

A time-motion analysis of elite
women's hockey – implications for
fitness assessment and training

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Preface

Acknowledgements

Firstly, I would like to acknowledge and thank my family and friends for the support and encouragement they have provided over the years whilst completing this thesis. Secondly, to my Supervisor Dr Derek Peters, through his guidance this thesis has gradually taken shape and provides some insight into the physiological demands imposed on elite level women's hockey in current contemporary games and is able to suggest some sport specific tests to be used.

Abstract

To-date no large scale studies have been published that have used player tracking technology to investigate continuous time-motion analysis in the modern era of Women's field hockey during Elite level International competition to investigate positional differences and inform fitness training and testing. A new computerised time-motion analysis method, Trak Performance was used to analyse individual player movement (n = 54) from 18 International Women's hockey matches (18 defenders, 18 midfielders, 18 forwards). Overall analysis identified distance covered 9.1 ± 1.6 km, of which $74.7 \pm 9.0\%$ was covered in low intensity activity of stationary, walking and jogging, $3.9 \pm 2.4\%$ match time was spent stationary. Mean sprint distance of 12.7 ± 1.7 m, with an average of 26.7 ± 11.5 s between each sprint. Positional differences were identified for the mean percentage of time spent, distances covered in locomotion activity, the mean duration of rest between sprint bouts, the frequency of sprints and work to rest ratios. The majority of contrasts in movement characteristics occur between the defensive players and other outfield positions. Analysis of repeated-sprint ability revealed forwards undertake a significantly greater amount of 16 ± 9 . Modern hockey dispels traditional positional roles with tactics and the more fluid nature of attacking plays requiring a more versatile player. Fitness assessment/training should therefore resemble the intermittent nature of the game with sprint recovery periods reflecting the different positional demands.

Keywords: hockey, time-motion, work-rate, repeated-sprint ability

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List of Acronyms and Abbreviations

BMC	Bloomfield Movement Classification
CAPTAIN	Computerised All-Purpose Time-motion Analysis Integrated
CBT	Computer-Based Tracking
IT	Information Technology
PC	Personal Computer
QT	QuickTime
SCE	SportsCode Elite
TMA	Time-Motion Analysis
TP	Trak Performance

Chapter I – Introduction

Rationale

As the margin between success and failure progressively decreases, the search for the most appropriate coaching method and strategy to help refine the players' athletic and technical competencies continues. Coaches, especially at the elite level, recognise that the achievement of today's athletes is a result of the integration of many factors. Each may contribute a variable amount to the final outcome. The recognition that a successful performance is dependent upon the interaction of these complex factors varies greatly both inter and intra sport, with the final performance being resultant of factors such as; genetics, training, health status, psychology, physiology, biomechanics, skills and the tactics employed (Wilsmore & Curtis, 1992; Bartlett, 2001; Lyle, 2002; Schokman, Rossignol & Sparrow, 2002).

Such continuing development of sport, has led to an increased emphasis towards the provision of scientific support to assist the coaching process (James, Mellalieu & Jones, 2005). Scientific elements of sport play an important part in the coaching process, as devising training schedules, the monitoring of performances, establishing techniques, and preparing the athletes for competition are all informed by this scientific knowledge (Maile, 2002). For this process to be the most effective, obtaining an accurate and reliable understanding of the actual sporting performance is a fundamental requirement (Shokman *et al.*, 2002).

The analysis of team games has tended to be more of a subjective and qualitative nature, characterised by the observational techniques and relying on a coaches' evaluation of the game (Hughes, 2008a). Two fundamental characteristics of field sport performance can be obtained through systematic analysis of the game. First, and most commonly reported, is the use of systematic analysis to permit the determination of the physiological demands of the game with the information gathered used to improve sport specificity of

fitness training and assessment (Withers, Maricic, Wasilewski & Kelly, 1982; Mayhew & Wenger, 1985; Treadwell, 1988; O'Connor, 2002; Gasston & Simpson, 2004; Di Salvo, Baron, Tshcan, Calferon-Motero, Bachi & Pigozzi, 2007). Second, aspects of quantitative systematic analysis have been used to assist in making recommendations for tactical and skills-related strategies for both individual players and teams as a collective (Lemmink, Elferink-Gemser & Visscher, 2004). Such analysis provides accurate information in quantifiable terms, allowing any misperceptions by coaches to be avoided. When used correctly, the results of objective performance analysis can enhance the coaching process, providing information and data to assist with decisions made about training, selection and talent identification (Hughes, 1988; Bartlett, 2001; Appleby & Dawson, 2002). This systematic analysis of sporting performances is widely known as "Performance Analysis" (Lyons, 1998).

