.99 respectively) (Table 6.1). There were, however, significant differences between the delta distances (P= 0.001) where the delta distance in the first test was greater than the other three (P=0.031; P= 0.002; P=0.006; comparison of test 1 vs. 2; 1 vs. 3 and 1 vs. 4 respectively) (Table 6.1). There was a trend for the fatigue index in test 1 to be generally higher than the other 3 tests (Table 6.1). The differences were only significant between the fatigue index in test 1 (11.6 ± 4.3 %) and test 3 (7.5 ± 3.8 %) (P = 0.012).

Table 6.1: Mean group data during the six shuttles over the 4 different testing sessions (± SD) (n = 23).

	Peak Distance (m)	Total Distance (m)	Delta Distance (m)	Fatigue Index (%)
Test 1	124.8 (± 7.9)	673.0 (± 44.8)	20.0 * (± 7.3)	11.6 # (± 4.3)
Test 2	122.1 (± 6.4)	676.6 (± 41.7)	14.2 (± 5.6)	8.5 (± 3.4)
Test 3	120.4 (± 5.4)	674.1 (± 39.5)	12.4 (± 6.5)	7.5 (± 3.8)
Test 4	120.7 (± 7.5)	675.7 (± 43.9)	13.2 (± 6.2)	8.4 (± 4.5)
Mean	122.0 (± 7.0)	674.9 (± 41.7)	15.0 (± 7.0)	9.0 (± 4.3)

* Test 1 vs Test 2 P = 0.031
Test 1 vs Test 3 P = 0.002
Test 1 vs Test 4 P = 0.006

Test 1 vs Test 3 P = 0.012

The intraclass correlation coefficient for the total, peak and delta distances and the fatigue index gave mixed results (total distance $R = 0.98$, peak distance $R = 0.86$, delta distance $R = 0.74$ and fatigue index $R = 0.74$)(Table 6.3). The 95% confidence intervals (95% CI) for the intraclass correlation coefficient (ICC) for the total distance (m), peak distance (m), delta distance (m) and fatigue index are; 0.96 – 0.99%, 0.76 – 0.93%, 0.58 - 0.86% and 0.58 – 0.86% respectively (Table 6.3). The 95% confidence intervals (95% CI) for the coefficient of variation for the total distance (m), peak distance (m), delta distance (m) and fatigue index are; 1.2 – 2.8%, 2.6 – 3.9%, 25.4 – 44.2% and 28.2 – 46.2% respectively.

The mean distance for each of the six shuttles decreased, (121.2 ± 7.5 m; 114.5 ± 7.5 m; 112.2 ± 7.5 m; 109.9 ± 7.9 m; 108.4 ± 8.1 m; 108.7 ± 8.3 m, $P= 0.0001$) similarly for each of the four testing sessions ($P = 0.99$) (Figure 6.1). The post hoc analysis showed that the results for shuttles 1,2 and 3 were significantly different from each other and significantly higher than shuttles 4,5 and 6 ($P < 0.01$). The last 3 shuttles, 4,5 and 6 were not significantly different from each other ($P > 0.05$).

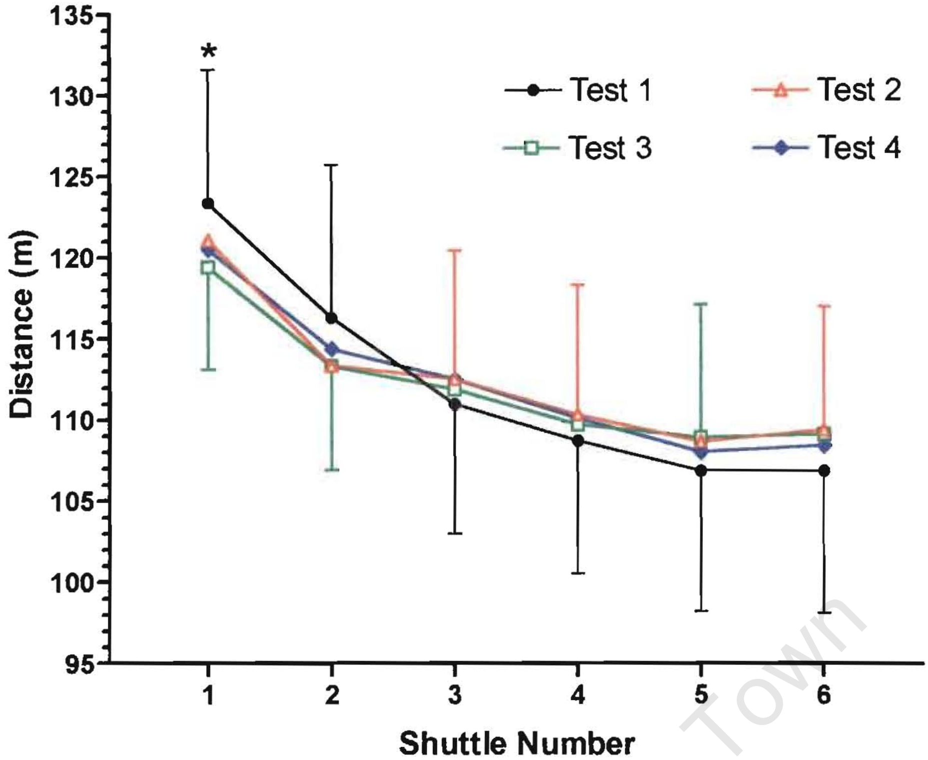

Figure 6.1: Mean Group data for the Distance (m) covered during a Test over the 4 different Sessions.

* represents significant differences between shuttles 1,2 and 3, from each other and from 4,5 and 6 ($P<0.01$).

The mean heart rate was similar for tests 1,2,3 and 4 (166.4 ± 11.6; 171.8 ± 8.6; 171.0 ± 8.7 and 171.6 ± 7.4 beats min^{-1} respectively) ($P = 0.42$). The mean heart rate for shuttle one (166.2 ± 11.9 beats min^{-1}) was significantly lower ($P = 0.001$) than the mean heart rate for the other five shuttles (177.9 ± 8.8; 179.1 ± 8.8; 179.2 ± 8.1; 178.6 ± 7.7 and 179.4 ± 7.8 beats min^{-1} respectively) (Figure 6.2). The intraclass coefficient for the mean heart rates ranged from $R = 0.65$ for shuttle 1 to $R = 0.97$ for shuttle 4 (shuttles 2,3,5 & 6 $R = 0.96$) (Table 6.4). The 95% confidence intervals (95% CI) for the ICC for heart rate are shown in Table 6.4.

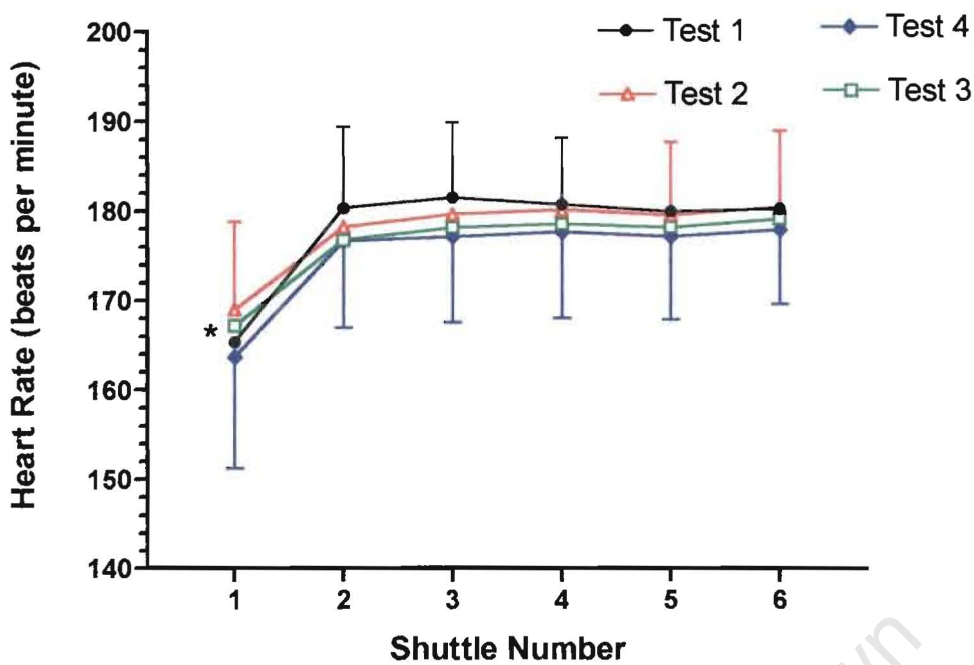

Figure 6.2: Mean Group data for the mean Heart Rate (beats per min^{-1}) recorded per shuttle during a test over the 4 testing sessions.

* represents significant difference between mean heart rate recorded for shuttle 1 and other 5.

The average RPE increased during each shuttle (Figure 6.3) (P = 0.001) with each of the 6 shuttles being rated progressively harder than the previous one. There were no differences in RPE between testing sessions (P = 0.095). The intraclass coefficient for RPE ranged from R = 0.85 for shuttle 1 to R = 0.91 for shuttle 3 (R = 0.86, 0.87, 0.90 & 0.90 for shuttles 2, 4, 5 and 6) (Table 6.4). The 95% confidence intervals (95% CI) for the ICC for RPE are shown in Table 6.4.

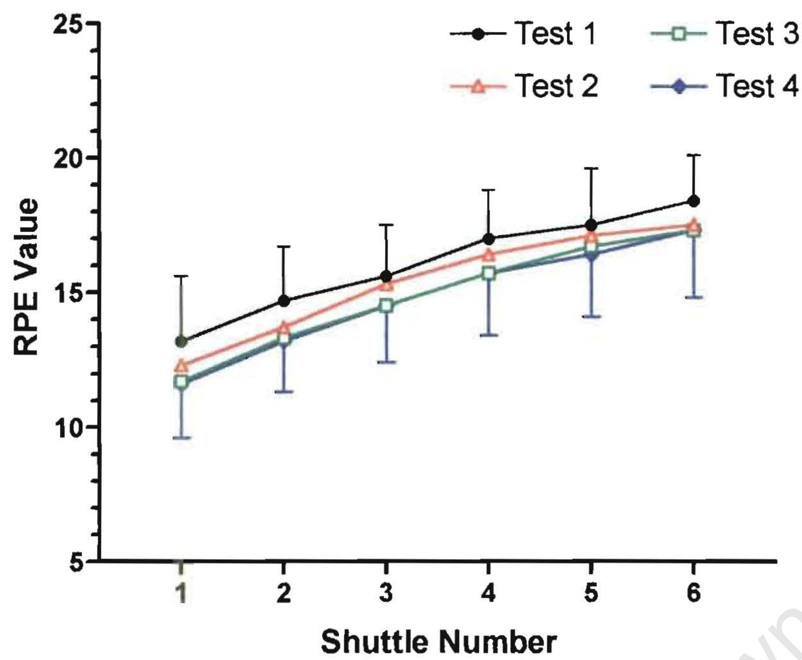

Figure 6.3 : Mean Group data for the RPE recorded during a test over the 4 different testing sessions.

The 95% CI calculated for the coefficient of variation for heart rates was relatively high for the first shuttle (3.2 – 6.2 %) but decreased to 1.2 – 2.0 % for shuttle 6 (Table 6.2). The 95% CI for RPE was highest for shuttle 1 (6.9 – 11.8 %) and lowest for shuttle 6 (3.8 – 8.3 %) (Table 6.2).

Table 6.2: Summary table of the 95% Confidence Intervals (CI) for the coefficient of variation (CV) for Distance covered during each shuttle, mean heart rate and RPE values recorded during the 5-m Multiple Shuttle Test (n = 23).

95% CI	Shuttle 1	Shuttle 2	Shuttle 3	Shuttle 4	Shuttle 5	Shuttle 6
Distance covered (m)	2.7 – 4.4	2.1 – 3.8	1.9 – 3.0	1.9 – 3.0	1.8 – 3.3	2.3 – 3.6
Mean Heart Rate	3.2 – 6.2	1.5 – 2.4	1.3 – 2.3	1.2 – 1.9	1.2 – 1.8	1.2 – 2.0
RPE	6.9 – 11.8	5.8 – 10.0	5.5 – 8.7	5.6 – 9.7	4.3 – 8.5	3.8 – 8.3

Table 6.3 Summary table of the Intraclass correlation coefficient and 95% Confidence Intervals (CI) for the Intraclass correlation coefficient (ICC) for total distance, peak distance, delta distance and fatigue index recorded during the 5-m Multiple Shuttle Test (n = 23).

	Total Distance	Peak Distance	Delta Distance	Fatigue Index
ICC (95%CI of ICC)	0.98 (0.96 – 0.99)	0.86 0.76 – 0.93)	0.74 (0.58 – 0.86)	0.74 (0.58 – 0.86)

Table 6.4 Summary table of the Intraclass correlation coefficient and 95% Confidence Intervals (CI) for the Intraclass correlation coefficient (ICC) for mean heart rate and RPE values during the 5-m Multiple Shuttle Test (n = 23).

ICC (95%CI of ICC)	Shuttle 1	Shuttle 2	Shuttle 3	Shuttle 4	Shuttle 5	Shuttle 6
Mean Heart Rate	0.65 (0.46-0.81)	0.96 (0.93-0.98)	0.96 (0.93-0.98)	0.97 (0.94-0.99)	0.96 (0.93-0.98)	0.96 (0.93-0.98)
RPE	0.85 (0.74-0.93)	0.86 (0.76-0.93)	0.91 (0.84-0.96)	0.87 (0.77-0.94)	0.90 (0.82-0.95)	0.90 (0.82-0.95)

6.5 DISCUSSION

The purpose of this study was to determine the reliability of a 5-m multiple shuttle test (5-m MST) that measures several of the sport-specific requirements of field hockey. In accordance with a demand that has arisen for the provision of physiological assessments, which have a proven validity and reliability in the context of a particular sport (British Association of Sport and Exercise Sciences (BASES), 1997).

The first finding was that the distance measurements with the most robust reliability were the total (R = 0.98) and peak distances (R = 0.86). Vincent (1995) stated that generally values above R= 0.90 are considered to have a high reliability and values from R= 0.80 to 0.89 a moderate, and below R=0.80 a low reliability for physiological data. Based on these criteria, it is reasonable to suggest that the total distance covered during the 5-m MST has a very high reliability and the peak distance a moderate level of reliability. The other factors, delta distance (R = 0.74) and fatigue index (R = 0.74) have a poor reliability and therefore should be used with caution.

The reliability coefficients from this study compare well with values attained from the evaluation of other field tests. Investigations into the 20-m multiple stage shuttle test, developed by Lèger and Lambert (1982), have reported a range of coefficients from R = 0.98 (Lèger and Lambert, 1982) to R = 0.73 (Mahoney, 1992). Pendleton (1997) evaluated a 5-m MST and reported intraclass correlation coefficients that ranged from R = 0.85 to R = 0.91 and from that concluded that the test was reliable. Reliability studies involving runners (Schabort et al., 1997) and rowers (Schabort et al., 1999) have established correlation coefficients of R = 0.90 (95 % CI of the coefficient of variation (CV) 1.8 – 4.0%) and R = 0.96 (95% CI of the CV 1.3 – 3.1 %) respectively. The data from this study (total distance and mean heart rates primarily) concur with the reliability studies previously published.

The relatively poor reliability of the delta distances and fatigue index suggests that the subjects adopted a pacing strategy after their first exposure to the test. This can be further illustrated by Figure 6.1 where the values recorded for test 1 are visually distinct from those of tests 2,3 and 4. This pacing or learning effect did not significantly alter overall performance of the 5-m MST because the total distance and mean heart rates did not vary with each testing session.

The high reliability recorded for the heart rates (R = 0.97) and the ratings of perceived exertion (RPE) (R = 0.92) indicates that the subjects' performed the test at the same relative intensity over each of the 4 testing sessions (Figures 6.2 and 6.3).

It is reasonable to assume that the 95% confidence intervals (95% CI) reported for the total and peak distance and mean heart rate (shuttles 2 – 6) (Table 6.2) indicate that this 5-m MST is sensitive enough to track major changes in fitness over time. Heart rate was the most sensitive physiological response in this study and it is therefore likely to track any small change in performance and is recommended for future testing. Future studies need to determine whether heart rate does indeed change as the state of training changes. It can be noted from this study that the heart rate data only stabilises between the second and third shuttles. To observe reliable heart rate data a minimum of three shuttles are required.

In summary, the field test examined in this study is currently used by coaches and fitness consultants to assess the fitness of athletes, who participate in team sports such as rugby, soccer and field hockey, that are characterised by short-duration high-intensity exercise bouts interspersed with recovery periods. It is also a practical test to implement on a regular basis because little equipment is required, several people can be evaluated at one time and the whole process (warm-up, test and warm-down) can be completed in 20 minutes.

This study shows that the mean heart rate and total distance components of the 5-m MST are the most reliable measurements of performance for female hockey players. In addition the relative perceived exertion response to the 5-m MST and the peak distance are reliable measurements and should be able to track changes in fitness. This finding will have to be confirmed in a future study. The delta distance and fatigue index are less reliable measurements, probably as a result of a learned pacing strategy, following the first test and should be interpreted with caution.

The reliability of the 5-m MST has been established in this study. The next Chapter aims to determine the validity of the test using both indirect and direct procedures.

CHAPTER 7

VALIDITY OF A 5-M MULTIPLE SHUTTLE TEST.

7.1 INTRODUCTION.

There is a tendency for fitness testing to move away from the laboratory tests that can only assess linear movements and are not sports specific towards the more representative field tests (Winkler, 1993). These field fitness tests need to be valid for the sports scientist to give the players and coaches any useful feedback after they have been assessed.

Validity can be determined in several ways according to the NCF (1995) (Chapter 4); logical (or face), criterion or construct validity. These categories of validation are important when trying to determine the usefulness of a fitness test. Unless direct comparisons can be made between the results obtained during a fitness test and the actual physical attributes (distances covered, speeds attained and so on.) of players during competitive matches, a certain amount of ambiguity will still remain about the results and subsequently how they can be interpreted and applied. Thus an additional validity category, direct validity was incorporated into this study.

One of the most frequently used fitness tests for team sport players is the 20-m Multiple Shuttle Test developed by Lèger and Lambert (1982). The validity of this test is questionable if it is used to evaluate fitness during immediate pre-season preparation or mid-season assessments (section 4.3.4). Another test that is frequently performed during training sessions and by the Sports Science Institute of South Africa during their fitness assessments of team sport players is a 5-m Multiple Shuttle test (5-m MST). On initial inspection this test appears to meet the criterion for logical validity. Limited time-motion studies are available for field hockey and therefore direct comparisons between fitness test results and physical match requirements are not possible for the 'modern' game of hockey.

The aims of this study are therefore four-fold. The first aim is to determine whether the 5-m MST has logical validity by comparing the components of the 5-m MST with the literature on team sports. The second aim is to determine whether the 5-m MST has criterion validity by comparing performance in this test to performance in the 40-m timed sprint and the 20-m multiple shuttle test (Ramsbottom et al., 1988). The 40-m sprint and the 20-m MST were used in this study to establish whether sprinting ability or endurance capacity was best related to performance of the 5-m MST. The third aim is to determine whether the 5-m MST has construct validity by comparing the performance in this test of provincial and club-level players. The fourth aim is to determine whether the 5-m MST has direct validity by comparing performance during competitive field hockey matches, from a time-motion study, to performance in the 5-m MST.

7.2 METHODS.

Logical validity was determined using literature on team sports and field hockey specifically (Aggiss, 1985; Aggiss and Walsh 1985; Cheetham and Williams, 1987; Proulx and Sexsmith, 1988; Cibich, 1991; Reilly and Borrie 1992; Dawson et al., 1993; Lothian and Farrally, 1992 & 1994 and Boyle et al., 1994). Construct validity was determined using data from Chapter 6 and subdividing the sample into provincial and club-level players. Direct validity was determined from a comparison with the time-motion data discussed in Chapter 5 and the data from the 5-m Multiple Shuttle Test.

The subjects for the criterion phase of the study included female hockey players (n=14) and female rugby players (n=17) who volunteered to participate in this study. Two hockey and nine rugby players withdrew from the study through injury, illness or work commitments. The remaining subjects (n= 20, aged 26.6 ± 4.0 years, height 165.3 ± 8.8 cm, mass 61.7 ± 8.1kg, and body fat 24.3 ± 2.9 %) completed a 40-m timed sprint, the 20-m Multiple Shuttle Test (20-m MST) on their first visit and the 5-m Multiple Shuttle test (5-m MST) on their second visit within a 2-week period. All testing occurred on rubberised indoor surfaces at the Sports Science Institute South Africa. Before testing, all subjects completed an informed consent form and a medical screening questionnaire. The study was approved by the Ethics and Research Committee of the Faculty of Health Sciences of the University of Cape Town.

7.2.1 Experimental Design

All tests were administered at the same time of day (within ± 30 minutes) and the subjects attended the laboratory with instructions to abstain from caffeine intake for 3 hours prior to testing and to control their training the day before and on the day of testing in an attempt to standardise the physical preparation before each test. Body weight, height and body fat (sum of 4 skinfolds;

triceps, biceps, subscapula and supra-iliac as described by Durnin and Womersley, 1974) were measured at the first session.

Each subject was allowed 10 minutes to complete her own specific warm-up for both visits. Before the 40-m timed sprints, each subject ran submaximally along the sprint track 3 times each separated by a minute. No additional warm-up was required for the 20-m MST. Preparation for the 5-m MST was the same as described in Chapter 6.

The 40-m sprint was performed on a special rubber sprint track with photocells placed at the start and then every 10 m, so that split times at 10, 20, and 30 m could also be recorded. The 20-m MST (Ramsbottom et al., 1988) required the subjects to run between two lines spaced 20 m apart in time with an audio cassette. The test was conducted about 20 minutes after the sprint test. The 5-m MST was conducted within 2 weeks of this testing. The 5-m MST required the subjects to sprint between a series of 6 beacons spaced 5 m apart for 30 seconds, and then rest for 35 seconds; this procedure was repeated a total of six times (Chapter 6).

7.3 Statistical Analysis.

Data are expressed as mean ± standard deviation. Maximal oxygen consumption was predicted from the results of the 20-m multiple shuttle test (Ramsbottom et al., 1988).

Pearson's product moment correlation was used to determine the relationships between variables. The criterion validity of the 5-m MST was determined by the strength of the relationship between the 5-m MST data and either the $VO_{2\,max.}$ estimated from the 20-m MST or the 40-m sprint test. A correlation coefficient between r = 0.5 to 0.7 was considered low, r = 0.7 to r = 0.8 are moderate, and r = 0.9 or higher are good for predicting Y from X values (Vincent, 1995). A strong relationship between the 20-m MST and the 5-m MST would indicate that endurance capacity is a prerequisite for the 5-m MST. A strong relationship between the 40-m timed sprint and the 5-m MST would indicate that sprint-ability is a prerequisite for the 5-m MST.

To establish whether construct validity existed, a two-way (shuttle x level of play) analysis of variance (ANOVA) with repeated measure was used. ANOVA was used to analyse the total and peak distances covered during the shuttles. The interaction between the "level of play" and "shuttle" was analysed with an ANOVA.

To determine the direct validity, Pearson's product moment correlation coefficients were calculated between the total and peak distances collected during the 5-m MST and the mean displacement per minute playing time, mean displacement and mean speeds recorded during the hockey time-motion study (Chapter 5). The strength of the relationship between these factors was used to determine whether the 5-m MST was valid for determining the fitness of field hockey players. The relationship between the 5-m MST data and the total displacement was not calculated because playing time varied between the players.

7.4 RESULTS.

Logical Validity.

The basic physical attributes of team sports and the components of the 5-meter Multiple Shuttle Test (5-m MST) are compared in table 7.1. There are similarities between the 5-m MST and team sports in 4 of the 9 areas. In the remaining 5 areas the fitness does not meet the requirements of team sports.

Table 7.1: Comparison of the Gross Physical Attributes of Team Sports with the requirements of the 5-m Multiple Shuttle Test.

Attribute	**Team Sports**	**5-m MST**
Frequent instances where subject has to rapidly accelerate, decelerate and change direction	✓	✓
Variation in distances covered	✓	✓
Recovery periods of varied length	✓	X (fixed 35 sec)
Variation in the length of the work bouts	✓	X (fixed 30 sec)
Repeated bouts of maximal effort	✓	✓
Extensive Submaximal Work.	✓	X (maximal throughout)
Work to rest ratios that mimic actual match demands	✓(1:2.5) (Reilly & Borrie 1992)	X (1:1.2)
Randomised movement patterns (angles of movement anywhere from 1 to 360^0)	✓	X (constant 180^0)
Requires adoption of low body position that places extra demands on body	✓	✓

Criterion Validity

The mean predicted maximal oxygen uptake value was 42.7±7.1 $ml.kg^{-1}.min^{-1}$. The mean time for the 40-m sprint was 6.37 ± 0.27 seconds. The mean total and peak distances calculated post-test from the 5-m MST were 650.9 ± 59.2 m; 114.8 ± 8.6 m, respectively.

The correlation coefficients between the predicted $VO_{2max.}$ from the 20-m MST and the performance in the 5-m MST and the 40-m sprint test are summarised in table 7.2 and figures 7.1 and 7.2.

Table 7.2: Correlation Coefficients (R) for the comparison of data obtained from the 5-m MST, 20-m MST and the 40-m Sprints (n =20).

5-m MST	$VO_{2\,max.}$ ($ml.kg^{-1}.min^{-1}$)	40-m Sprint (seconds)
Total distance (m)	0.92	-0.73
Peak distance (m)	0.83	-0.77

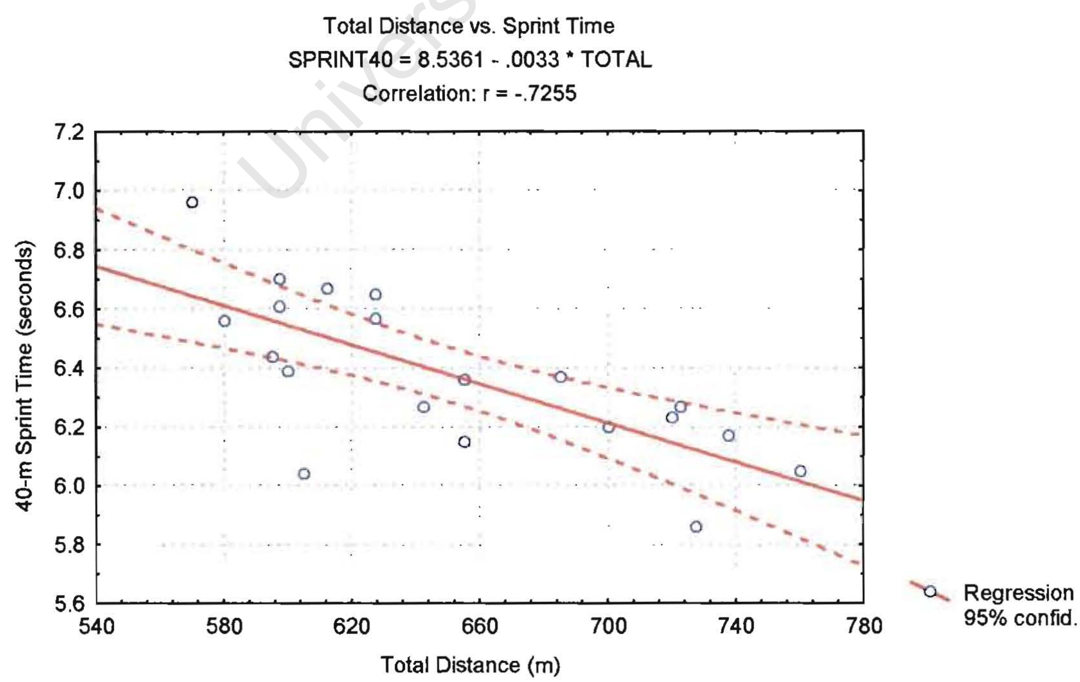

Figure 7.1a: Correlation Coefficient between the 40-m Sprint time (seconds) and the Total Distance (m) covered during the 5-m MST (n=20).

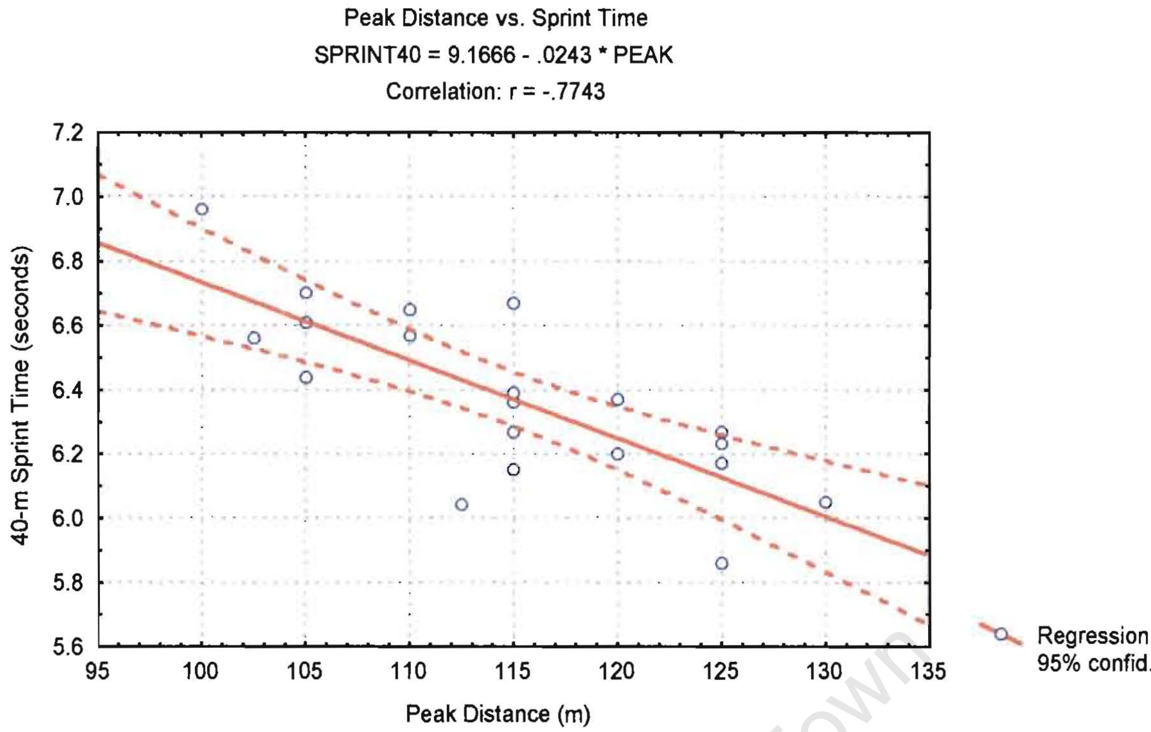

Figure 7.1b: Correlation Coefficient between the 40-m Sprint time (seconds) and the Peak Distance (m) from the 5-m MST (n = 20).

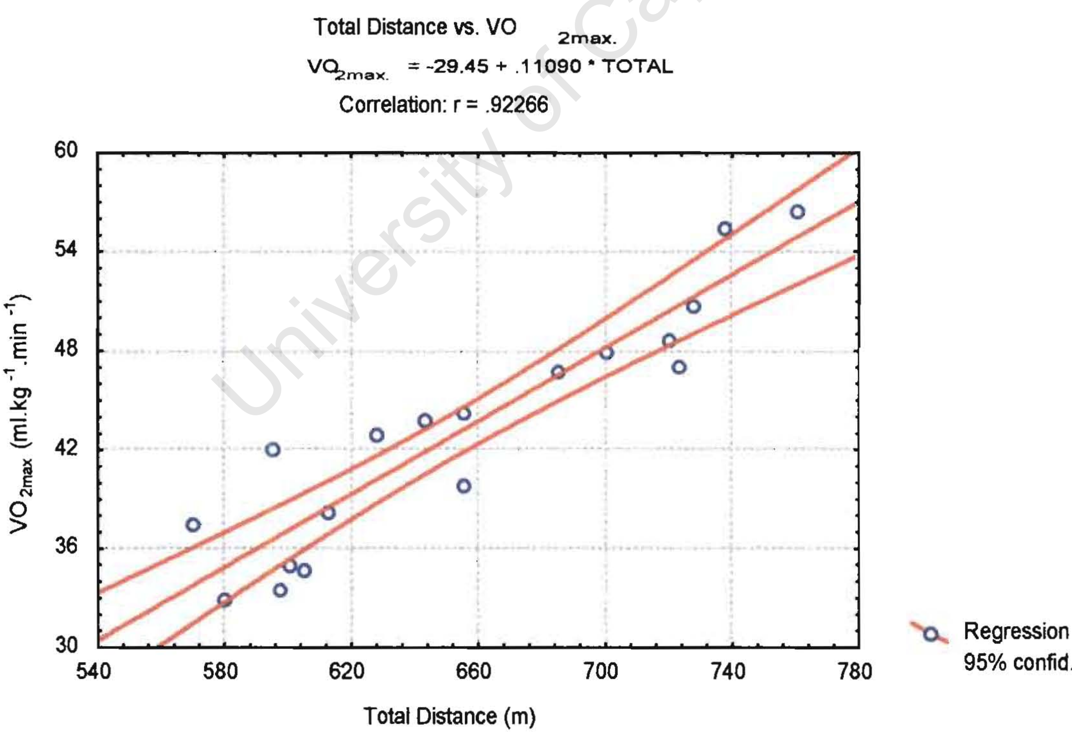

Figure 7.2a: Correlation Coefficient calculated between $VO_{2\,max}$ data estimated from the 20-m MST and the Total Distance (m) from the 5-m MST (n = 20).

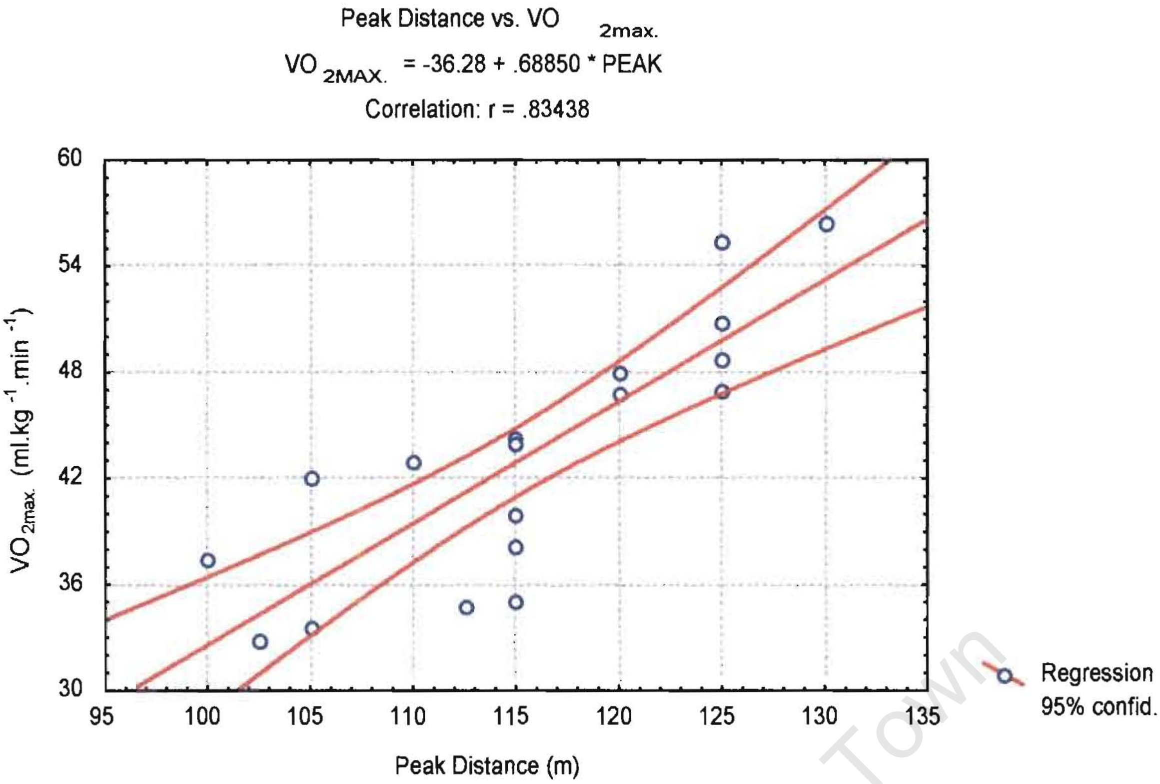

Figure 7.2b: Correlation Coefficient calculated between $VO_{2\ max}$ data estimated from the 20-m MST and the Peak Distance (m) from the 5-m MST (n = 20).

Construct Validity

The characteristics of the subjects were; Provincial n= 12, aged 22.8 ± 4.3 years, height 164.6 ± 3.9 cm, mass 59.4 ± 5.9kg, and body fat 22.9 ± 4.3 % and Non-provincial n = 11, aged 22.1 ± 3.4 years, height 167.7 ± 3.5 cm, weight 69.1 ± 9.5kg, and body fat 27.2 ± 4.4 %. There were significant differences between the provincial and non-provincial players for weight and % fat ($P < 0.05$).

There were significant differences between the provincial and non-provincial players for all of the variables measured during testing or calculated post-test for the distance covered during each shuttle (m) (P = 0.002); total distance covered (m) (P = 0.001) and peak distance (m) (P = 0.04). The mean data for these factors are shown in Tables 7.3 and 7.4 and Figure 7.3.

The provincial players covered significantly more distance than the non-provincial players for shuttles 1,3,4,5 and 6 (P = 0.01) (Table 7.3 and Figure 7.3). The provincial players also had greater total (P = 0.01) and peak (P = 0.05) distances than the non-provincial players (Table 7.4).

Table 7.3: Mean data for distance covered (m) for each of the 6 shuttles for Provincial (n =12) and Non-Provincial (n =11) Players.

Shuttle Number	Non-Provincial	Provincial
1 *	119.3 ± 7.9	123.3 ± 6.6
2	113.3 ± 7.2	115.8 ± 7.7
3 *	109.6 ± 5.1	114.9 ± 8.6
4 *	107.4 ± 5.8	112.6 ± 9.0
5 *	105.6 ± 5.8	111.4 ± 9.2
6 *	105.8 ± 6.4	111.9 ± 9.1

* represents a significant difference between non-provincial and provincial level players (P < 0.01).

Table 7.4: Mean data for Total distance and Peak distance for Provincial (n = 12) and Non-Provincial (n = 11) Players.

	Non-Provincial	Provincial
Total Distance (m) **	661.1 ± 31.0	689.9 ± 46.6
Peak Distance (m) *	120.6 ± 7.2	123.5 ± 6.5

* represents a significant difference between non-provincial and provincial level players (P < 0.05).
** represents a significant difference between non-provincial and provincial level players (P < 0.01).

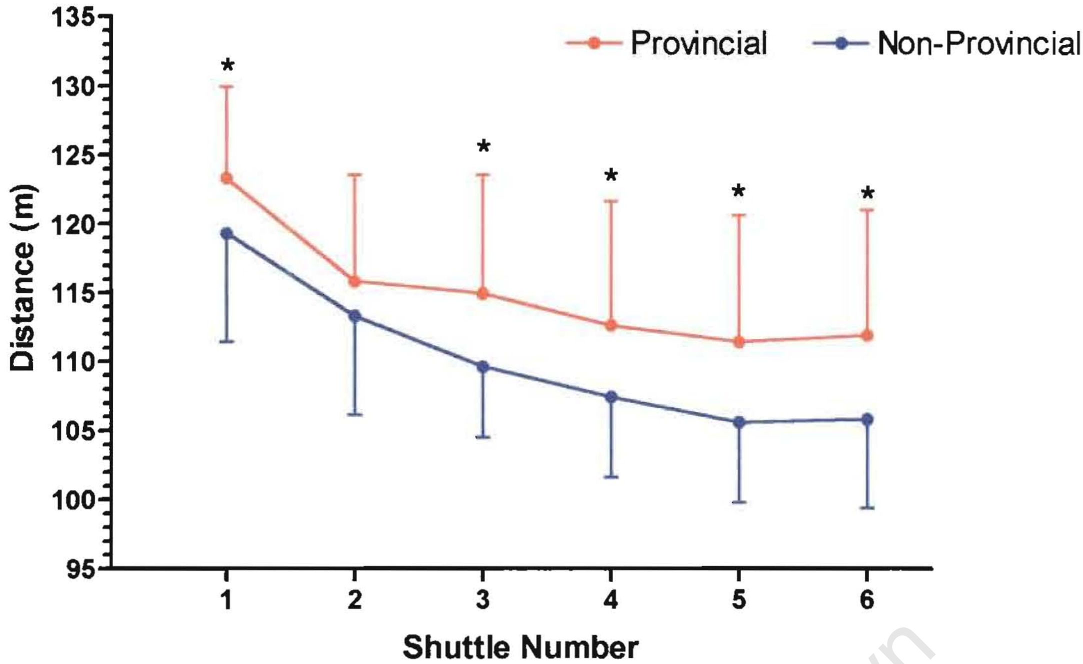

Figure 7.3 : Mean Group data for the Distance covered (m) during testing for Provincial and Non-Provincial Players.

* represents significant differences between the Provincial (n =12) and Non-Provincial (n = 11) players (P<0.01).

Direct Validity

Correlation coefficients were calculated for the time motion data collected in Chapter 5 with the data from the 5-m multiple shuttle test. The results are summarised in Table 7.5 and Figures 7.4 and 7.5.

Table 7.5: Correlation Coefficients (R) for the comparison of data obtained from the 5-m MST fitness tests and the Field Hockey Time-motion Study (n = 10).