Performance analysis involves the investigation of actual sports performances or training. Considerable overlap exists between performance analysis and other disciplines. As most performance analysis investigations are concerned with identifying aspects of performance such as technique, energy systems or strategy and tactics employed. The fact that it is concerned with the analysis of actual sporting performance, whether it be within competition or training, differentiates it from other disciplines that are more concerned with activity undertaken in controlled laboratory based environments or from data obtained via self reports such as interviews or questionnaires (O'Donoghue, 2008).

Hughes and Bartlett (2008) described the five main purposes of performance analysis to be tactical evaluation, technical evaluation, analysis of movement, development of a database and modeling, and finally for educational use with coaches and players. This study was primarily concerned with the analysis of movement or time-motion analysis (TMA), to assist with the identification of the physiological demands of hockey. Time-motion analysis is concerned with the investigation of activity of players during competition and not restricted by on-the-ball activity. To date, a variety of systems and methods from simple pen and paper notation of events using short-hand symbols and tallies (Brookes & Knowles, 1974) to video recordings for subsequent analysis

(Krustrup & Bangsbo, 2001), have been employed. Many of these methods have been criticised in terms of the validity and reliability of the data that they report. This is somewhat disconcerting as the usefulness of any TMA data relies upon the extraction of valid and reliable data from performances. Systems have been produced that have improved the methods of hand-notation and labour-intensive digitisation techniques towards user-friendlier, computer-based, real-time tracking technologies that more accurately reflect movements of players during team game situations. Further technological advancements have led towards automatic data collection of such movement data using GPS, image recognition and three-dimensional motion capture (Liebermann, Katz, Hughes, Bartlett, McClements & Franks, 2002). However many of these techniques are expensive, inaccessible or have cumbersome, preclusive equipment, that inhibit them from being used in field-based settings.

Time-motion analysis has been implemented for over 30 years, with research published for many different sports (Reilly & Thomas, 1976; Hughes & Knight, 1995; Deutsch, Kearney & Rehrer, 2002; Cabello & Gonzalez-Badillo, 2003). Many of the aims of this research have been to increase the knowledge and understanding of the physiological demands of the specific sport to assist with the development of training regimes (McLean, 1992). Whilst some research has been orientated toward men's elite level field hockey (Boyle, Mahoney & Wallace, 1994; Johnston, Sproule, McMorris & Maile, 2004; Spencer, Lawrence, Rechichi, Bushop, Dawson & Goodman, 2004), at the initiation of this research programme only three research papers had been published that had investigated any form of time-motion analysis in the women's game (Lothian & Farrally, 1994; Robinson, Murphy & O'Donoghue, 2001a; Boddington, Lambert, St Clair-Gibson & Noakes, 2002). Little of this has been undertaken at the elite level or investigating positional specific demands. Since the publication of this research however, there have been some significant rule changes within the sport that make the findings of these studies inappropriate to contemporary hockey today.

As such, the use of objectively measured time-motion analysis to underpin and inform fitness training and assessment for the range of playing positions in the elite women's game had not been made possible.

Aim

The overall aim of this thesis therefore was to quantify the potentially position specific physiological demands of International Women's hockey, using computerised time-motion analysis.

Specific objectives

The specific objectives within the overarching aim were to:

1. Explore the validity and reliability of a new computerised time-motion analysis system and employ this method to identify the physical demands of elite women's hockey.
2. Identify position specific differences in time-motion analysis variables such as distance covered, time spent in locomotion categories, duration of activities, sprinting characteristics including repeated sprint activity and work to rest ratios.
3. Propose physiological characteristics of elite women's field hockey.

Thesis Structure

The thesis structure has been chosen to most effectively focus the thesis towards the satisfaction of the stated aim and objectives:

Chapter I (Introduction pgs 10-15) serves as an introduction to the thesis and acts as a concise rationale for its need.

Chapter II (Review of Literature pgs 16-41) highlights the recognised importance of a complete and rigorous analysis of sport. Information is then provided about the most relevant literature relating to time-motion analysis methods that were available for use at the time of data collection. Following this the issues relating to measurements in time-motion are discussed.

Chapter III (Validation Study, pgs 42-52) includes a brief introduction, details the method used and provides representation of results and brief discussion on the validation of the time-motion analysis method proposed.

Chapter IV (Reliability Study, pgs 53-64) includes an introduction, method, representation of results and brief discussion on the reliability of the time-motion analysis method proposed.

Chapter V (Methods, pgs 65-68) identifies the methods of data collection employed within the main empirical study upon which the thesis is predominantly based and the statistical analyses employed.

Chapter VI (Results, pgs 69-71) represents the results obtained from the main time-motion study.

Chapter VII (Discussion pgs 72-81) firstly it discusses the methods employed within the current study and secondly, the findings from the empirical studies and lastly concluding with directions for future research.

Chapter VIII (Conclusions pgs 82-83) discusses findings in relation to the aim and objectives of the thesis in order to draw conclusions from the research.

Chapter II – Review of Literature

Understanding Sports Requirements

Athletic performance has progressed dramatically over the past few years with performance levels that were previously unimaginable now commonplace, and the number of athletes capable of outstanding performance ever increasing. Exceptional achievement of today's athletes is a result of an integration of many factors such as training, genetics, health status, psychology, physiology, biomechanics and skill, each may contribute a variable amount to the final outcome. Certain performance variables such as genetic endowment are at least currently beyond legal, external manipulation. As the rewards have increased, an industry has grown up to provide the support for the participants. Justifying the application of exercise science, sports specialists and systematic training regimes to harness full potential, as reliance on traditional training methods and skills alone are insufficient. However, one challenge that faces those seeking to apply science to sports performances is that a large majority of research is based on non-elite athletes (Bompa, 1999; Maile, 2002; Maughan 2008).

Each sport has its own specific physiological profile and characteristics. It is important that coaches understand the requirements of their sport and adjust the intensity and duration of training to suit. For sports such as cycling, swimming and running, where the intensity is fairly uniform for the duration of the event, it is possible to estimate the relative demands and contributions of each energy system. For instance, the energy provision for the 100 m sprint is split 50% from the ATP-PC system and 50% from the anaerobic glycolysis system, whereas a marathon relies entirely on the aerobic system. By contrast, it has been acknowledged that team sports are characterised by variations in intensity, where short sprints are interspersed with periods of jogging, walking, moderate-paced running and standing still (Bompa, 1999; Bishop, Spencer, Duffield & Lawrence, 2001). Such an intermittent work-rate requires energy production from all three production systems. A player

depends mostly on the aerobic metabolism, however when that player is required to sprint at full speed, the energy provision shifts to the anaerobic phosphocreatine system to use the stored or resynthesised ATP. If the high intensity continues for between 5 and 15 s per se, then energy would be provided by the anaerobic glycolysis system. As the player returned to lower intensity activity, the reliance on the aerobic metabolism would return, with the oxygen and lower intensity level of exercise assisting in the regeneration of the other energy systems.

Understanding the demands placed upon a player in competition and providing detailed descriptions of such work to rest ratios and distances covered is a fundamental requirement in prescribing training programmes specific to players (Bompa, 1999). Accurate indication of such physiological stress can be provided by oxygen uptake ($\dot{V}O_2$), however it is logistically difficult to measure this as it involves the collection of breathing samples which is impossible during competitive gaming situations (McArdle, Katch & Katch, 1991). To overcome this, heart rate has been used as a quantitative measurement of physiological strain (Ali & Farrally, 1991; Robinson *et al.*, 2001). This is based on the linear relationship between $\dot{V}O_2$ and heart rate at sub-maximal workloads (McArdle *et al.*, 1991). However the collection of heart rate data during competition still poses some logistical difficulties. Additionally, when heart rate data is collected, psychological features of competition, such as anxiety and arousal, may influence the data. In conjunction with these issues, heart rate is not a good indicator of anaerobic work due to the slow response of heart rate to exercise. Blood lactate data collection is more intrusive than heart rate and even more difficult to collect during competition (Bangsbo, Nørregaard & Thorsøe, 1991). However this would only provide an indication of the work intensity a matter of minutes prior to the blood sampling. Whilst it is possible to collect data during training; training sessions are not always a good representative of match play (Duthie, Pyne & Hooper, 2003). Therefore time-motion analysis can provide an objective, non-invasive method for the quantification of work rate during field sports (Bangsbo, 1994) and it is

proposed to be the most effective method of assessing physiological demands placed upon players at elite levels during competition.

Demands of a game are in part resultant of the rules and structure imposed, as well as the skill and tactical ability of all players involved. In order to identify the demands placed on players when competing at the highest level, it is important that analysis is conducted of the game itself, since these factors are major constraints on the individual performance. The part that any one individual plays in a game may also be constrained by their fitness. Thus the analysis of one individual may severely underestimate the physical demands of the game (McLean, 1992). To ensure this, analysis of the sport in terms of overall movement patterns, including technical considerations and time on task should be undertaken. Within this, there must also be some recognition of the intensity, frequency and duration of exercise associated with successful performances, leading to an understanding of the integration of energy processes. Although such global time-motion analysis data may provide valuable information on the overall physiological demands, it only provides limited insight into the physiology and requirements of repeated-sprint characteristics (Dawson, Fitzsimmons & Ward, 1993; Spencer *et al.*, 2004). This information then needs to be translated into sports-specific conditioning programmes. Considering the major conditioning principles, in particular those associated with progressive overload, specificity and tapering towards competition (Deustch, Maw, Jenkins & Raeburn, 1998; Maile, 2002; Duthie *et al.*, 2003; Bloomfield, Polman & O'Donoghue, 2004).