5-m MST	**Time-motion Study**		
	Displacement per minute ($m.min^{-1}$)	**Mean Displacement (m)**	**Mean Speed ($m.s^{-1}$)**
Total Distance (m)	0.63	0.74	0.73
Peak Distance (m)	0.49	0.70	0.70

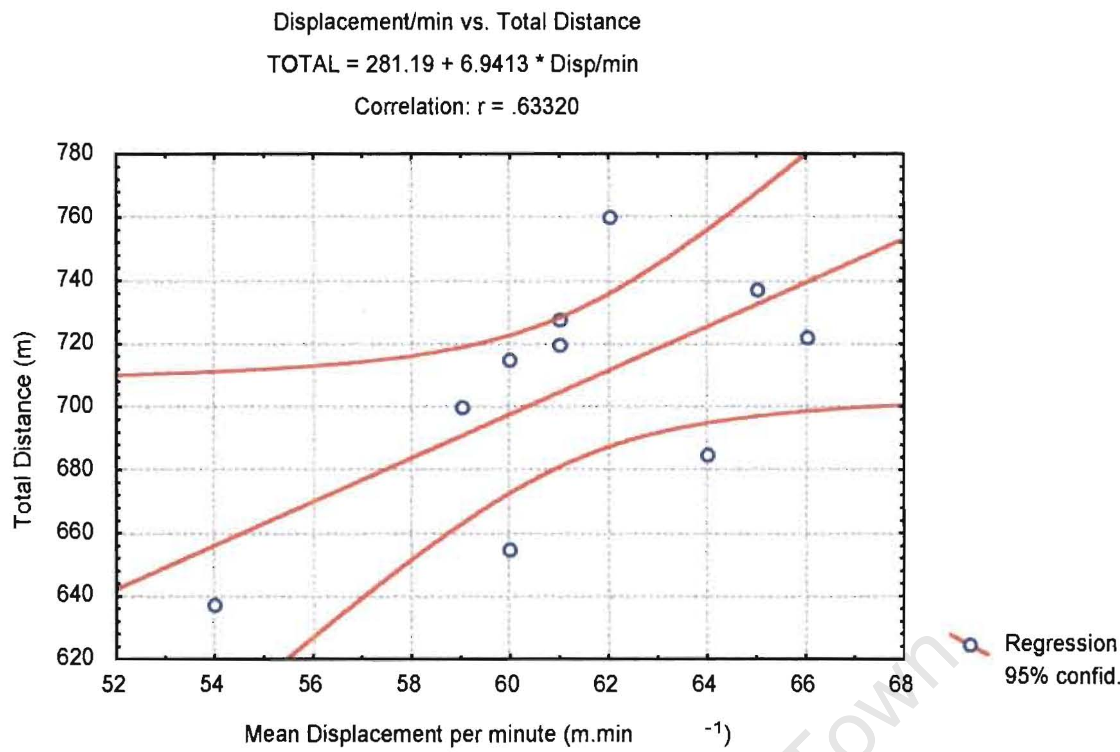

Figure 7.4: Correlation Coefficient calculated between Total distance (m) data from the 5-m MST and the Mean Displacement per minute of playing time (m.min^{-1}) (n = 10).

7.5 DISCUSSION.

The purpose of this study was to determine the validity of the 5-m MST field test that is used for the physical assessment of team sport athletes. For a test to be valid it must directly measure an aspect, or aspects, of actual sporting performance (Wragg et al., 2000).

Two techniques for determining validity were used in this study. Firstly indirect methodology was used to determine logical, criterion and construct validity. Secondly, using direct methodology the fitness test data and data from a time-motion study on field hockey were compared.

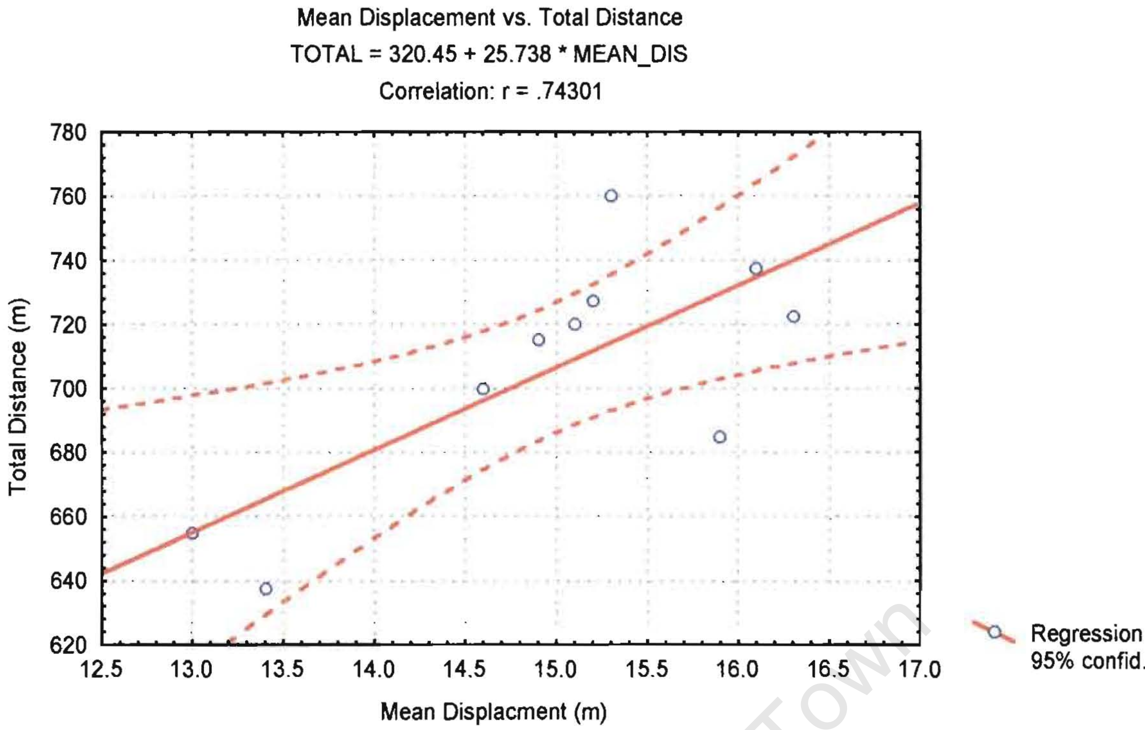

Figure 7.5a: Correlation Coefficient calculated between the Total Distance (m) data from the 5-m MST and the Mean Displacement (m) (n = 10).

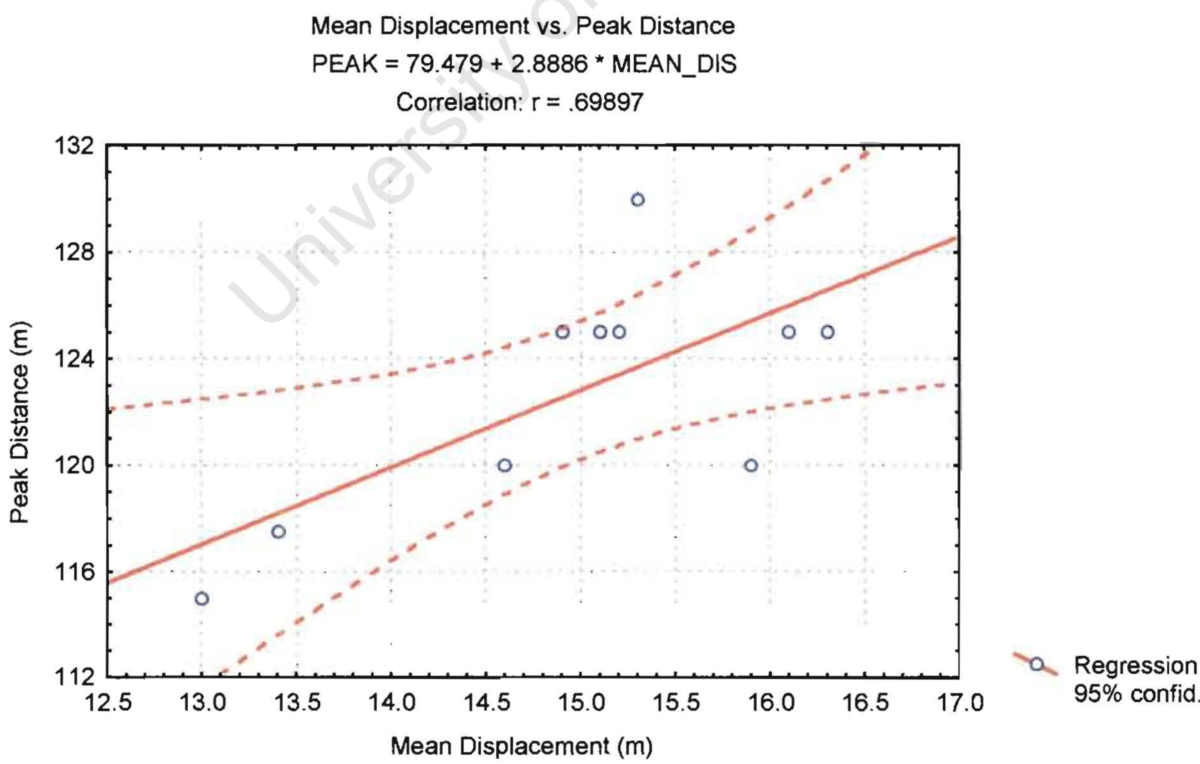

Figure 7.5b: Correlation Coefficient calculated between Peak Distance (m) data from the 5-m MST and the Mean Displacement (n = 10)

The first finding of this study was that the 5-m multiple shuttle test (5-m MST) contains 4 out of 9 (44%) of the gross physical attributes that are associated with team sports (Table 7.1). Hawley and Burke (1998) described the 5-m MST test as a test that measures the speed, agility and endurance of team sport players and these demands are clearly reflected in the qualities that Wein (1981) described as being important for a successful hockey performance. This according to NCF (1995) is the requirement for logical validity.

There are some limitations to the design of the 5-m MST that are explained by the remaining 5 out of 9 physical attributes of team sport performance. The turning movements that have to be executed during the 5-m MST are not fully representative of the variable and multidirectional movements that occur during a game. The durations of the work and recovery periods during the test are fixed, in contrast to a team sport where the duration of the work bouts and recovery or periods of low-intensity effort vary randomly. The intensity of the work during the 5-m MST is consistently higher than observed during a match.

It is obvious that a fitness test can never fully replicate the demands of team sports because team sports contain many variable factors that may influence performance. Compromises therefore have to be made to ensure that the test results are reliable, able to detect changes in fitness levels and test many players simultaneously at the expense of replicating exact activities that occur during sports.

In determining the relationship between the 5-m MST, 20-m MST and the 40-m Sprint test, it was found that the strongest relationships occurred between the

$VO_{2\,max.}$ data predicted from the 20-m MST and the total distance covered during the 5-m MST (r = 0.92) and the $VO_{2\,max.}$ and the peak distance from the 5-m MST (r = 0.83). This indicates that players with a higher predicted $VO_{2\,max.}$ would cover a greater distance on their first sprint and maintain that greater work throughout the 5-m MST than players with a lower $VO_{2\,max.}$. It also indicates that both endurance and sprint-ability are prerequisite characteristics for the 5-m MST. Although Pendleton (1997) also found a relationship between $VO_{2max.}$ and total distance covered during the 5-m MST (r = 0.72), this was lower than the relationship reported in this study (r = 0.92).

The 5-m MST was able to differentiate between the two different standards of players in this study. In particular the provincial players achieved greater distances in the 5-m MST than the non-provincial players. This result confirms the observation that as the level of expertise of the players increase, so too should their fitness levels (National Sports Medicine Institute, 1998). Pendleton (1997) found that a very similar fitness test to that used in this study was able to discern performance differences between endurance-trained athletes and those with a sprint training background. The ability of the test to distinguish between playing abilities and training backgrounds increases the usefulness of the 5-m MST for assessing fitness of hockey players. However there remains a need to evaluate whether the 5-m MST has sufficient precision to track changes in fitness in the same players throughout a season.

When the direct validity data were analysed, significant relationships were found between the displacement covered per minute playing time (m) and the total distance of the 5-m MST (r = 0.63 for displacement per minute vs. total distance). An alternative interpretation is that about 40% (i.e. coefficient of determination) of the variation in displacement covered per minute playing time could be explained by the total distance of the 5-m MST. There were also significant relationships between the mean displacement and mean speed during the match and the characteristics of the 5-m MST. This suggests that the players who recorded a greater displacement during the hockey matches also covered the greater distances during the fitness test.

It is acknowledged that there are many other external influences (opposition, weather conditions, amount of playing time for each player, umpiring and importance of the match) that will determine displacement or distance covered during a hockey match other than just level fitness. It would also be presumptuous to expect any physiological test to be able to predict performance of a team sport more accurately than has been shown in this study because there are psychological and skill factors that are not taken into account in a fitness test (Bar-Or, 1987). Therefore, it is reasonable to suggest that correlation values of $r = 0.6$ to 0.7, indicate that a fairly strong relationship exists between physical performance during competition and performance in the 5-m MST.

In summary this study has shown that the 5-m Multiple Shuttle Test has indirect validity in terms of logical validity, the demands of the test replicating the physical demands of the sport, criterion validity, the relationships between $VO_{2\,max.}$ and speed and performance in the 5-m MST and finally construct validity with the ability of the test to distinguish between different levels of playing ability. All of these factors enhance the usefulness of the test but there still remains the question how does this relate to sporting performance.

The second part of the study related data from a time-motion study on field hockey to performance of the 5-m MST and found that fairly strong relationships existed between these variables. It is therefore reasonable to suggest that the 5-m MST also has a direct form of validity when it comes to assessing the fitness of field hockey players.

The first part of this thesis has examined at the physical component of field hockey and how that can be assessed with a fitness test. The second part of the thesis evaluates the skill-related components. The next Chapter analyses hockey matches to determine whether a normative performance profile exists.

CHAPTER 8

THE ANALYSIS OF SKILLED PERFORMANCE AND GAME PARAMETERS DURING LEAGUE HOCKEY MATCHES.

8.1 INTRODUCTION

Media coverage of sport has made extensive use of video recordings to give the viewers a greater insight into sporting events. Slow-motion playbacks and freeze-frame images are regularly used to replay moments of sports where either points were scored or a disputed decision has to be made (Treadwell and Lyons, 1997). Facts about the match are also often displayed during the half-time interval and again at full-time describing the statistics of various activities that occurred during the match.

Although the data obtained from broadcasts or other video media can be interesting for the spectator, they can also be combined into a database for that specific team or event. Computer technology has now made it possible to provide unprecedented amounts of information on any team or individual performance (Allen et al., 2001). Statistics can be used to describe the data and thus models of performance can be generated. This information can direct the analyst to critical aspects of the data that delineate successful performance (McGarry and Franks, 1996).

Hughes et al. (2001b) raised fundamental questions regarding the consistency and interpretation of the mean data generated from the same team from match to match. Large deviation in the frequencies of the different variables between the matches gives no credibility to the presentation of the data as a performance profile (Hughes et al., 2001b). Therefore, before the data can be interpreted with precision it is essential to determine whether a consistent profile exists for that specific element of performance.

The aim of this study was therefore to establish whether a consistent performance profile could be established for a variety of different performance variables or match descriptors for club-level women's field hockey. The outcome of this study will contribute to practical decisions about how visual feedback is used to inform coaches and players on their sporting performance.

8.2 METHODS

Female hockey matches during the 2001 season (28 July – 1 September) were recorded with a domestic video camera (Sony® Handycam Vision™ CCD- Video Camera Recorder TRV 46E, Japan). The matches (n = 11) were club standard (Western Province Hockey Union Grand Challenge league Cape Town). The location of the camera could not be standardised due to differing facilities around each ground, however, the cameras were positioned as high above the ground as possible.

All of the hockey matches were filmed for the entire duration (70 minutes) and analysed using Sports Code (Sportstec, Lower Hutt, New Zealand). The match descriptors that were analysed include circle entries (both the team in the study and their opponent's), short corners (attacking and defending), goals scored, goals conceded, the ratio of shots to goals, the number of free hits inside the attacking area, the number of long corners, the distribution of the ball during the game (Figure 8.1), ball possession and playing time. For a more in depth definition of the terminology of the match descriptors see Appendix A. Two games against the same opposition were also compared. All the analyses were conducted post-match. The data from ten matches were used to calculate whether data consistency existed. The eleventh match was against the same opposition as the tenth match. The first game was lost and the second was won.

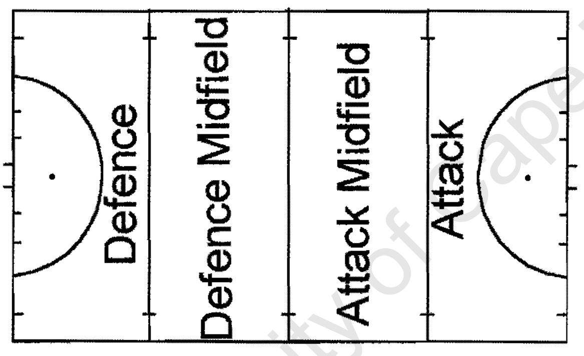

Figure 8.1 Diagram of the hockey field divided into 4 different areas.

During initial analysis of the data, it was observed that the defensive short corner formation was very similar between the different matches. A more detailed evaluation of defensive short corner movements was conducted with three independent observers all of whom had extensive hockey playing and coaching experience. The observers where asked to randomly select 10 video clips of defensive short corners and to compare them to one another. The outcome of this would be used to determine whether the movement patterns associated with defensive short corners were consistent. The other match descriptors were not subjected to this more detailed qualitative analysis because by their very nature consistency or lack of variation would prove to be detrimental as their opposition would be able to predict the movements and thus effectively defend them.

The intra-observer reliability repeatability of the video analysis was determined by a test-retest viewing and repeated analysis of one of the matches (match 10) with a 20-day period between the viewings.

8.3 STATISTICAL ANALYSIS

The means and standard deviations for each of the match descriptors were calculated.

Chi-square (χ^2) tests were used to determine whether there was any difference in the frequency of the match descriptors determined in each of the 10 matches. Normative performance profiles were calculated (Hughes et al., 2001b) when the Chi-square test found no significance in the data. This calculation and graphical representation established when the performance variable displayed the least variation about the mean. An alternative explanation is that this technique determined the minimum number of matches that could be analysed to establish a consistent profile. Chapter 3 outlines how a consistent profile is established. The normative profile was calculated using the following equation:

Cumulative mean = (Sum of the frequencies of 'the match descriptor')/n

Where n = the number of matches analysed.

The cumulative mean was then plotted graphically with the limits of error, 10% and 5%. The limits of error were calculated below:

Limits of error (10%) = Mean ± (Mean x 0.1)

Limits of error (5%) = Mean ± (Mean x 0.05)

(Hughes et al., 2001b).

Ratios were also calculated between the number of shots, goals scored, short corner goals and the number of short corners to quantitatively determine the relationships.

8.4 RESULTS

The mean and standard deviations of the match descriptors recorded are displayed in Tables 8.1 and 8.2. There were significant differences observed between the circle entries, short corners, long corners ($P < 0.05$), free hits ($P < 0.05$) and the goals (both from open play and short corners) conceded over the 10 matches ($P < 0.01$) (Table 8.1 and 8.2). The number of goals scored and the numbers of goals scored from short corners did not significantly differ between the different matches ($P > 0.05$). The cumulative mean for the number of goals scored is shown in Figure 8.2.

Table 8.1: Summary of the number of Short Corners, Circle Entries and Goals scored during the league matches (n = 10).

Game	Circle Entries *	Opponent's Circle Entries *	Short Corners *	Defensive Short Corners *	Goals Scored	Goals conceded *
1	57	15	9	3	8	0
2	55	5	16	1	6	0
3	74	4	17	0	8	0
4	82	8	20	1	8	0
5	47	21	4	3	6	0
6	51	23	8	4	8	1
7	34	23	7	7	3	0
8	45	25	14	4	3	1
9	30	27	5	1	3	0
10	30	40	13	10	2	5
Mean	50.5	19.1	11.3	3.4	5.5	0.7
SD	17.5	11.2	5.5	3.1	2.5	1.6

* denotes significant differences at P = 0.01

Table 8.2 Summary of the number of shots at goal, long corners, goals scored during short corners and free hits during the league matches (n = 10).

	Shots at Goal *		**Long Corners ***		**Goals from Short Corners**		**Free Hits ***	
	Team	Opponent	Team	Opponent	Team	Opponent*	Team	Opponent
1	32	4	7	2	0	0	4	1
2	27	1	6	0	5	0	5	2
3	46	0	10	1	4	0	19	3
4	35	0	12	0	3	0	12	1
5	22	4	2	2	2	0	11	6
6	30	6	2	0	2	1	8	5
7	16	8	4	2	2	0	7	9
8	20	14	3	3	2	0	5	5
9	14	6	5	4	1	0	5	4
10	7	34	2	6	2	3	4	9
Mean	24.9	7.7	5.3	2	2.3	0.4	8	4.5
SD	11.4	10.2	3.5	1.9	1.4	0.97	4.8	2.9

* denotes significant difference at P = 0.05

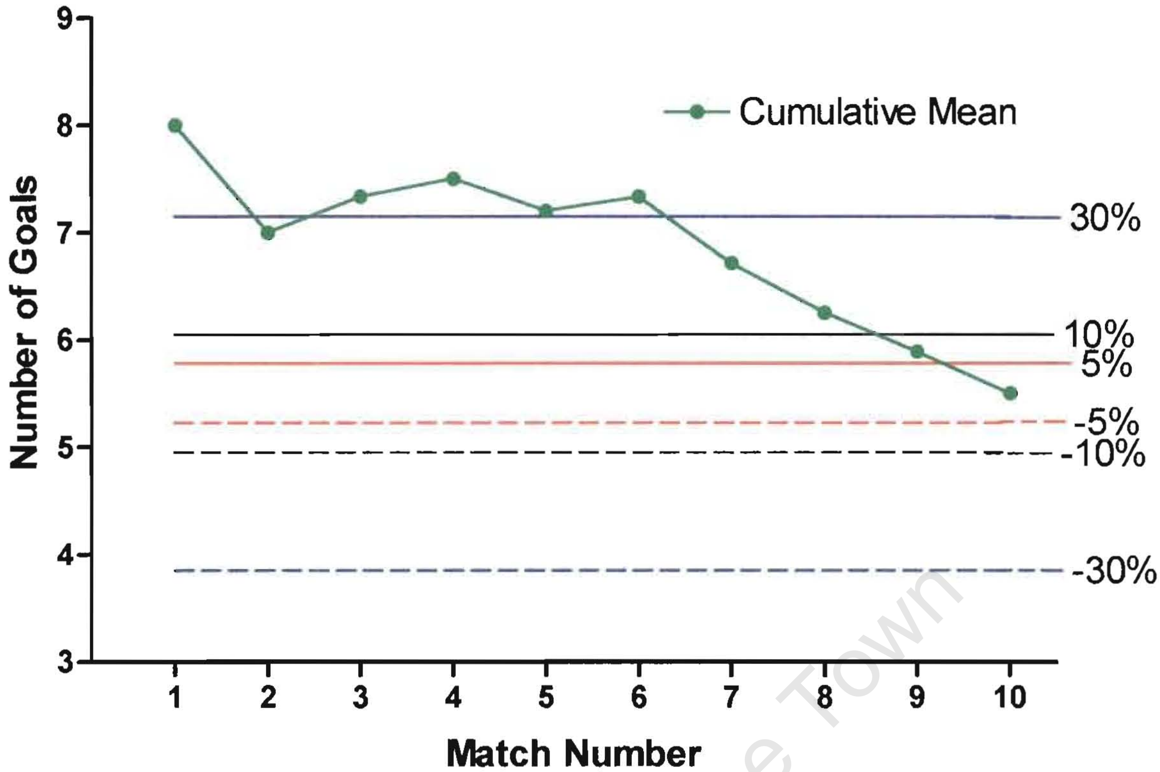

Figure 8.2 % Difference Plot for cumulative mean number of goals scored.