Time-motion analysis methods

This section critiques information on a variety of different methods used for the analysis of movement in sport and highlights how the use of time-motion analysis has developed since the earliest reports in 1936. It also details how advances in technology has assisted and discusses any methodological issues associated. Trends of methods used are apparent and mirror the advances in technology. Pre 1970 the use of hand notation for real-time observation was prevalent, with post 1970 authors able to take advantage of portable video recording equipment, allowing researchers to analyse post event. Advances in computer technology have impacted on time-motion analysis methods, providing assistance in the data processing and evaluation of more detailed analysis.

Early investigations into time-motion analysis used simplistic low-technology methods. Espenschade (1936) used manual tracking methods to map players' movements onto scaled pitch diagrams real-time over periods of three minute blocks. This coupled with manual time recordings of time spent with the ball, and the time spent stationary, allow the calculation of players' distances covered and speed of movement. Despite reported good levels of reliability in player tracking and timing, the method was inadequate in the estimation of distance covered, due to calculation from the average speed over the three minute blocks. As an alternative to individual player tracking methods, Brookes and Knowles (1974) developed a shorthand symbolic method to express type of locomotive activity and distance travelled from real-time observations. Individual player movements were categorised into one of four categories (stationary, walking, jogging and sprinting) by corresponding symbols each of which denoted 5 yd of travel. The reliability reported for this method highlighted significant issues with the measurement of distance covered. It is purported that the procedure of recording movement over distances of 5 yd is liable to introduce a degree of insensitivity to the measurement, with no report as to how movement less than 5 yd in a particular motion should be treated. Thus making this method unsuitable and unreliable for the analysis of movement per se.

As technology advanced, out-of-studio video recording was made possible by means of compact video cameras and portable video recorders. With this technology available, researchers in time-motion were able to make video recordings of sporting events for subsequent 'post-event' analysis. One of the first exponents of 'post-event' analysis were Jacques and Pavia (1974). The realisation that notating all movement analysis information of Australian Rules football players by mere observation alone during the game was an impossible task, prompted their method design. Capitalising on the technology, six cameras were used to record individual players during the game. Post-event, video recordings were reviewed and players' movements were plotted onto a scaled pitch diagram with accumulative times spent in four basic activities of standing, walking, jogging and running, obtained via manual timing. The analysis for one player required three people working simultaneously; two recording timed activities and controlling the video playback, and the other plotting the players' movements (Jacques & Pavia, 1974). The advantageous nature of mapping movement post-game from the video, meant that during data capture the replay could be stopped and players' movements retraced, permitting greater accuracy than when undertaken in 'real-time'. However, the authors acknowledged the potential bias of making judgments on the movement patterns of players within a team sport from only one game quarter and recognised this as a limitation of the generality of the findings from their study.

Reilly and Thomas (1976) used a combination of hand notation, audiotape recording and scaled pitch mapping to provide a comprehensive report of professional football players movements. Players' movements were divided into walking, backing and running, with running encompassing further categorisation of jogging, cruising and sprinting. Distances covered were estimated by a combination of pitch markings and stride lengths, despite the acknowledgment by the authors of issues related to stride lengths variations at differing intensities. In order to assess the reliability of this time-motion analysis method, concurrent filming was undertaken during the original matches and were later analysed using the same subjective analysis

methods. High correlation coefficients were obtained between these two observations methods. Despite some methodological similarities between the studies of Reilly and Thomas (1976) and those published earlier, it is only the Reilly and Thomas (1976) study that has widely acknowledged methodologies and has been used a 'gold standard' to which others have been compared. Inherent issues in reliability and accuracy of data reported due to subjective categorisation of locomotion activity and estimations of the distances covered remain, however such limitations have stimulated methodological advancements in time-motion analysis research.

Further advancement in technology, more specifically within Information Technology (IT), have influenced the manner in which data are collected and analysed in performance analysis research studies. As the introduction of the Personal Computer (PC) continued, the combination use of PC's and video recordings provided researchers with a more flexible and efficient process of data collection and subsequent processing. Treadwell (1988) acknowledged these technological advancements provided the opportunity to extract a more detailed objective analysis of sporting events than the methods previously reported. With the suggestion of a computer-aided study in order to provide rapid feedback and assist in the strategic development of the sport and its training, Treadwell (1988) used a BBC 'B' computer and an A3 size concept keyboard for data collection. The touch sensitive keyboard provided a greater flexibility than that provided by a conventional QWERTY keyboard, and allowed for different overlays to be used according to each data collection method. Data was collected in respect to time as opposed to distance covered, as the author expressed this method more suitable to provide a greater degree of accuracy for analytical purposes and the presentation of time-based data. The PC and touch sensitive keyboard allowed for the observer to measure time spent in individual movement categories. Considering that Treadwell (1988) had proposed a new format for the computer-aided study of time-motion analysis of sport, the fact that no information regarding the validity or reliability of the method was reported was surprising. However the new method reported by Treadwell (1988) was merely a technological advancement of previous subjective categorisation

methods, as used by other researchers. Therefore the same inherent problems of subjectively categorising movement still exist.

Methods that encompass the estimation of distance covered from observation and the categorisation of individual locomotion modes reduce the precision and objectivity of data collected (Ohashi, Togari, Isokawa & Suzuki, 1988). Proposing a completely new and alternative method for time-motion analysis in an attempt to provide more precision, Ohashi *et al.* (1988) deployed the use of triangular surveying techniques linked to a data logging computer system. Connecting potentiometers to two video cameras, positional data was collected from visually tracking individual players; signals from these measuring devices were sequentially converted into x,y coordinates at an interval of 0.5 s via the data logging computer system. Differences between consecutive coordinate values were used to calculate changes in movement speed and distance covered. Regardless of the relative accuracy of this newly implemented method, no validation or reliability information was provided with the report of the study (Ohashi *et al.*, 1988). Despite this, the method and techniques proposed provide the first method of time-motion analysis collected in an objective manner.

It is purported that all of the methods reported above have provided some basis as to which the more contemporary methods used today are based. Advancements in technology have, and will, continue to assist the development of methods for time-motion analysis. Some distinct factions appear amongst the plausible methods, with notable use of subjective categorisation of individuals' movements from either real-time or post-event observations, with a clear distinction between those concerned with time spent or distances covered. The alternative method eliminates subjective observation of movement and replaces this with continuous player movement tracking coupled with computations of displacement using grounded mathematical calculations.

Differences have been apparent in the subjective observation methods applied, with some researchers taking advantage of advancements in video

and information technology in order to obtain more accurate timing, whilst others have used varying numbers of locomotion categories. Bloomfield *et al.* (2004) categorised movement in terms of event with 14 'timed-motion' and 3 'non-timed motion' events, speed of movement into 4 intensities, and turning parameters of 14 directions and 5 turning categories plus 7 'on the ball' activity classifications to provide a more detailed analysis for speed, agility and quickness of movement and the possible identification of risk of injury. In contrast O'Donoghue (2002) reduced the analysis to two broad movement categories of work and rest to describe the intermittent work-rate of English FA Premier League Football players. Further additions have included sport specific activities such as jumping (Mayhew & Wenger, 1985) and 'on the ball' activities analogous to shuffling (McErlean, Cassidy & O'Donoghue, 2000; O'Donoghue, Boyd, Lawlor & Bleakley, 2001).

Time-motion research continues to use methods that involve human observation of player movements, despite its limited objectivity and reliability. To overcome this, extensive training and evaluation of inter-observer agreement is usually undertaken. However the classification of movement according to locomotion category, especially in running modes is difficult, with observable differences between sprinting and striding limited (Withers *et al.*, 1982). Some authors have attempted to reduce this by conducting analysis from video recordings, employing the use of frame-by-frame advance features to see minute changes in stride patterns and player directions (Bloomfield *et al.*, 2004; Williams & O'Donoghue, 2005).

During their study, Bloomfield *et al.* (2004) argued that previous research did not encompass a complete profile of motion and performance demands, providing merely crude measurements of physical exertion. In an attempt to improve these highlighted shortfalls, and to provide information on modern physical performance requirements, Bloomfield *et al.* (2004) analysed football motion using 14 'timed-motion' and 3 'non-timed motion' events, 14 directions, 4 intensities, 5 turning categories and 7 'on the ball' activity classifications. This new method known as the "Bloomfield Movement Classification' (BMC), provides detailed accounts of the motions, directions, intensities and events of