Figure 8.2 shows that the cumulative mean number of goals scored varies about the mean by 30% or more during matches 1 - 6. After 7 matches the mean falls within the 30% limits of error and after the 9th match there is less than 10% variation about the mean.

Figure 8.3 shows the cumulative mean for the number of goals scored from short corners.

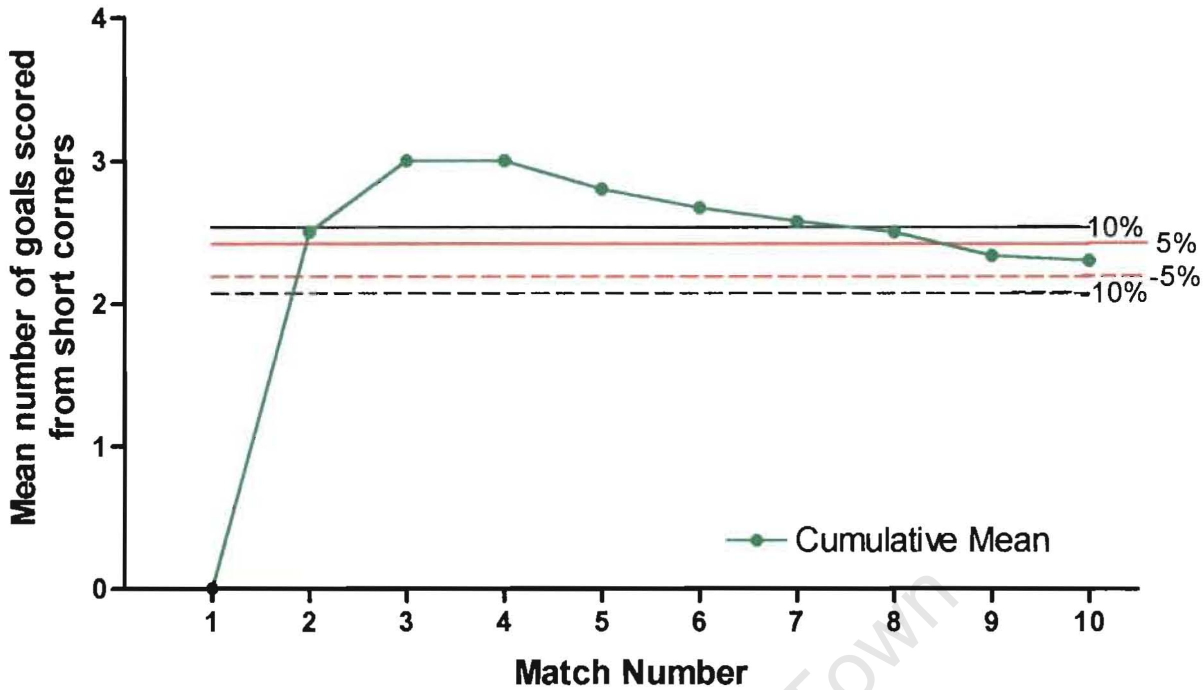

Figure 8.3 % Difference between the cumulative mean number of goals that were scored from short corners.

After analysing 8 matches, the variation of the cumulative mean number of goals that were scored from short corners about the overall mean was within a 10% limit of error. The variation in the cumulative mean was further reduced to within 5% after 9 matches (Figure 8.3).

Table 8.3 is a summary of the ratio data calculated related to the goal scoring opportunities. This can be interpreted as in game 2 where, for example 1 goal was scored from every 5.4 short corners, 1 goal was scored for every 4.5 shots at goal, 1 goal was scored for every 3.2 short corners awarded and 1 short corner was awarded for every 1.7 shots at goal.

Table 8.3 Summary data relating the goals scored to number of shots and number of short corners

Game	Ratio Shots: Goals from Short corners **	Ratio Shots: Goals scored	Ratio Short corners: Goals from Short corners	Ratio Shots: Short Corners
1	0	4.0: 1	0	3.6: 1
2	5.4: 1	4.5: 1	3.2: 1	1.7: 1
3	11.5: 1	5.8: 1	4.3: 1	2.7: 1
4	11.7: 1	4.4: 1	6.7: 1	1.8: 1
5	11.0: 1	3.7: 1	2.0: 1	5.5: 1
6	15.0: 1	3.8: 1	4.0: 1	3.9: 1
7	8.0: 1	5.3: 1	3.5: 1	2.3: 1
8	10.0: 1	6.7: 1	7.0: 1	1.4: 1
9	14.0: 1	4.7: 1	5.0: 1	2.8: 1
10	3.5: 1	3.5: 1	6.5: 1	0.54: 1
Mean	9.0: 1	4.6: 1	4.2: 1	2.6: 1
SD	4.7	1.0	2.2	1.4

** denotes significant difference P = 0.01

Figure 8.4 shows the cumulative mean ratio of the number of shots at goal: number of goals scored. The profile was observed to lie within the 10% limits of error for the ratio of shots: goals scored after 2 games and then after 7 games the profile stabilised further to fall in the 5% limits of error (Figure 8.4). Figure 8.5 shows the ratio of short corners: number of goals scored from short corners decreased within 10% limits of error after 8 games and remained within the 10% limits for the remaining matches (Figure 8.5). Figure 8.6 shows that the profile for the ratio of shots at goal: short corners appeared to decrease to within the 5% limits of error after the 2nd game, although variation in the subsequent playing performance destabilised the profile (outside the 10% limits of error). The variation in the ratio of the number of shots at goal to the number of short corners decreased to within the 10% limits of error after the 8th game and by the 10th game it was within the 5% limits of error again (Figure 8.6).

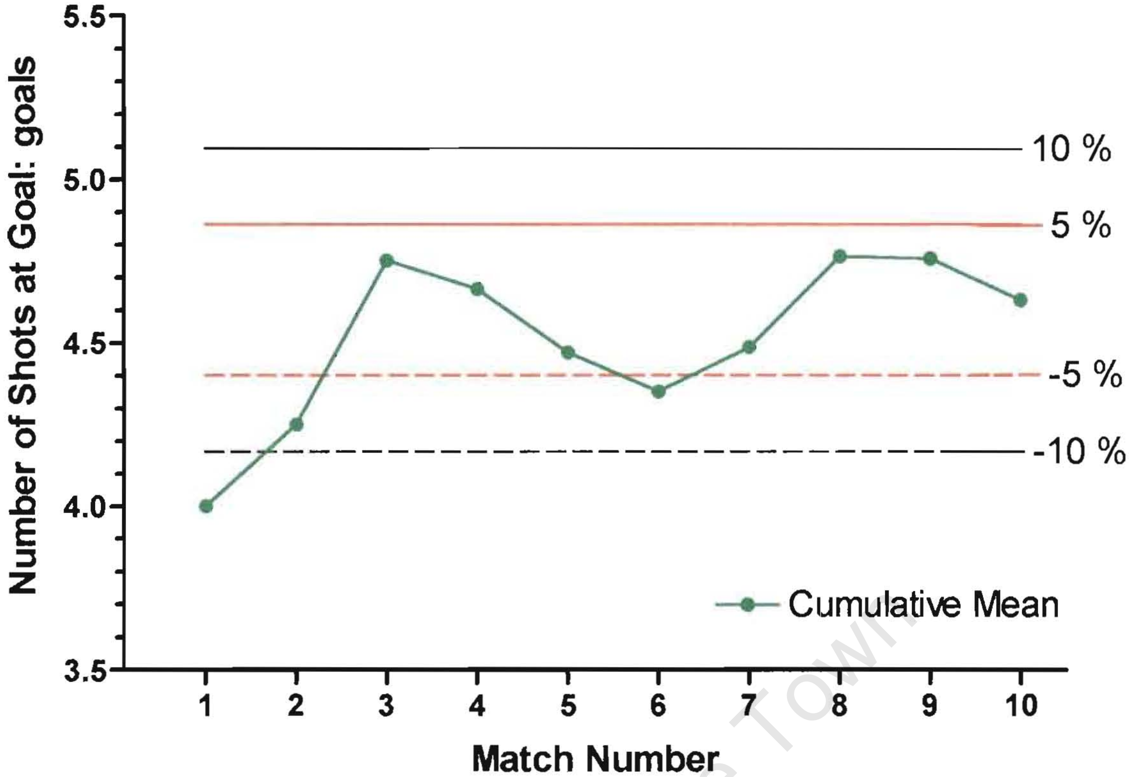

Figure 8.4 % Difference between the cumulative mean ratio of the number of shots at goal: number of goals.

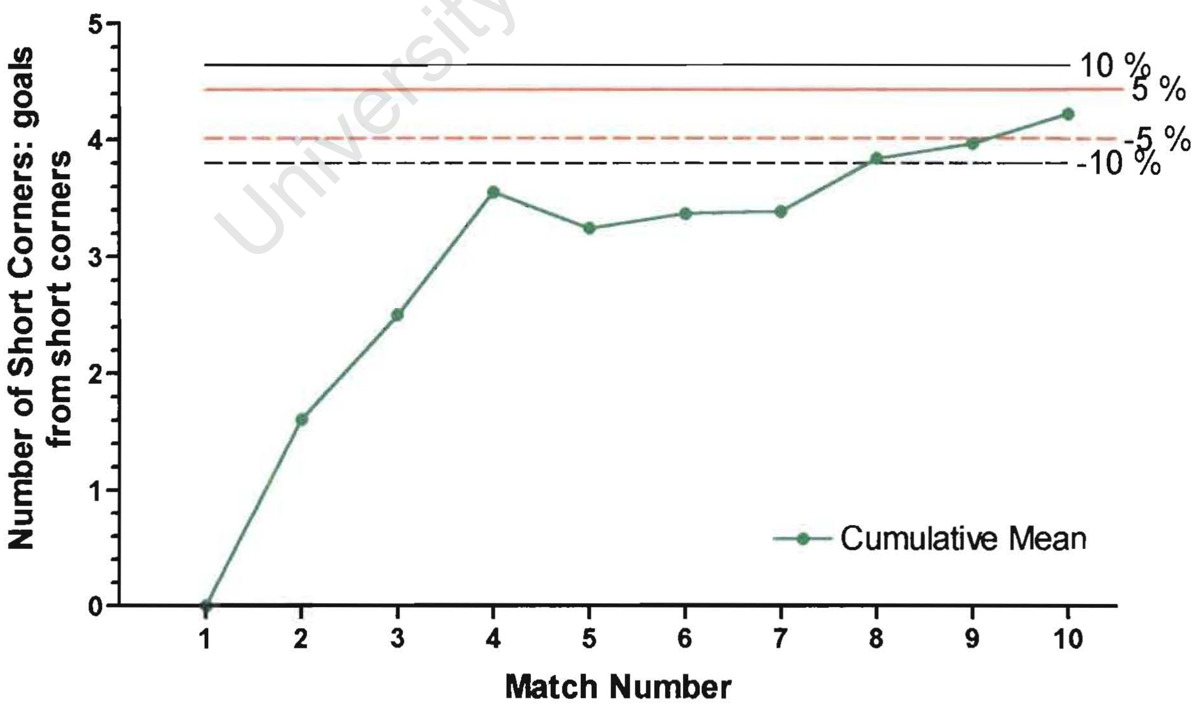

Figure 8.5 % Difference between the cumulative mean ratio of the number of short corners: number of goals from short corners.

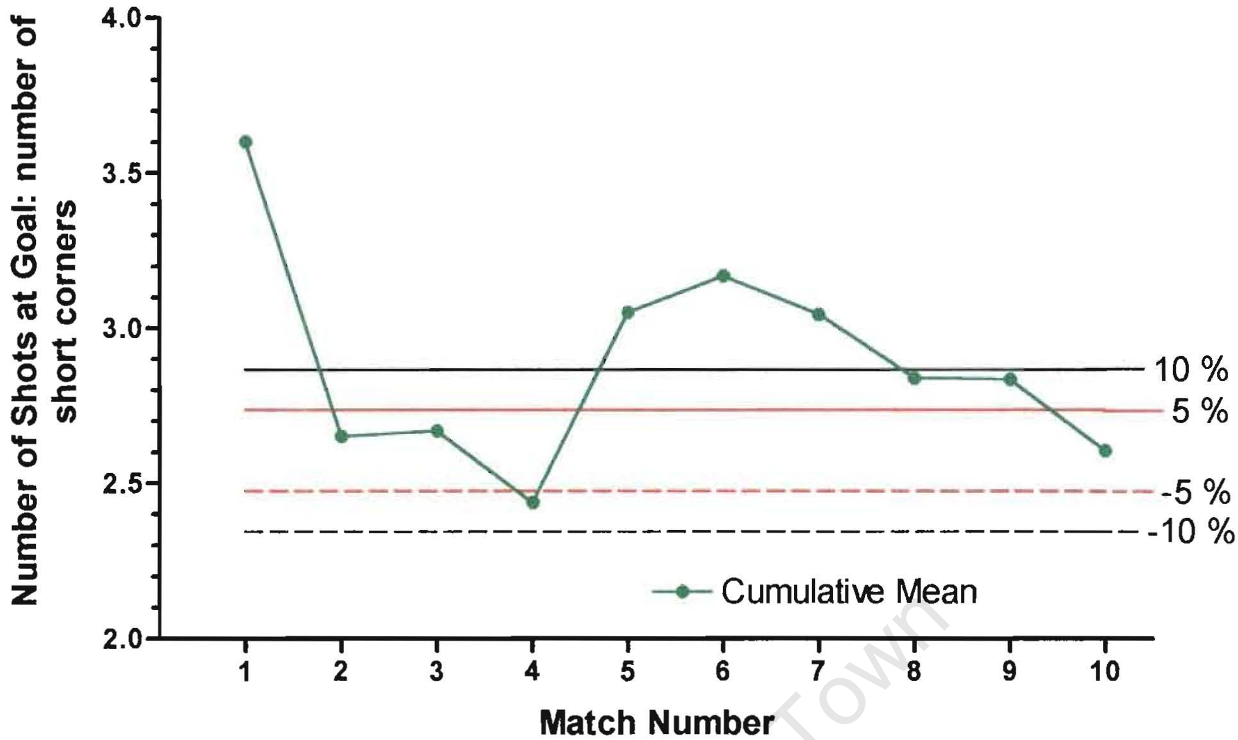

Figure 8.6 % Difference between the cumulative mean ratio of the number of shots at goal: number of short corners.

Table 8.4 summarises the amount of time that the ball was located in a certain area of the field, defense, defensive midfield, attacking midfield or attack. The amount of time that the ball spent in the attack and defense areas of the field was significantly different between the different matches. The percentage of time that the team being studied had possession of the ball (this was calculated by the total time that team 1 had the ball divided by the total time that team 1 had the ball + total time that team 2 had the ball and multiplied by 100) and the percentage playing time (total time that the ball was in play divided by 70 minutes multiplied by 100) are also summarised in Table 8.4.

Table 8.4 Summary of Ball Distribution, % Possession and % Playing time.

Game	Defence *	Defensive Midfield	Attacking Midfield	Attack *	% Possession	% Playing Time
1	14	23	30	33	56	53
2	6	19	31	44	60	57
3	4	16	32	48	68	50
4	6	16	31	47	70	50
5	19	25	29	27	59	58
6	16	23	28	33	60	54
7	20	27	29	24	57	53
8	17	29	30	24	60	54
9	21	28	33	18	54	57
10	28	25	24	23	45	52
Mean	15.1	23.1	29.7	32.1	58.9	53.8
SD	7.7	4.7	2.5	10.8	7.0	2.8

* denotes significant difference (P <0.01)

Figure 8.7 shows the cumulated mean percentage time that the ball was located in the defensive midfield area. There were no significant differences between the % time spent in the defensive midfield area and the different matches. The profile for the % time spent in the defensive midfield area stabilised between the 10% limits of error after 7 matches and between the 5% limits of error after 8 matches (Figure 8.7). Figure 8.8 shows the cumulative mean for the percentage time the ball spent in the attacking midfield area. The % time spent in the attacking midfield was relatively stable (5% limits of error) from the first match (Figure 8.8).

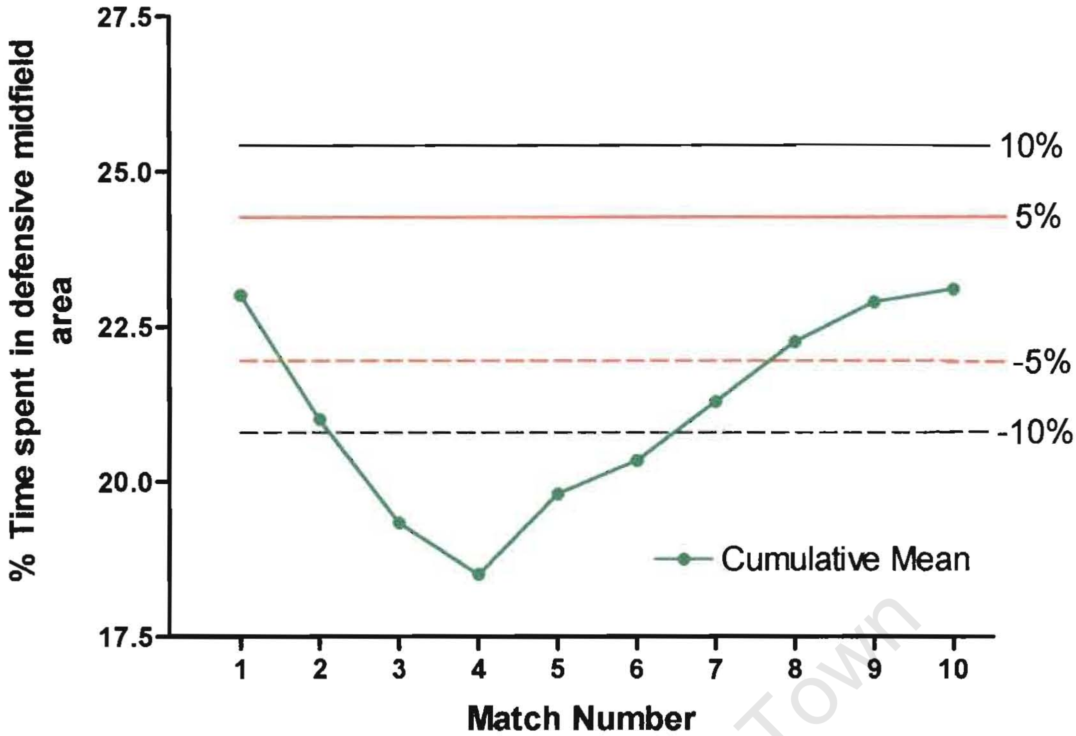

Figure 8.7 % Difference between the cumulative mean time that play was located in the Defensive Midfield Area.

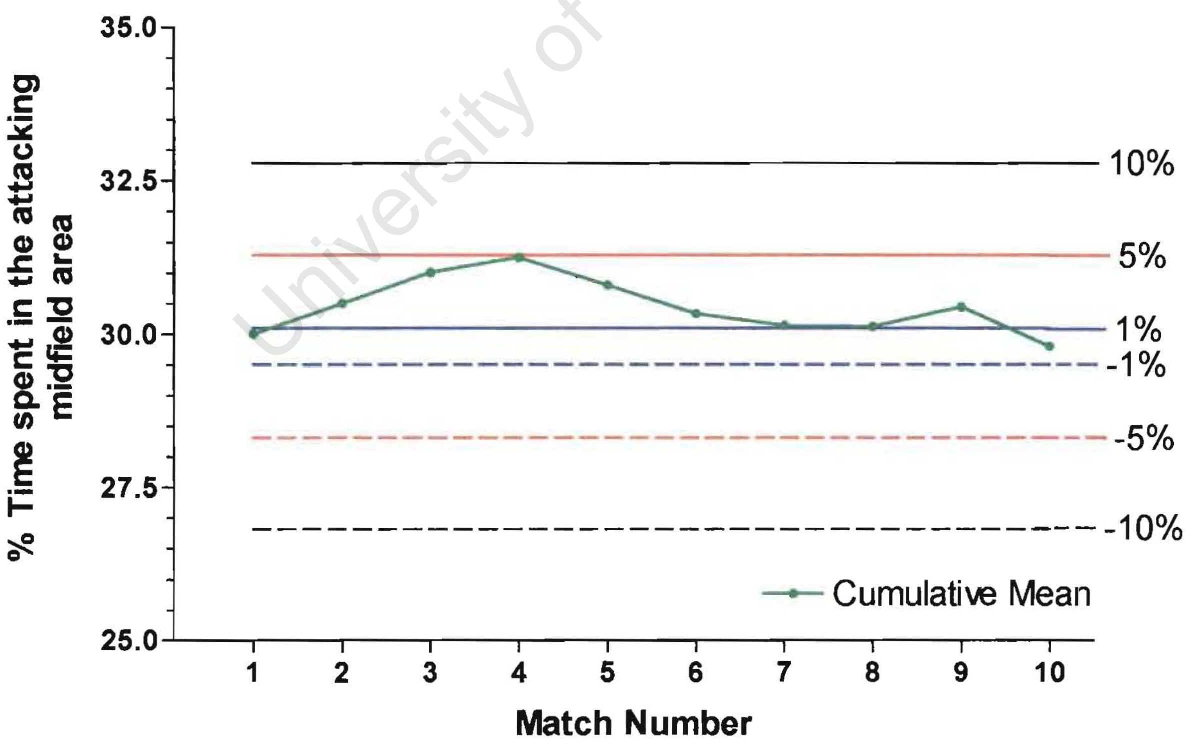

Figure 8.8 % Difference between the cumulative mean time that play was located in the Attacking Midfield Area of the field.

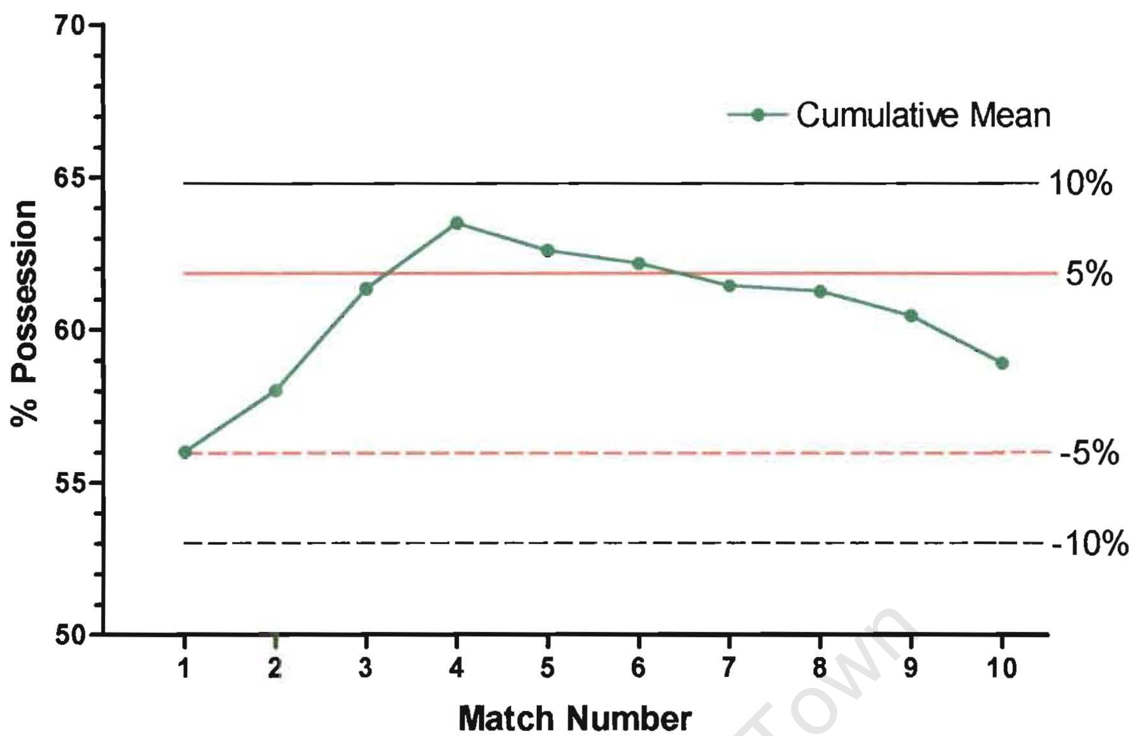

Figure 8.9 % Difference between the cumulative mean time in Possession of the Ball during the match

Figure 8.9 shows the cumulative mean for the % time that the team being studied was in possession of the ball. A normative profile was established (10% limits of error) from the 1st match for the % time in possession of the ball. This profile stabilised to ± 5% limits of error after game 7 (Figure 8.9). Figure 8.10 shows the cumulative mean for the % time that the ball was in play. Percentage playing time did not vary between matches 1 and 10 ± 5% limits of error. The error was further reduced after the 5th game to fall within the 1% limits of error (Figure 8.10).

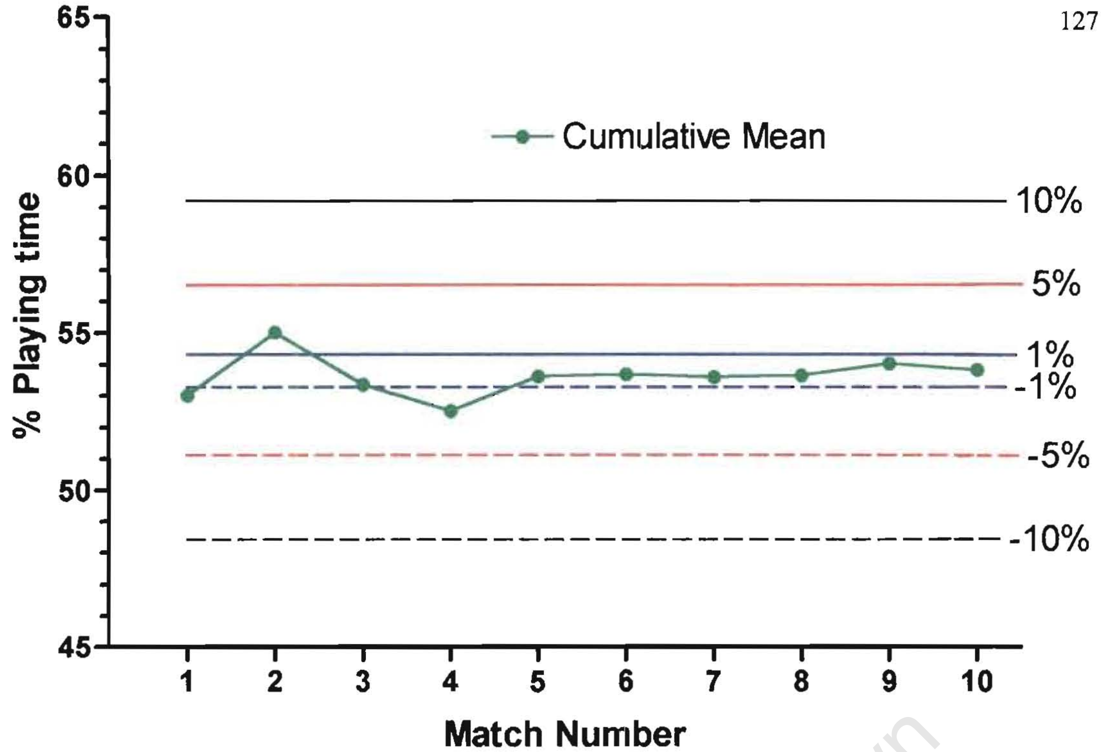

Figure 8.10 % Difference between the cumulative mean playing time during the Matches.

Comparison of the matches against the same opposition found significant differences in only two match descriptors; the number of attacking short corners ($p < 0.05$) and the number of shots against ($p < 0.01$). No significant differences occurred in any of the other match descriptors (Table 8.5). The results between the two games however, were different because in the first game they suffered a defeat (2-5) but won (3-2) the second match.

The match descriptors collected for match 10 were evaluated a second time by the same observer to establish the intra-observer reliability. The software used allowed the operator to record the match descriptor frequency and also its duration. This meant that the exact time period between the start of the match descriptor, and its finish point was recorded by the Sports Code Pro software and not dependant on subjective decisions of the observer. Therefore, there was no intra-individual variation for these descriptors.

Table 8.5 Summary of match data from 2 games against the same opposition.

	Game 10	Game 11
Circle Entries	30	25
Circle Entries against	40	43
Short Corners *	13	4
Defensive Short Corners	10	7
Shots at Goal	7	11
Shots against **	34	15
Long Corners	2	4
Long Corners against	6	5
Goals scored	2	3
Goal conceeded	5	2
Goals from Short Corners	2	2
Goals against from Short Corners	3	0
% time in Defense	28	31
% time in Defense Midfield	25	25
% time in Attack Midfield	24	24
% time in Attack	23	20
% time in Possession	45	47

*denotes significant difference at P = 0.05 ** denotes significant difference at P = 0.01

Each of the three independent observers was asked to evaluate the formation of the defending players in 10 different short corners. These 10 short corners were randomly selected from all the short corners (n = 113) awarded during the 11 recorded matches. The defensive formation of all short corners analysed was considered to be consistent within the constraints of a match situation (players running to similar positions each time) by all of the impartial observers. Examples of the formation adopted by the defensive players are shown in Figure 8.11, 8.12 and 8.13. All of the figures show one player higher (closer to the edge of the circle) than the others running out towards the edge of the circle (player 1). There are always 2 players (players 2 & 3) positioned to her left and the goalkeeper behind her. The remaining player, player 4 was on the right side and was level with the goalkeeper.

Figure 8.11 Examples of short corner defensive formations.

Figure 8.12 Examples of short corner defensive formations.

Figure 8.13 Examples of short corner defensive formations.

8.5 DISCUSSION

The purpose of this study was to determine whether constant performance profiles existed during competitive club standard field hockey. A constant performance profile suggests that this behaviour can be used to provide information for future events, on the expectation that there is a great probability that these behaviours will be repeated in the future (McGarry and Franks, 1996).

The main finding of this study was that significant variability existed in the incidence of 8 out of 14 match descriptors analysed during hockey matches. No significant differences were observed for 6 out of the 14 match descriptors recorded and 3 of the 4 ratios that were calculated over the 10 different matches. In past notational studies, researchers have assumed that if they analyse enough performances then the data will have stabilised and a mean score of the measured variables would be consistent from match to match (Hughes et al., 2001b). A stable mean for a match descriptor is important when comparisons between data sets from different seasons or teams for example are being considered. The previous studies have not clarified how many performances are considered 'enough' for the calculation of a consistent mean. The methodology developed by Hughes et al. (2001b) was used in this study to quantify the existence of consistent means for any of the match descriptors. If consistency was observed the procedure calculated how many matches had to be analysed before the variance was reduced to an acceptable level. This study found that stable means were established for 6 match descriptors and 3 ratios after the analysis of a maximum of 10 matches. It also shows that many of the match descriptors did not show consistent performance profiles, even after the analysis of 10 matches. It can thus be stated that after the analysis of 10 hockey matches a combination of invariant (or consistent), and variant (or inconsistent) match descriptors exists. This supports the findings of McGarry and Franks (1994 and 1996) who analysed 6 matches (2 semi finals and a final, and 3 qualifying matches) and found that variant and invariant behaviours coexist in competitive squash.

The number of matches that had to be analysed before a consistent profile was observed for the invariant match descriptors or ratios varied greatly. Four descriptors (the percentage of time in possession of the ball, the percentage playing time, the amount of time spent in the attacking midfield area of the field and the ratio of shots at goal to the number of goals) required the analysis of only two matches to elicit a consistent profile. However, the five remaining factors (the amount of time spent in the defending midfield area of the field, the number of goals scored, the number of goals from short corners, the ratio of goals scored from short corners to the number of short corners and the ratio of the number of shots at goal to the number of short corners) required the analysis of between 8 to 10 matches before showing signs of consistency. It would be interesting to note if additional normative profiles occurred or if greater stability could be established if the matches in the second half of the season were analysed. Comparisons could then be made between playing performance in different seasons or even for different coaches. This type of information relating to performance should be made a priority if the behaviour in future sporting competitions is to be explained and optimised (McGarry and Franks, 1996).

It is unclear whether the number of matches analysed or the type of analysis performed on the data influenced the findings of this study. For example, studies into squash found that initial modelling of competitive performance was limited in its ability to predict future performance (McGarry and Franks, 1994). A later study established that the analytical conditions that were previously used greatly reduced the chances of finding invariant behaviours (McGarry and Franks, 1996). By analysing the location in the court that the shot was played, in addition to the type of shot, McGarry and Franks (1996) were able to identify more invariant or consistent behaviours than in the previous study where only shot selection was recorded (McGarry and Franks, 1994). It would be therefore advisable in future studies to identify where possible, the location on the field where a particular match descriptor occurred. For example, if the position on the field (right, left or centre) of match descriptors such as circle entries, free hits or shots at goal were given more invariant behaviour might have been found. A similar subdivision (right, left or centre) could be applied to the location of the ball e.g. right sided defense, left sided defense or central defensive. It is also however acknowledged that variance will exist in sports, and will be independent of the number of matches analysed or the type of statistics used.

The match descriptors that were the most stable in this study were all related to the positioning of the ball during the matches. The majority of the play was within the attacking half of the field. This was to be expected of a team that was consistently dominating their opposition (55 goals scored and only 6 conceded). The team also had almost 60% ball possession, which also illustrates the domination of the team that was studied. In the match that the team lost their ball possession was 45%. This therefore supports the view that the quantity of ball possession has a strong influence on success. However, it is over-simplistic to state that for success during matches a team needs to keep the ball in the attacking area of the field and maintain a higher level of possession than their opponents. There are critical events during a game that need to be identified in order to influence the ability of a team to score goals (McGarry and Franks, 1996). This study found that a goal was scored every 4.6 shots and for every 2.6 shots at goal a short corner was awarded. The reasons for the failure of the other shots are unclear. This type of information may provide the coach with greater insight into the team's performance than just providing a simple ratio of successful outcomes to the number of attempts. This may be especially true when statistics such as the ratio of goals from short corners are known, i.e. 2.3 ± 1.4 goals from 11.3 ± 5.5 short corners.

The data presented above have just focused on matches where the opposition is constantly changing from game to game. When the data from two games with the same opponent were analysed, there were far more consistent or invariant behaviours observed. Significant differences were observed for only 2 (number of short corners awarded and the number of shots the opposition had at goal) of the 15 match descriptors. These data concur with that of McGarry and Franks (1994, 1996) who found that two players exhibited general consistency in their playing patterns when they played each other (1987 final and subsequent 1988 semi-final). Additional matches against these two teams would have to be analysed to determine if predictions about future performance could be accurately made from these data. However, this does suggest that if two games are played against the same opponent during a season, that analysis of the first match's performance can give insight into the performance during the second match, independent of the location of the match.

This study has so far concentrated on the quantification of match descriptors between different matches. These findings suggest that there is a combination of variant and invariant behaviours present within hockey. However, the qualitative analysis of performance has so far not been investigated. According to Hughes and Franks (1997) observation of performance and subsequent visual feedback is of great importance to the coach and athlete. A simple subjective visual analysis was conducted during this study by three experienced observers who looked at the defending formation of short corners. It was concluded that the formation was not visually different, i.e. the players ran to similar positions each time, over the different short corners or the matches. Information of this nature can assist coaches with the development of their team. If an invariant behaviour proves to be a successful one, then no changes need to be made but, if the behaviour is unsuccessful then the required changes can theoretically be made. The requisite alterations to performance may be very subtle in nature and may not have been observed during the pressure of competition but only later during the visual analysis.

In summary, this study has shown that invariant sporting behaviour coexists with variant sporting behaviour in club-level competitive field hockey. The degree of variation in behaviour increases when the opposition are continually changing; when the opponents remain consistent the degree of invariant behaviour increases. Due to the combination of invariant and variant behaviour within the match descriptors it may be of more use to the coach or players to investigate the factors governing successful and unsuccessful performance irrespective of whether they are quantitative or qualitative. It is also important to recognise the importance of qualitative visual feedback for sporting performance and the coaching process. This type of feedback provides information on the technical aspects of performance that cannot be quantified and could therefore be overlooked if only quantitative analysis was conducted.

The final study of this thesis investigates further how qualitative visual feedback can be used to enhance sporting performance.

CHAPTER 9

THE USE OF QUALITATIVE VISUAL FEEDBACK TO ENHANCE SKILLED PERFORMANCE DURING HOCKEY MATCHES.

9.1 INTRODUCTION

Notational analysis has generally focused on a quantitative retrospective analysis of sporting data to generate models of either the physical or technical aspects of the sport, from which future inferences about performance are made (Reep and Benjamen, 1968; Reilly and Thomas, 1976; Lewis and Hughes, 1987; McLean, 1992; and Treadwell, 1992). Studies by McGarry and Franks (1994, 1996) have shown that there is much variation in the data describing squash. It is reasonable to assume that this also applies to other sports. Hughes et al. (2001b) have also addressed the variability that occurs when describing specific events (match descriptors) that occur in sport and have described a method to calculate the minimum number of matches that need to be analysed for consistent performance profiles of a match descriptor.

Chapter 8 established that general numerical descriptors of hockey (goals conceded, number of circle entries, shots at goal, long corners, free hits etc) require the analysis of multiple matches before trends in performance can be determined. However, matches between the same opposition did elicit similar or invariant behaviour (Chapter 8; McGarry and Franks, 1994). This occurred despite the results of the matches being different (game 1 lost 2 – 5 and game 2 won 3 – 2) and both teams having a similar number of potential goal-scoring opportunities (circle entries and short corners). In addition, the qualitative analysis of match descriptors (defensive short corner formation) from Chapter 8 elicited a very consistent performance whether the analysis was conducted intra- (that is the defensive short corner formation was consistent during a match) or inter-match (the defensive short corner formation was consistent between matches).

On the assumption that there is invariant behaviour of certain match descriptors when playing against the same opposition, it could be suggested that the half-time interval divides a match into two separate, but similar matches. If this were the case the provision of feedback during the half-time interval could be similar to comparing performance of the same teams on different occasions. Therefore any observations noted and analysed during the first half of the game, for example the defensive short corner formation of the opposition, could be discussed during the interval and used strategically in the second half of the match.

With this as background, the first aim of this study was to establish whether post-match analysis and subsequent visual feedback of skilled performance could enhance sporting performance. The second aim of the study was to determine whether real-time analysis and subsequent feedback during the half-time interval, could provide adequate visual feedback of the events that occurred during the first half of the match to effectively enhance technical performance during the second half of the match. The information collected in this study is predominantly qualitative and therefore the results and discussion should be interpreted within this context.

9.2 METHODS

Eleven hockey matches were recorded with a domestic video camera (Sony® Handycam Vision™ CCD- Video Camera Recorder TRV 46E, Japan) during the 2001 season (28 July – 1 September). The matches were at both club (Western Province Hockey Union Grand Challenge league Cape Town, n = 6) and provincial (Spar Inter-provincial Tournament, Randburg, n = 5) level and involved female players. The location of the camera could not be standardised due to differing facilities around each ground. Nevertheless, for each match the camera was positioned in the stands as high above the ground as possible.

Each hockey match was filmed for the entire duration (70 minutes) with the exception of the WP vs. KZN match which was only recorded for 35 minutes due to the coach requiring information on another team playing at the same time as this match. All match recordings were analysed using a digital analysis software programme (Sports Code version 3.1, Sportstec, New Zealand). Before the analysis began the coach requested specific aspects of the hockey match to be analysed. Generally these aspects of the match consisted of attacking and defending play, short corners and the play of specific players that the coach wanted more information on. The analysis was conducted either post-match (n = 11) or in real time (as the match was taking place, n = 8) or a combination of post-match and real time (n = 8). An independent panel of qualified hockey coaches (n = 3) was asked to analyse visually the video clips of the short corner formation of the defending teams to determine whether consistent patterns could be identified. The observers were allowed to watch the video clips as many times as they needed to and at whatever playback speed they required.

Feedback of the specifically requested events was given to the coach and the players. Visual feedback was given in the form of video clips (qualitative information) that were played at normal or slow speed depending upon the detail required. The post-match feedback sessions lasted about 30 minutes and generally took place 2.5 hours before the start of the next match. The players were permitted to see the video as many times as they deemed necessary to attain all the information from the clip. The coach, with assistance from the captain made tactical changes to the teams as a result of the information from the match analysis. The real-time feedback took place during the half-time interval of the match. The feedback was of the defensive formation of the opposition. The video clips were initially shown to the players at normal speed and then replayed and paused to show the formation of the opposition at the various positions leading up to the ball being stopped at the top of the circle. The players then used this information to develop their attacking short corners formation for the second half of the match. The half-time interval was 10 minutes, during that period the players had to have verbal feedback from the coach (6 minutes) and receive visual feedback (2 minutes) and get back onto the field ready to start the second half. No verbal feedback was supplied by the video analyst during the half-time interval.

9.3 STATISTICAL ANALYSIS

Data are presented as the mean and standard deviation.

Chi-square (χ^2) tests were used to test for differences in match descriptors between the different matches. Normative performance profiles were calculated (Hughes et al., 2001b) when the χ^2 test found no significance differences in the frequency of the data between the matches. A description of the calculation for a normative profile was provided in Chapters 3 and 8.

9.4 RESULTS

9.4.1 Post-match Sports Code Analysis

Databases for 6 teams (WP, EP, WITS, KZN, NW, SG) in the Spar Inter-provincial tournament were created on the following parameters;

- Circle entries right, left and centre
- Defensive play
- Short Corners, attacking and defending
- Specific individual play
- Midfield play

Each match descriptor was analysed by the coach for specific movement patterns to determine how they could be either improved upon or counteracted in subsequent matches. The short corners were examined in greater detail for two specific reasons;

- To determine if a consistent defensive formation was adopted during the different games as found in the previous chapter (Figures 9.1 – 9.8).
- To establish if there were any areas of weakness in the set pieces that could either be exploited (opposition) or improved (own team).

Analysis of the post-match data using Chi-square found that the number of circle entries when grouped together did differ significantly between the 4 games (WP vs. KZN not included in the calculation because only half of the match was recorded). When analysed separately (the location of the circle entry left, right or centre), no significant differences were found in the number of left-sided circle entries and circle entries made in the centre of the circle by the opposition between matches. Left-sided and central circle entries stabilised (< 5% variation) after the analysis of 3 matches (Figures 9.1 and 9.2).