multiple sprint invasion sports such as football, hockey, rugby, basketball and netball. Footage collected from Sky Sports Interactive Service using the 'PlayerCam' facility, provided a focused view solely on one single player for approximately 15 min each. Analysis was undertaken using a computer based analysis package 'The Observer 5.0' (Noldus Information Technology, Wageningen, Netherlands). In preliminary investigations, motions, movement and playing activities were noted, recorded and discussed with participants. All classifications were then thoroughly defined for interpretation and inter-reliability purposes. The detailed nature of the BMC meant the process of data entry was extremely time consuming, considering the frequency of changes in discrete movement. Therefore short sections of between 3 - 15 s were initially viewed at normal speed, and then replayed to perform data entry using a frame by frame analysis at a rate of 0.04 s for the discrete activities, and then reviewed a third time at normal speed for continuous, unchanging motion (Bloomfield *et al.*, 2004).

Such a high level of detail in the BMC, can also be detrimental to its use. Firstly, the BMC cannot be used during live observations and has to be implemented using a commercial performance analysis software package to allow a frame-by-frame inspection of the individual subjects' movements. Tagging the video with the start of movements identifying turning, direction and intensity attributes. Secondly, the implementation of the BMC is very time consuming and can require 30 min to successfully record all movements of a player in a 1 min period of play. Whilst such diligent post match analysis is typically more reliable than other real-time methods, reliability is reduced by observer fatigue coupled with the subjective nature of classification (Bloomfield, Polman & O'Donoghue, 2007). Despite this, the authors of the BMC reported inter and intra-observer kappa values interpreted as indicating a good to very high level of agreement. However, the BMC is inhibited by the time to undertake analysis, making it unsuitable for large samples. This is evidenced in the use of the BMC to date. Williams and O'Donoghue (2005) only used 7 - 8 min of video recorded movement for 7 netball participants and 15 min in football (Bloomfield *et al.*, 2004).

Alternatively, reducing the number of categories, O'Donoghue, Hughes, Rudkin, Bloomfield, Cairns, and Powell (2005) progressed on the previous work using the CAPTAIN system to develop the POWER system. The POWER system developed to allow the analysis of just 'work' and 'rest'. Although this system still requires subjective observations to categorise activity into either work or rest, choice reaction time of movement classification has been reduced, consequently improving the reliability of the data collection process. Regardless of the subjective nature of classifying observed activity into work and rest, the POWER system can be used objectively, with a very good strength of inter-observer agreement ($\kappa=0.83$). The POWER system, can be seen to be rather simplistic with just two movement categories, however it can compete with other more complex system in the breadth of information that it can provide. The strength of the POWER analysis system exists in the portrayal of the intermittent nature of activity performed by players of team sports. POWER provides data on the frequency, mean duration and percentage of time spent in work and rest activities, number of work and rest periods of different durations, and the summary statistics relating to repeated work bouts.

Developments in the methods used for objectively assessing time-motion have also been apparent. Combining video recording and mapping of players movements, Boddington *et al.* (2002) used a new approach of measuring hockey players' displacements. Two panning video cameras provided the video footage of all outfield players to be used for the subsequent analysis. Re-play of the video allowed players' movements to be mapped onto a scale diagram of the hockey field. Players' initial position on the pitch and then at 15 s intervals throughout the match were recorded and used to calculate horizontal displacement. From these measurements, the following variables were calculated: total displacement, mean displacement per min of playing time, mean displacement per 15 s and mean speed per 15 s for each player. The time each player spent on the playing field was also recorded. Movement intensity was determined using the speed parameters similar to categories identified by Lothian and Farrally (1992) in the relation of energy expenditure

to speeds of movements, with categories of; standing 0 m/s, walking 0.03 - 1.7 m/s, jogging 1.7 - 2.8 m/s, cruising 2.8 - 3.9 m/s and sprinting above 4.0 m/s. The movement displacement method used by Boddington *et al.* (2002) sampled movement displacement every 15 s, calculating speed during each period and subsequently categorising each period of activity into a locomotion activity based on pre-determined speeds. Whilst it is accepted that the movement displacement method is a more valid data capture method than the subjective categorisation of movement, the application of this method in the current study is inhibited by the displacement calculated over a period of 15 s. In a sport identified as being fast, free-flowing, and intermittent in nature, with players continually changing their motion (Boyle *et al.*, 1994; Lawrence & Polglaze, 2000), it could be suggested that this severely underestimates the actual movement and changes in speed demonstrated by an individual during game play.