Table 9.1: Summary of Post-match Provincial Parameters

	WP vs. EP		WP vs. WITS		WP vs. KZN+		WP vs. NW		WP vs. SG	
	WP	**EP**	**WP**	**WITS**	**WP**	**KZN**	**WP**	**NW**	**WP**	**SG**
Circle Entries (right) *	33	9	9	11	3	5	18	2	3	15
Circle Entries (left)	8	2	6	4	10	0	14	4	9	21
Circle Entries (centre)	19	9	6	7	3	3	11	4	4	8
Short corners (attacking)	11	2	10	4	7	1	19	3	7	6
Short corners (defending)	2	11	4	10	1	7	3	19	6	7
Result	WP 4 – 1		1 - 1		WP 3 – 0		WP 3 - 0		SG 2 – 0	

* denotes significant difference between the matches P < 0.01
+ denotes only 35 minutes of the game was recorded and analyzed.

Analysis of the post-match data using Chi Square found that the number of attacking and defending short corners, did not differ significantly between the 4 games (WP vs. KZN not included in the calculation because only half of the match was recorded). Although no significant differences were observed between the number of short corners attacking or defending, they did not produce stable normative profiles (Hughes et al., 2001b) (See Chapter 3 for definition of a normative profile).

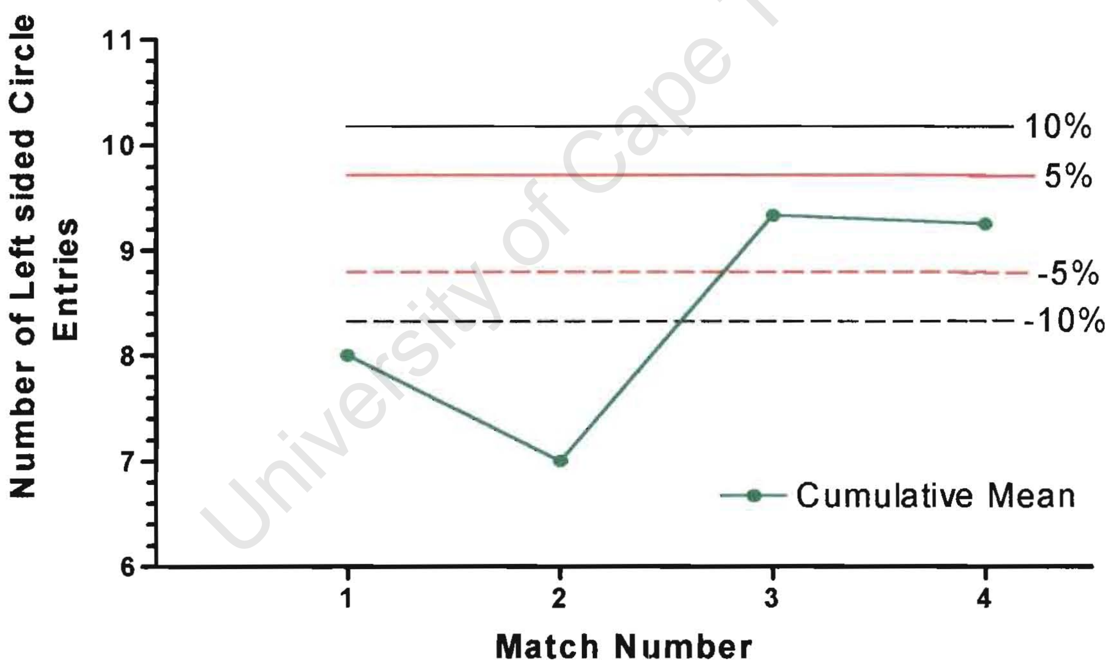

Figure 9.1: % Difference plot for the cumulative mean number of left sided circle entries by the opposition.

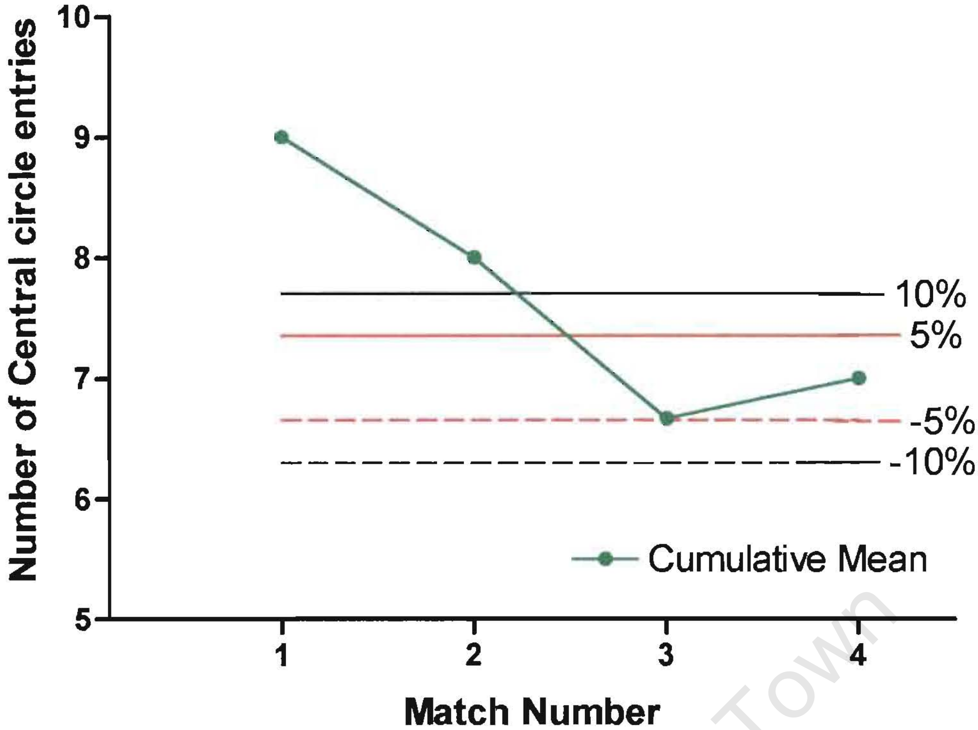

Figure 9.2: % Difference plot for the cumulative mean number of circle entries from the center of the circle by the opposition.

The video clips of the short corners were analyzed in two places before the ball was pushed out and once the ball had been stopped by the attacking team before any shot or pass.

Observing the attacking formation of the same team, it can be seen that there was great variation between the position of the attacking players for the different short corners (Figures 9.3a – 9.5b). The attacking players are positioned around the edge of the circle. The central figure (1) stops the ball and the other players are arranged around her. The positioning of the players determines where the ball is going to be played during the short corner.

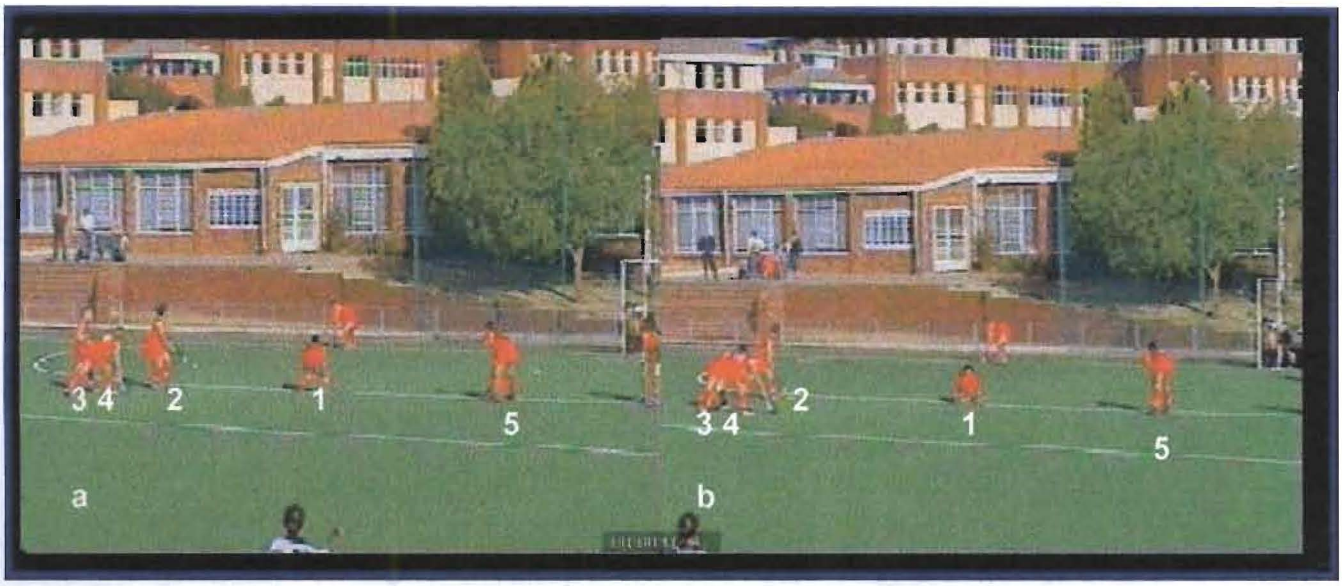

Figure 9.3: Differences in Attacking Short Corner line-up formation within the same game WP (red) vs. KZN.

Figure 9.4 Differences in Attacking Short Corner line-up formation within the same game WP (red) vs. SG.

In Figure 9.3 the position of player 2 is different in Figure 9.3a and Figure 9.3b. Player 2 is located on the right side of players 3 and 4 in Figure 9.3a and then on the left side of players 3 and 4 in Figure 9.3b. In Figure 9.4a there are two players on the left side of player 1 however, in Figure 9.4b there are no players on the left of player 1.

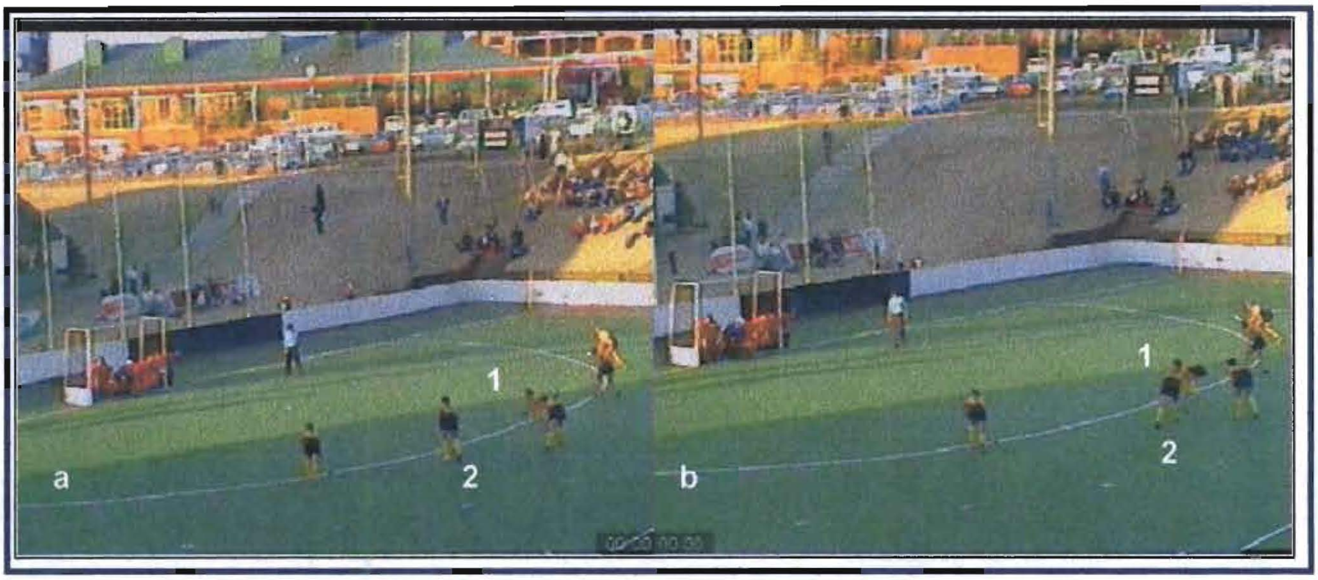

Figure 9.5 Differences in Attacking Short Corner line-up formation within the same game SG vs. WP (red).

In Figure 9.5a player 2 is positioned further to the left of player 1 than in Figure 9.5b.

Similarities could be observed in the formations of the defending team. By careful examination of Figures 9.6a & b & 9.7a & b by the 3 independent observers it was seen that each team had their own defensive formation. For example, player 2 in Figures 9.6a & b runs from a position that is further from the goalkeeper than player 2 in Figures 9.7a & b. This, however, did not vary between the different short corners, during the phase between the push-out and the ball being stopped (Figures 9.6a & b & 9.7a & b).

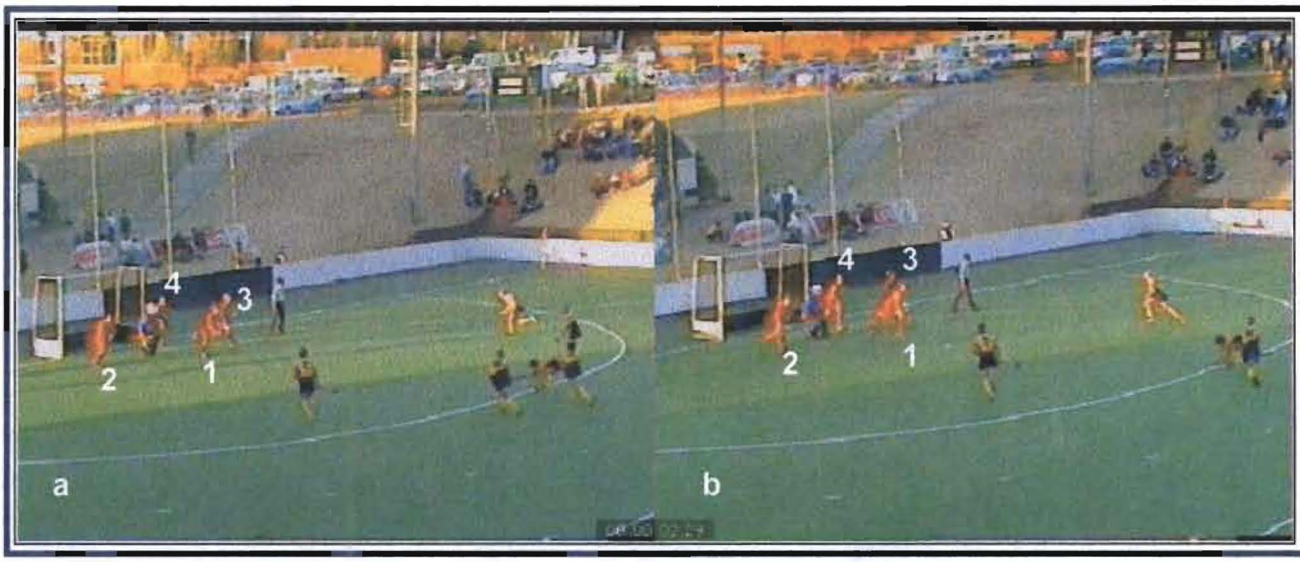

Figure 9.6: Short Corner positioning of both attacking and defending team once the push-out has been stopped (SG vs. WP (red)).

Figure 9.7: Short Corner positioning of both attacking and defending team once the push-out has been stopped (WP (red) vs. SG).

Prior to the WP vs. KZN match tactical observations were noted by the coach during post match analysis of a KZN match against other opposition. The information attained from this analysis of the KZN midfield play resulted in a strategic change, made by the coach in the midfield formation of WP. The central midfield player for WP was required to adopt a position closer to the strikers than in previous matches (Figure 9.8). This change in formation does not affect match statistics and therefore can only be represented visually (Figures 9.9 –9.12).

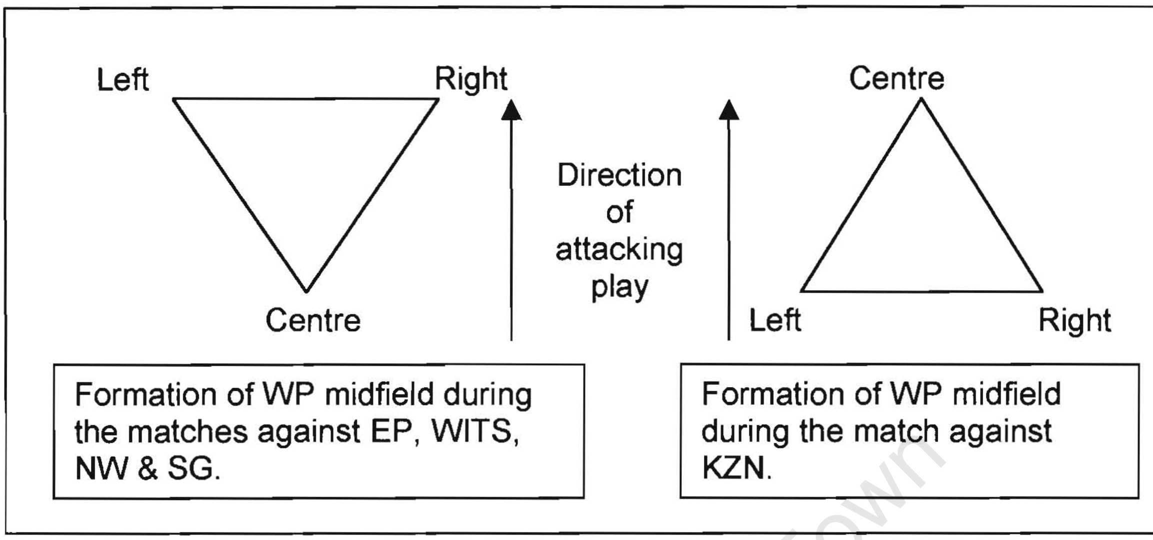

Figure 9.8 Diagrammatic illustration showing changes in the strategy of the midfield players for WP during the 5 matches.

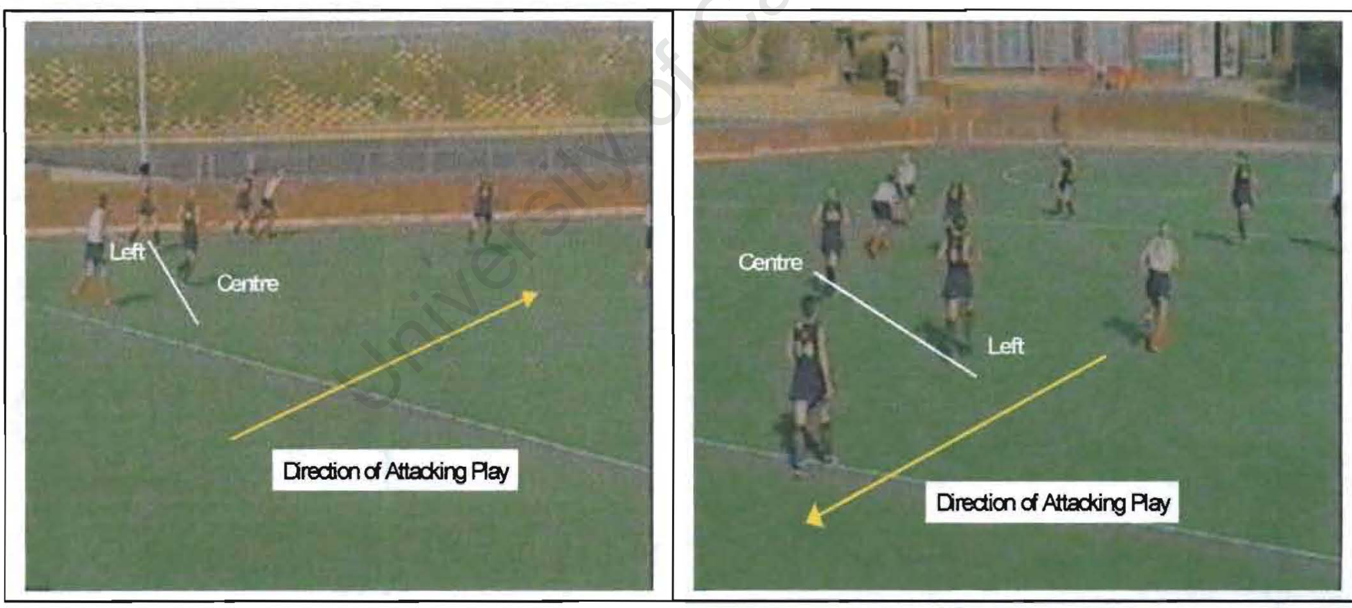

Figure 9.9: Midfield formation during the WP (blue) vs. EP match indicating the location of the midfield players and the direction of play.

Figures 9.9, 9.10 and 9.11 are very similar and show the central midfield player behind the line of the right and left sided midfield players (as shown diagrammatically in Figure 9.8). However Figure 9.12 shows the central player ahead of the other two midfield players which reflects the tactical change implemented by the coach for the match against KZN.