PROZONE ® (Prozone Sports Ltd, Leeds, UK) improved the method detail above, and developed a computerised video motion analysis system that enabled the quantification of motion characteristics semi-automatically. Using motion measurement concepts adopted from biomechanics, the PROZONE ® (Prozone Sports Ltd, Leeds, UK) data collection method provides the opportunity to quantify the kinematics of movement patterns (Di Salvo, Collins, McNeill & Cardinale, 2006). Using eight fixed cameras, each area of the pitch is covered by at least two cameras for accuracy, occlusion, resolution and resilience. Direct video feeds from each camera are connected to a central video distribution box, which splits three ways into a primary capture, back-up and telemetry facility. The primary capture facility consists of a high specification server that captures and synchronises each video feed. The server then instigates an automatic tracking of the videos. Each video is tracked independently determining image coordinates and continuous trajectories of each player. Each individually tracked file, from all eight cameras, is then automatically combined into one single dataset. To achieve this, the combination process requires knowledge of the visions field of view and logic around normal player behavior, with objects qualifying as being of human size with Kalman filters used to predict possible direction given current

object speed. Each individually tracked file contains whole pitch coordinates per player every 0.1 s. The final stage of the process, involves manual operators to identify each player and verify that the trajectories identified for the player remain with the actual player being tracked (Di Salvo *et al.*, 2006).

A validation study of this method showed near perfect correlation with velocity data reported from the PROZONE ® system (Prozone Sports Ltd, Leeds, UK) when compared with timing gate measurements. A clear demonstration that the eight fixed camera analysis system provided an accurate calculation of the velocity of athletes. Such a high level of accuracy being more pertinent when highlighting that the product allows for the tracking of all players on the pitch (Di Salvo *et al.*, 2006). However despite this high level of accuracy, the reliability method employed and therefore any data obtained in such a manner is an unknown quantity. The considerable amount of automation in the system does not necessarily make this method reliable. For this method to be deemed reliable and an appropriate method for the collection of time-motion data, then test, re-test sampling needs to be undertaken. This method is limited by its own inherent methodological constraints. To provide this level of service and accuracy, mainly to elite level professional football, the PROZONE ® (Prozone Sports Ltd, Leeds, UK) systems is solely reliant upon the eight-fixed camera set-up, video distribution box, high specification server and back-up equipment, inside a stadium facility. All of this equates to a high cost and the necessity of a large installation process, plus the need for a dedicated operator to run the data collection and analysis process. However, the authors keenly stressed that PROZONE ® (Prozone Sports Ltd, Leeds, UK) does not require special equipment (i.e. transmitters) or clothing (i.e. colour coded shirts) to be worn during performance, unlike GPS, which allow the measurements to be performed during official matches.

In a study to compare subjective observation time-motion analysis techniques to an image digitising system and present an alternative time-motion analysis method, Roberts, Trewartha and Stokes (2006) utilised five fixed cameras situated around a rugby pitch. The image digitising technique, adopted from the biomechanics discipline, utilised a global 2-dimensional Cartesian

coordinate system, and allowed for a single point (hip-centre) on a player to be digitised once every second. The 1 s time displacement derived from the digitised data was used to categorise movement into activity classifications. The discrete movement classifications were constructed based on speed estimates. For the subjective time-motion analysis, players were individually followed by a video camera. Video replay allowed for the players movement to be categorised into the same discrete movement classifications as the digitised method. Examination of the data highlighted that hand notation reported a 27.5% greater time spent in work, and on average a 792 m greater distance covered per game, than the digitising method. Some discrepancies in the percentage of time spent in activity between the two methods could be attributed to the fact that a seven activity classification model was used. Making it inherently more difficult to select the appropriate activity, as the observer has to make a greater number of decisions regarding mode, frequency and duration of activities. The differences between calculated distances from hand notation methods and distances reported from digitising method are augmented by the calculation method of distance for the notation method; time spent in activity multiplied by average speed. The accuracy and greater sensitivity of the digitising style method offers distinct improvements in investigating issues concerning playing position and movements, over the traditional subjective notational method (Roberts *et al.*, 2006).

Trak Performance (TP) a software package (Sportstec Limited, Australia) produced to enable objective information about the changing physical demands of a sport to be gathered. The observer, relying on ground markings and visual cues as reference points for translation onto a miniaturised, calibrated version of the playing field on the computer, manually track the movements of players' continuously around the pitch during competition periods. The software, TP records positions of the cursor, in x,y coordinate pixels on the screen at 1 s time intervals, and calculates the linear distance traveled since the previous x,y position recorded. A calibration factor converts pixels on the computer screen to metres on the pitch. This calibration factor varies depending on the field dimensions and the screen resolution of the computer used. TP allows the measurement of players' distances covered,

continuous mean speed and the breakdown of time spent in various speed categories (Burgess, Naughton & Norton, 2006; Edgecomb & Norton, 2006). Validity and reliability assessments on the use of TP for the analysis of players' movements identified high correlations with distance measured and actual distance covered, but with significant differences. The average difference between these methods was 5.8 - 7.3% error for mean and absolute error, suggesting an overestimate in the distances reported. However a potential source of error that must be considered with this method is that of human error associated with the procedures involved in the TP system. These errors, were however introduced by different trackers, with slightly different techniques and visual cues (Edgecomb & Norton, 2006).