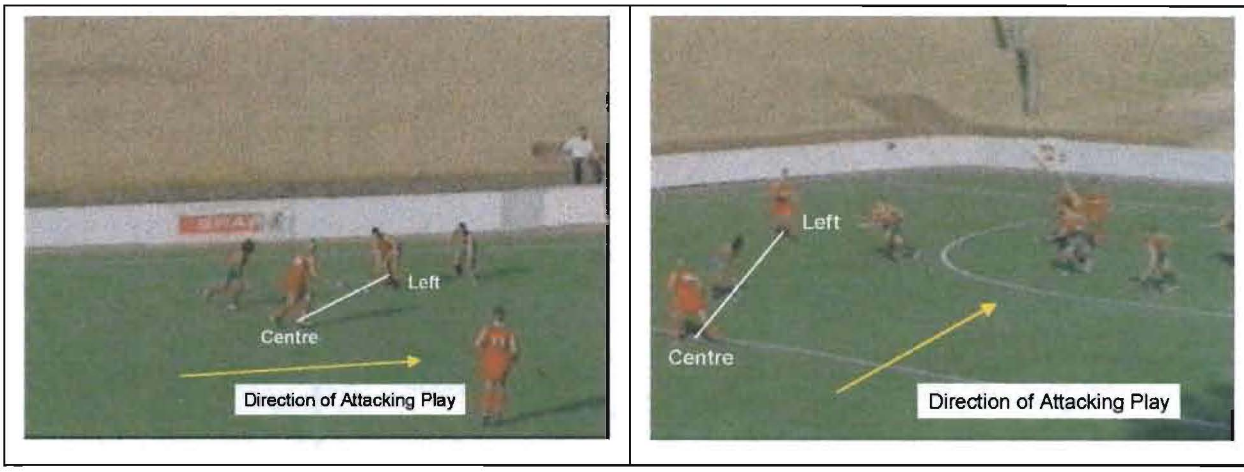

Figure 9.10: Midfield formation during the WP (red) vs. NW match indicating the location of the midfield players and the direction of play.

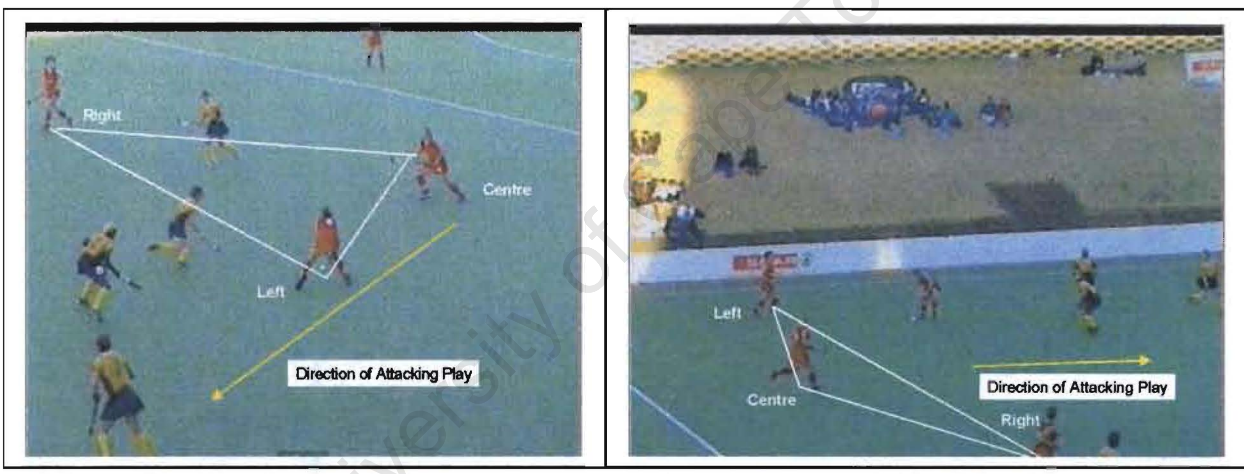

Figure 9.11: Midfield formation during the WP (red) vs. SG match indicating the location of the midfield players and the direction of play.

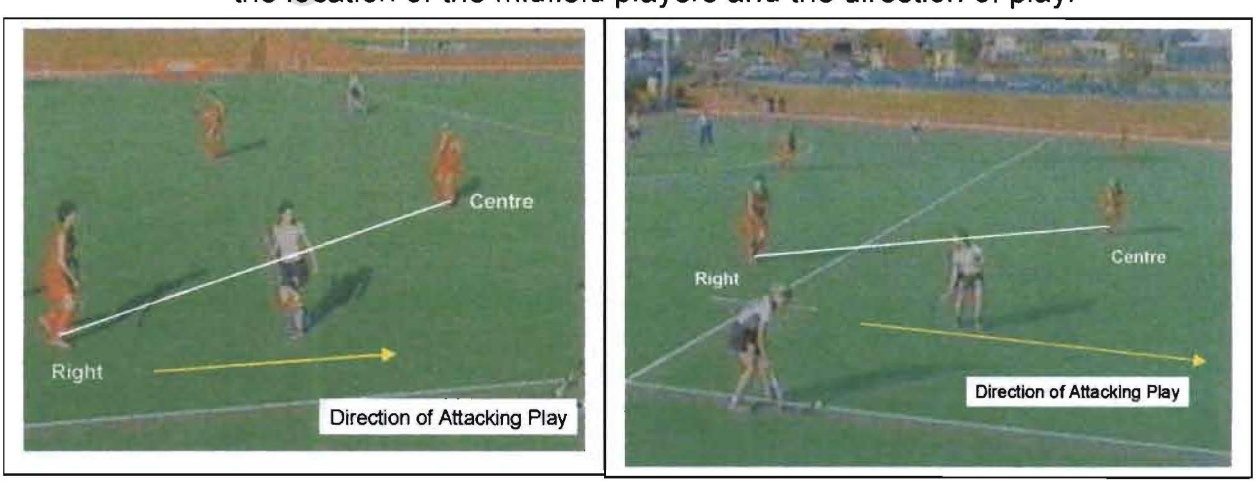

Figure 9.12: Midfield formation during the WP (red) vs. KZN match indicating the location of the midfield players and the direction of play.

Post-match (about 5 days later) analysis of a club-level league match was performed to establish areas of play that required a strategic change after losing (2 – 5 game 10 chapter 8). This opposition was played a second time later in the season and the result was reversed, winning 3 – 2. Analysis of the first game found that the opposition was allowed a great deal of space and time in their defensive areas of the field, ref Chapter 8, Figure 8.1 for the description of playing area. Photographs representing this are shown in Figures 9.13a, b, c & d.

Figure 9.13: Photographs taken from Game 10 (Chapter 8) illustrating the location of players around the ball while the opposition (white shirts) are in defensive areas of the field.

Figure 9.14: Photographs taken from Game 11 illustrating the location of players around the ball while the opposition (yellow shirts) are in the defensive area of the field.

Figure 9.13 illustrates how much space the team in white, i.e. few green shirts in the picture, had in the first match played. In contrast, in Figures 9.14 the space allowed to the opposition (this match in yellow shirts not white of the previous match) was greatly reduced by the increased number of green shirts. The photographs, wherever possible where taken at equivalent time points. Figures, 9.13 – 9.14 clearly illustrate the much tighter marking of the opposition's defensive play during the second game (match 11) than was previously undertaken in the first match (match 10).

9.4.2 Real-time Sports Code Analysis.

The defensive short corner formations were similar during the 1st half and visual feedback as to the location of the defenders was provided at the half-time interval (see Chapter 8 and Figure 9.15). Of the 8 matches analysed using real-time feedback only 2 matches, 1 provincial and 1 club incorporated tactical changes. Subsequent changes were made and in the case of the provincial match WP vs. NW resulted in 2 goals being scored. Figures 9.15 illustrates the formation adopted by the defensive team (green and red). It can be seen from figure 9.15 that players 1,2 and 3 run out from the goal in a triangle formation with player 1 being the apex. Player 4 remains next to the goalkeeper on all occasions.

Figure 9.15: The defensive formation adopted by NW during the game against WP for both the first (a&b) and second halves (c&d).

Figure 9.16: A representation of the opposition's (green & red) weaknesses observed using visual analysis.

Figure 9.16 illustrates the running formation of NW (green and red). Due to this formation NW leave gaps between the goalkeeper and the posts, areas circled in Figure 9.16. These areas were exploited by WP (red) and Figure 9.17 a, b & c illustrates this.

Figures 9.17 and 9.18 very simply illustrate how the ball was played around the circle, from the point where the ball was stopped (Figures 9.17a & 9.18a), where the ball was moved around the circle (Figure 9.17b & 9.18b) to the final shot at goal (Figure 9.17c & 9.18c), by WP (red) to exploit the areas of weakness shown in Figure 9.16 to score their 2 goals.

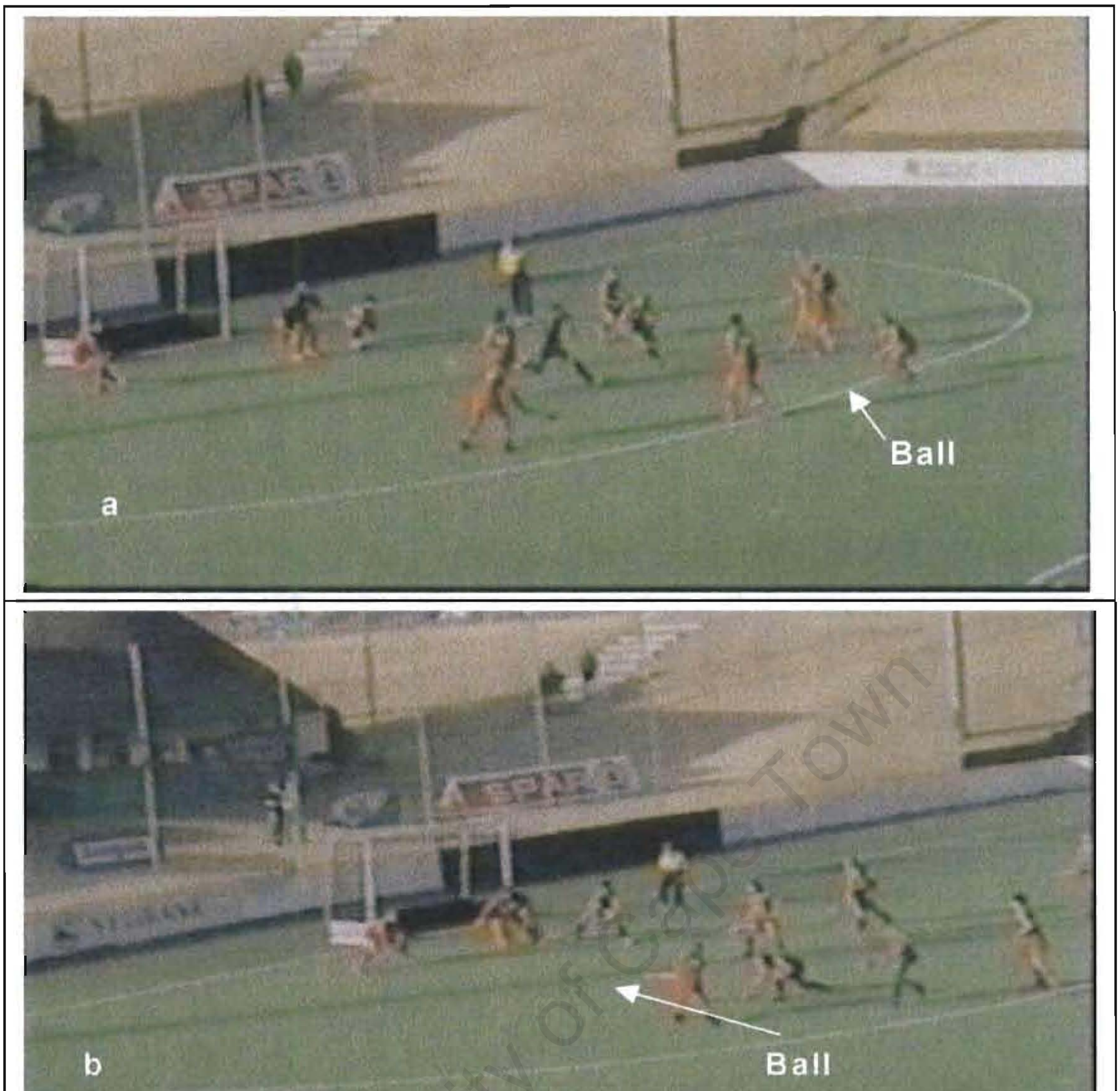

Figure 9.17: The sequential positions of the players and the ball illustrating how a goal was scored from a short corner.

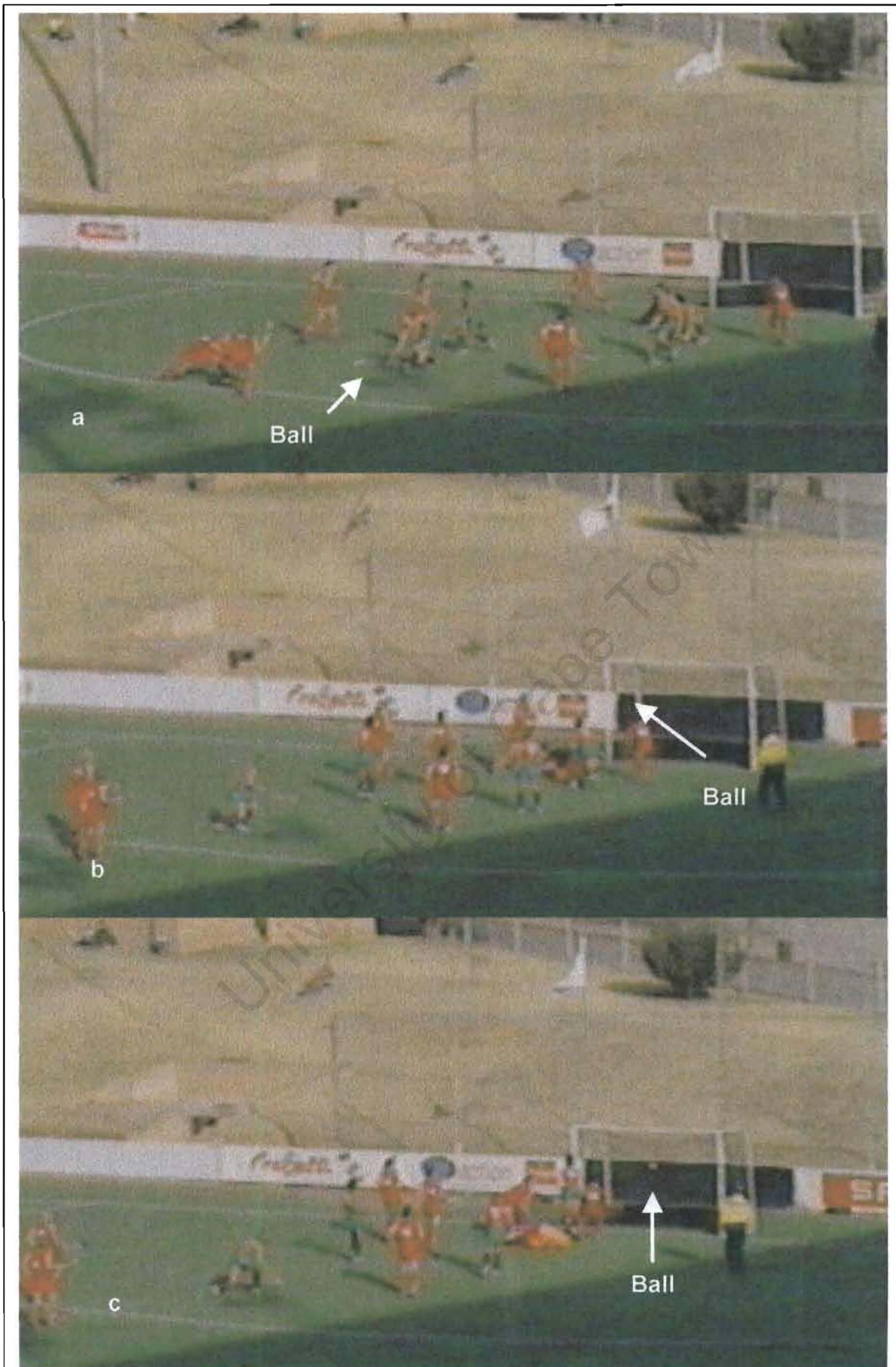

Figure 9.18: The sequential positions of the players and the ball illustrating how a goal was scored from a short corner.

The same effect was found with club-level league matches, only the final execution was not as effective on that occasion.

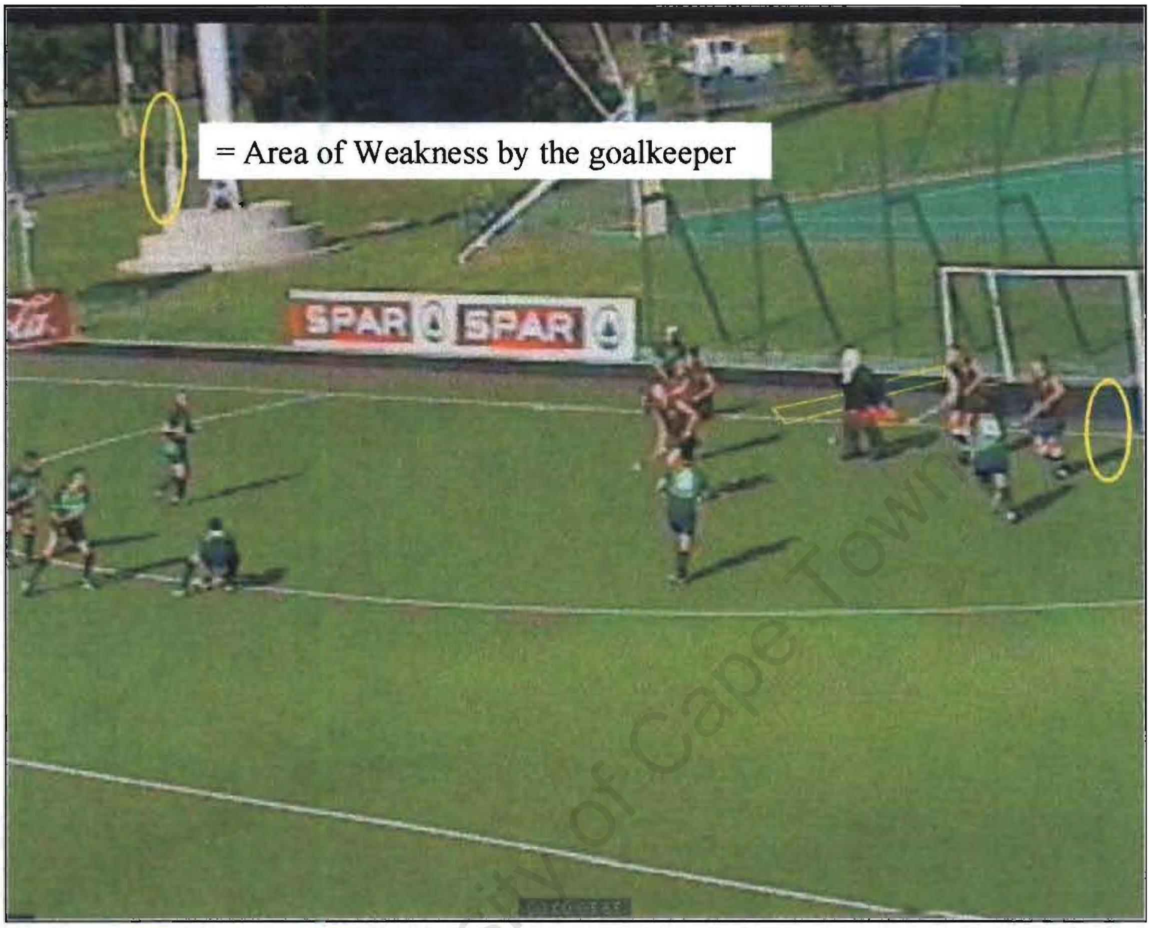

Figure 9.19 A representation of the opposition's (blue) weaknesses observed using visual analysis.

Figure 9.19 illustrates the areas of weakness around the goalkeeper that were observed during real-time analysis and displayed during the half-time interval. Figures 9.20 simply illustrates how the ball was played around the circle, from the point where the ball was stopped (Figures 9.20a), where the ball was moved around the circle (Figure 9.20b) to the final shot at goal (Figure 9.20c & 9.18c), by CB (green) to exploit the areas of weakness shown in Figure 9.19.

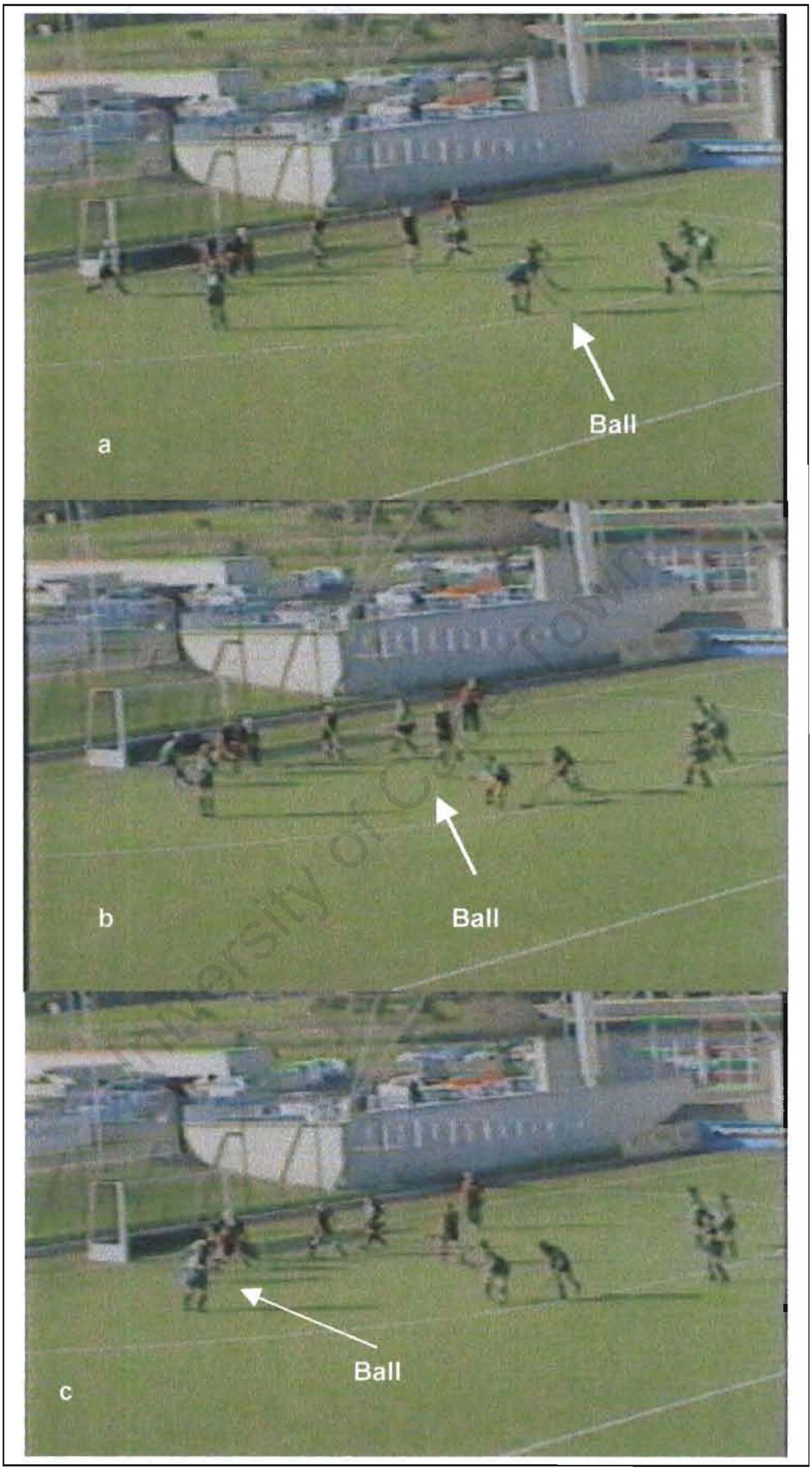

Figure 9.20: The sequential positions of the players and the ball illustrating how the space around the goalkeeper was exploited.

9.5 Discussion

The purpose of this study was to determine whether visual feedback could be used to enhance competitive sporting performance. Qualitative rather than quantitative visual feedback was provided during the study. This was due to the variation in performance that was found in Chapter 8 when the match descriptors were quantified. However, when performance for certain match descriptors was simply observed in a quantitative way for patterns of similarity, consistency was established. For example, the formation of the short corner defence appeared to be consistent when analysed by three independent observers.

The main finding of this study was that qualitative visual feedback could provide coaches and players with information that could be used to enhance elements of competitive skilled performance. Work by Hughes and Crowley (2001) has also highlighted the importance of providing qualitative visual feedback. The findings of this study (Chapter 9) applied to when the analysis was done after a match or when the analysis was performed during the first half and the results were reported and discussed at half time. The quantity of feedback that could be given during post-match analysis was limited only by the amount of information required by the coach. In this study the post-match visual feedback was used to determine playing patterns of the opposition during open play and which players of the opponent's team were the most influential. The application of real-time analysis was limited to simple events such as set pieces for this phase of the study. The practical limitation of time during the half time interval (10 minutes) was the reason for only analysing the set pieces. The amount of time the coach required to analyse the video clips and develop tactics for playing formations (10 to 30 minutes) is far greater than the time needed to process information on set pieces (1 - 2 minutes). The half-time interval was 10 minutes. During that period the players had to have verbal feedback from the coach (6 minutes) and receive visual feedback (2 minutes) and get back onto the field ready to start the second half. During that time the coaches need to give verbal feedback and evaluate what the players are feeling and make appropriate changes for the second half before having time to incorporate additional visual feedback. From a practical perspective this leaves a very short time, approximately 1 minute for visual feedback to the team and the development of the appropriate tactical responses. Therefore, the visual feedback has to be implemented within these practical constraints.

A quantitative analysis was conducted on the circle entry and short corner data collected post-match. It was seen from this simple analysis that the way in which the data were analysed affects the identification of invariant behaviour, supporting the work of McGarry and Franks (1996). For example, if the circle entries were analysed as a single entity then the data suggest that much variation exists with this match descriptor. However, if the circle entries are categorised by location, i.e. left, right and centre, then invariant behaviour can be identified. The circle entries from the left and the entries from the top of the circle by the opposition displayed invariant behaviour after the analysis of three matches.

In summary, this study has established the importance of visual feedback as a method for enhancing competitive performance during field hockey. Analysis of the performance of either simple or complex activities can result in the detection of successful and unsuccessful behaviours. The dissemination of this information is key to determining whether visual feedback enhances or negates performance. The success of visual feedback depends upon the skill of the coach or athlete and the type of feedback provided (Hughes and Franks, 1997). It is therefore suggested that the relationship between the sport analyst and the coach (coaches) is of paramount importance. The information must be related to a specific area of performance requested by the coach. In addition, the feedback must also be presented in a way that the athletes can understand what is being shown to them. The subjective efficacy of visual feedback shown in this study cannot simply be related to the provision of visual feedback but also on the interaction of the sports analyst and the coach to provide the team with the most relevant information required to enhance their performance.

CHAPTER 10

SUMMARY AND CONCLUSIONS.

The purpose of this thesis was to determine the efficacy of visual feedback to enhance sporting performance, specifically in hockey. The thesis was divided into two areas, physical and skilled performance and subsequently subdivided into five research questions:

1. What are the physical demands of the 'modern' female field hockey match?
2. Is the 5-m Multiple Shuttle Test (5-m MST) a reliable test for female hockey players?
3. Is the 5-m MST a valid test for determining fitness levels for female field hockey players?
4. Can a normative profile for match descriptors of field hockey performance be established after half a season?
5. Can visual feedback be used to enhance skilled performance during competitive hockey matches?

1. What are the physical demands of the 'modern' female field hockey match?

The study established that female club level field hockey players cover on average 3914 m during a match at an average speed of 0.99 $m.s^{-1}$. The range of speeds and displacements recorded together with the frequent changes in direction all demonstrated the random nature of the movement patterns in hockey. There were also significant differences observed in the displacement covered between the 1st and 2nd halves of the games and the different matches once again making performance predictions difficult. Although the data suggests that the differences between 1st and 2nd half performance could be due to fatigue this is unlikely. The data for game 1 in this study suggests that the decrease in performance is not a fatigue response because there is actually an increase in physical performance during the 2nd half of the match. This finding suggests that factors other than fatigue affected second half performance in the other two matches. The subjective ratings of pre match preparation were the same for each of the three games. Therefore, it may be suggested that a change in playing tactics caused the change in physical performance during the 2nd half of the match.

The data can be used to aid the fitness coaches with their prescription of training programmes. From this study it would be suggested that a training programme for hockey should be designed to prepare the players for running up to 4000 m with bouts of high intensity activity interspersed with bouts of low intensity. The ratio of high to low intensity exercise would be attained from work to rest ratios but due to the limitations of this study, this calculation was not possible.

In addition to developing the endurance capacity of the players, their speed and agility components must also be trained. This statement is demonstrated by the range of speeds and displacements and the variation in movement patterns that were observed during this study. These findings supports the suggestion of Mafe (1998) that fitness training has to move away from the conventional 180^0 change in direction. Rather, players should train in a more 'sport related' way which incorporate the specific movement patterns that occur during a game (Mafe, 1998).

The data from this study is a useful starting point to establishing the physical demands of the 'modern' game of field hockey although, there were several associated limitations. The main limitation of the study was the limited number and the quality of the cameras available. To extend and improve on the quality of the data collected from this research project several recommendations should be included:

- The number of cameras used to film the matches should be increased (a minimum of two each side of the field) and they should be as near to broadcast quality as possible.
- The time interval between each data point should be reduced to as close to zero as possible. This will require the development of a tracking system that can follow the movements of all of the players during the game.
- Additional data pertaining to time spent in possession of the ball would contribute to understanding the demands of the 'modern' game of hockey.
- Increase the number of matches analysed and also analyse games of higher standard (provincial or international) to assess the differences in physical performance between different levels of playing experience.

2. *Is the 5-m Multiple Shuttle Test (5-m MST) a reliable test for female hockey players?*

This study found that heart rate and total distance covered during the test were the most reliable components of the test whereas the fatigue components (delta distance and fatigue index) were the least reliable components and should be used with caution when the results are interpreted. The findings from this study compared well with other field tests that have been subjected to a similar evaluation.

This study (Chapter 6) also suggested that the 5-m MST is sensitive to track major changes in fitness over time. The practical application of this finding is that changes in performance of the 5-m MST during phases of the season can be interpreted as changes in fitness rather than just error associated with variation in test performance. Further studies into this area are needed to establish the precision of the test and the magnitude of change in fitness that can be detected by the 5-m MST.

The poor reliability of the fatigue components of the 5-m MST suggests that there is a learning period associated with pacing during the test. Therefore, subjects need to be familiarised with the testing process before data are collected. The fatigue data from this study stabilised after three repeats of the test. Once the subjects have been familiarised with the 5-m MST, studies into the effect of fatigue in repeated sprint tests could be conducted. The conclusions could then give an insight into how fatigue could be reduced in team sports.

3. *Is the 5-m MST a valid test for determining fitness levels for female field hockey players?*

Two general types of validity were investigated (indirect and direct). A general comparison of the components of the 5-m MST and the physical characteristics of team sports found a logical validity to exist for the 5-m MST. The relationships between established fitness tests (the 20-m Multiple Shuttle Test and the 40-m Sprint) and the 5-m MST were determined. The strongest relationship existed between the $VO_{2\ max.}$ estimated from the 20-m MST and the total distance covered during the 5-m MST. Other low to moderate relationships existed between the components of the 5-m MST and either sprint ability or endurance capacity. These observed relationships concurred with the requirements for criterion validity. The final indirect form of construct validity was conferred when there was a clear distinction between the performance of provincial and non-provincial players during the 5-m MST.

Data from Chapter 5 and from the 5-m MST were compared to establish whether the results of a fitness test could be related to sports performance. There were significant relationships between the displacement per minute playing time and the mean displacement or speed and the components of the 5-m MST. Although these relationships would be considered low to moderate predictors of performance in other circumstances, the complete randomness that is associated with team sports and the numerous factors that influence the outcome of matches make any prediction of team sport performance a difficult task. Therefore, these can be interpreted as significant relationships with a significant practical outcome.

Further research needs to investigate whether changes in fitness according to the 5-m MST effect a change in physical performance during competition. If the specific movements of each player had been characterised during the time-motion study it would have been useful to investigate the association between high-intensity activity as recorded during competition and the 5-m MST data.

4. *Can a normative profile for match descriptors of field hockey performance be established after half a season?*

This study found that 8 out of the 14 match descriptors did not have a stable profile even after 10 matches had been played. These 8 unstable descriptors were; circle entries, attacking and defending short corners, shots at goal, number of goals conceded, long corners, free hits and ratio of shots at goal: goals scored from short corners. The remaining 6 descriptors had normative profiles, some of which were very stable. The 6 stable descriptors were; % ball possession, % playing time and % time in the attacking midfield area of the field, which stabilised after only one match, and % time in the defending midfield area of the field, number of goals scored and number of goals scored from short corners which only stabilised after 7 to 9 matches.

Two matches against the same opposition were analysed. A comparison was made between the match descriptors to determine whether similarities in performance existed between different matches when the opponent remained constant. The only differences that existed were the number of short corners, the number of shots at goal by the opposing team and the final result, (lost first game 5-2 and won second game 3-2). It was therefore concluded that similar performance profiles existed when the opposition remained consistent.

A qualitative analysis of the formation used in all the defensive short corners from all the matches was also conducted. The three independent observers established that defensive short corner formation was independent of opposition or attacking short corner formation. This information can be used to establish where the strengths and weaknesses of a particular formation are. This can help the coach to select the best formation for the team, based on the strengths of the players involved.

This study identified that the quantitative description of hockey only in the majority of cases, provided information about that particular match and did not enable future performance predictions when the opposition differed. However, when the opposition remained constant performance was also consistent. It could therefore be reasonable to suggest that if a database of performance against the same opposition were to be collected then future performance could be predicted. Additional studies of this nature need to be conducted to establish if repeated performances can predict future match outcomes. It would also be interesting to develop a database on playing performance between seasons to establish whether performance profiles were specific to certain teams or coaches.

The importance of the qualitative analysis of visual feedback was also highlighted in this study. Observing similarities in performance that were independent of opposition suggests that predictions can be directly made about future performances. If this is a successful behaviour then it can be encouraged and developed. However, if this is an unsuccessful behaviour coaching interventions can be implemented to change it. The next study, (Chapter 9) considers the potential of qualitative visual feedback in performance enhancement.

The data from this study found that there was a great deal of variant behaviour associated with hockey where the opposition differed. McGarry and Franks (1994) found the same pattern when they investigated squash matches. Later, McGarry and Franks (1996) found that simple data description limited the degree of invariant behaviour or performance consistency that could be observed. However, when an additional descriptor, such as the position in the court from where the shot was made, left, right or centre, was included more invariant behaviour could be identified. It would therefore be reasonable to suggest that the level of invariant behaviour found in this study could have been influenced by the limited description of the data.

To determine whether there is a greater degree of invariant behaviour in club-level hockey than found in this study, it would be useful to increase the sensitivity of the data description. There are numerous ways in which this could be done in future studies. A few examples are listed below:

- Identify which side of the pitch the descriptor took place.
- Identify where on the pitch the movement started.
- Determine whether time is a factor.
- Determine the number of passes required for that specific performance outcome.

In addition, changing the level of analysis may be beneficial for future studies to examine the skilled performance of players and determine their level of variance or invariance in match play. This information may be useful for coaches, especially in professional sports, to help them decide on player selection. If the coaches know objectively how players respond to situations and the players around them, then better tactical and strategic decisions can be made which theoretically could lead to greater successful behaviours and winning performances.

5. *Can visual feedback be used to enhance skilled performance during competitive hockey matches?*

Visual feedback of qualitative aspects of playing performance was provided for a coach to analyse and develop the appropriate tactical and strategic responses. The information pertaining to patterns of play and player positioning during general game play needed to be provided during pre-match preparation. However, information relating to player positioning at set pieces could be given during the half-time interval and prove to be effective during the 2nd half of the match. Time was a limiting factor in processing the information and this affected the quantity of information collected. This study was able to establish that visual feedback post / pre-match and during real-time could enhance playing performance. The level of information required by the coach will determine if real-time analysis can be used or whether a more in-depth analysis is required which must be conducted post / pre match.

The level of visual feedback intervention was kept simple for these last two studies. The use of this visual feedback technology in South Africa is mainly limited to the well-funded professional sports (cricket and rugby) and therefore is novel to most coaches in hockey. Time was required to develop a rapport between the coach and the sports analyst as to the level of information that could be provided in a match situation. To extend and improve information that can be provided to coaches, studies need to investigate cause and effect relationships between successful shots at goal and those shots that prove to be unsuccessful, or 25-yard entries that result in shots at goal and those that do not even result in a circle entry. These critical events are caused by perturbations, changes in the stability of play (Hughes et al., 2001a and McGarry and Franks, 1996) and if they could be understood, predictions for future performance could be made during real-time analysis and thus have an immediate impact on performance.

Conclusion

This thesis has established that visual feedback has efficacy for enhancing sporting performance with hockey players. The understanding of hockey performance, both physical and skilled, will enable coaches to develop more appropriate training interventions. Theoretically this should result in hockey players that are better prepared for competition. In addition the evaluation of the physical requirements of hockey during competition has enabled the reliability and validity of a fitness test to be conducted.

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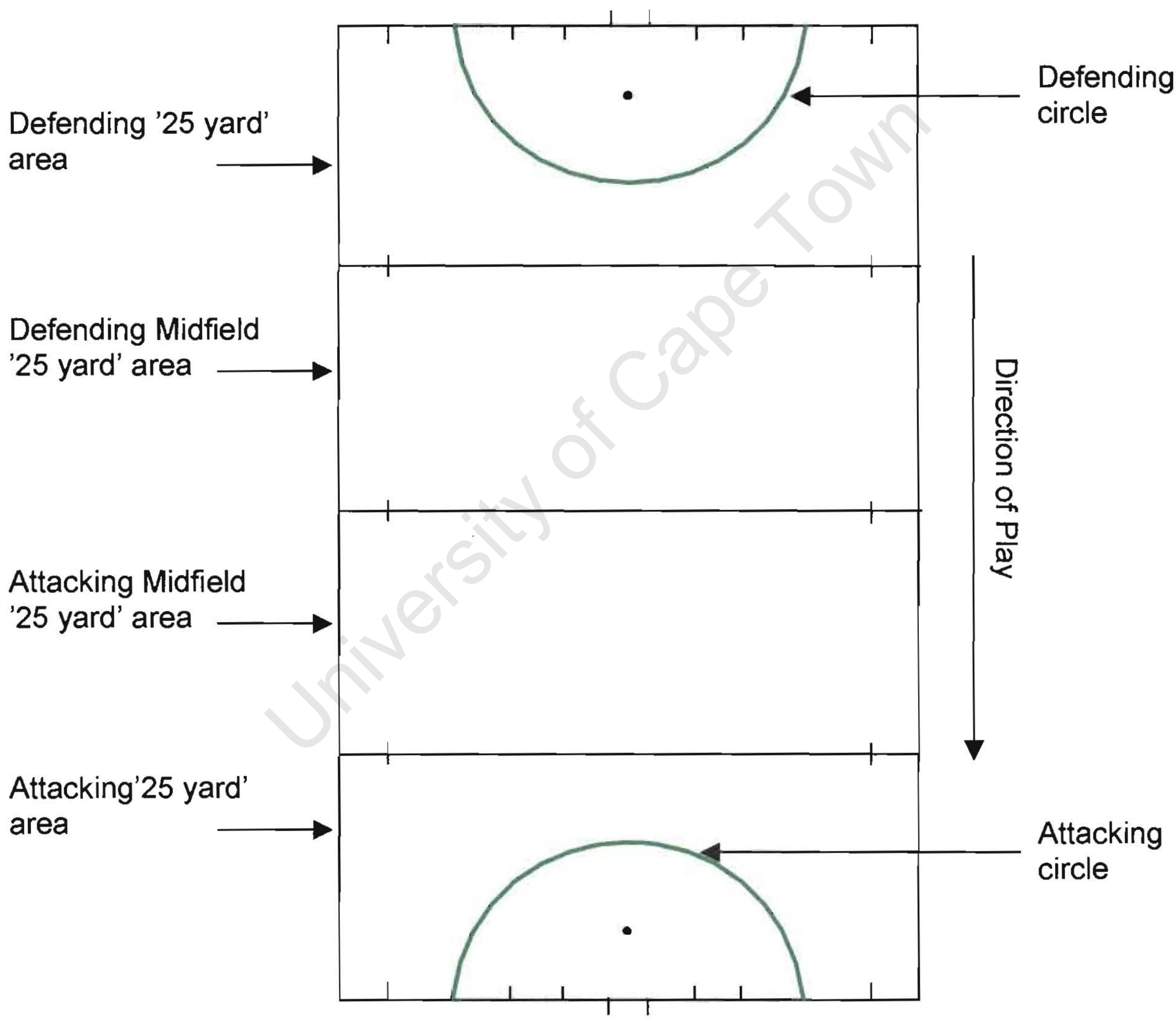
APPENDIX A

HOCKEY TERMINOLOGY

Introduction

Field hockey is played on a field that is 100 yards long and 60 yards wide. The figure below is a scale diagram of a pitch. The surface that matches were played on in this thesis was an artificial turf. However, matches are still played on grass by the lower club standard player.



Scaled Diagram of a hockey field

Terminology

Circle	These are lines marked in a semi-circle on the inside the field, 4 yards long, parallel to and 16 yards from the back-lines to the top of the circle. The 16 yards is measured from the outside of the back-line to the outer edge of the lines (see diagram).
Circle Entry	This is when the ball crosses the circle line and is heading towards one of the goals. Goals can only be scored when the ball is played in the circle.
Goal	This can only be scored when the ball is played in the circle by an attacker and does not go outside the circle before passing completely over the goal-line and under the crossbar.
Short Corner	An attacker shall push or hit the ball from a spot on the back-line 10 yards from the goal-post on whichever side the attacking team prefers. The remaining attackers shall be outside the circle with neither their hands nor their feet touching the ground inside the circle. Not more than 5 defenders including the goalkeeper shall be behind the back-line with their sticks, hands and feet not touching the ground inside the circle. The remaining defenders

shall be beyond the centre line. The ball is pushed/hit from the back-line outside the circle from where it is stopped completely still before any shot towards the goal is made. Only once the ball has been stopped can it be hit towards the goal or passed around until a goal-scoring opportunity is available. The ball must cross the back-line at a height of not more than 18 inches above the ground on the first shot. However flicks, deflections or scoops and second subsequent hits at goal may be raised subject to safety. The short corner is deemed to have finished when the ball has moved 5 yards from the circle, a goal is scored or the ball passes over the back-line.

Free Hit Inside the Attacking Area

A free hit is awarded for a foul that occurs inside the attacking '25 yard' area and is not considered by the umpire to be serious enough to merit a short corner.

Long Corner — This occurs when the ball has crossed the back-line and the last player to touch the ball was a defender. This must not however, be a deliberate push/hit over the back-line.

Ball Possession	The amount of time the team being analysed was in possession of the ball before the opposition could control the ball.
Playing time	The amount of time that the ball was within the field of play, not the total game time of 70 minutes.

Distribution of the Ball

The amount of time that the ball spent in each of the 4 '25 yard' areas of the field, defensive '25 yard' area, defensive midfield '25 yard' area, attacking midfield '25 yard' area and attacking '25 yard' area. See diagram above for exact location of the different areas.