As is evident from the literature, numerous methods have been applied to the time-motion analysis of players in a variety of different sports. The most commonly and widely cited study by Reilly and Thomas (1976) is still seen as the 'gold-standard'. This method allows for the analysis of motion, with a degree of detail that reports time spent in locomotion activities, distances covered and frequency of events. A more detailed approach, the BMC, allowing analysis in terms of speed, agility and quickness with possible identification of risk of injury, categorises movement in terms of event, speed of movement and turning parameters (Bloomfield *et al.*, 2004; Williams & O'Donoghue, 2005). Several fixed camera methods that require some detailed understanding of formula and data manipulation (Needham & Boyle, 2001; Di Salvo *et al.*, 2006). The combination of digital video footage and digitising methods previously associated more with the field of biomechanics (Boddington *et al.*, 2002; Edgecomb & Norton, 2006; Roberts *et al.*, 2006). Advances in technology have been further exploited with the automatic player tracking systems and the use of GPS units (Liebermann *et al.*, 2002; Edgecomb & Norton, 2006). Each of these currently used systems can be deployed in the analysis of players' movements, each with their own unique features, constraints of use, limitations and criticisms in data capture methods. There is not as yet a new 'gold-standard' of time-motion analysis method identified, validated and shown to be both reliable and time efficient.

Measurement Issues in Time-Motion Analysis

Time-motion analyses have been undertaken using both manual and computerised methods to determine the time spent during competition among different movement classes and distances covered (O'Donoghue, 2008), many of these have been criticised in terms of the validity and reliability of the data in which they report. Many of these methods require an element of human manipulation to extract data, and therefore introduce some operator error (O'Donoghue, 2004b). When new methods are proposed, very few have been compared against recognised automated criterion measurement methods. This is alarming, since the validation of these systems is fundamental when proposing new methods for the identification of time-motion variables of team sports.

In addition to the requirement for validity of measurement, time-motion analysis, like many other areas of sports science, is an area where the reliability of measurement is critically important. Hughes, Cooper and Nevill, (2002) stress the significance that the reliability of any data gathering system used for performance analysis purposes, is demonstrated clearly and in a manner that is compatible with the subsequent intended analyses of data; time-motion analysis systems are no exception to this. Unless automatic player tracking systems are used, most methods will still require at least some level of manual data input, where a human operator becomes part of the measurement instrument (Liebermann *et al.*, 2002). Inaccurate movement data is resultant from subjective human movement recognition error and variable observer reaction to events being performed by the subject and indeed different interpretations of performance indicators relating to work-rate and movement by different observers. For example, McLaughlin and O'Donoghue (2002) found that one observer had a tendency to record 10% more time spent performing high intensity activity than the other observer used in an inter-operator reliability study involving 28 subjects.

Assessing the reliability or measuring the consistency of data is synonymous with repeatability, where the first measurement of data is compared against

subsequent information collated in the same manner, and is concerned with the reproducibility of the observed values when the measurement is repeated by either the same (intra) or different (inter) observers (Vincent, 1999; Hopkins, 2000; Cooper, Hughes, O'Donoghue & Nevill, 2007). Even when fully automated systems are used, there may still be errors due to incorrect labeling, occlusion or limitations in the system used. Therefore, reliability evaluation is essential so that the information produced can be interpreted with the full knowledge of the level of measurement error involved (O'Donoghue, 2007).

Hughes *et al.* (2002) published a survey of papers presented in performance analysis and their reliability analysis undertaken, if any at the first three World conferences in Science and Football (Reilly, Lees, Davids, & Murphy, 1988; Reilly, Clarys & Stibbe, 1993; Reilly, Bangsbo, & Hughes, 1997), the first two conferences in Science and Racket Sports (Reilly, Hughes, & Lees, 1995; Lees, Maynard, Hughes & Reilly, 1998) and the first world conference in Notational Analysis of Sport (Hughes, 1997). Hughes *et al.* (2002) identified that 70% of papers did not present any mention of reliability studies. Identifying then, that minimal acknowledgement had been given to the importance of reliability analysis. This is somewhat surprising since the research by Reilly and Thomas (1976), a seminal study in this discipline, demonstrated such significance in establishing and reporting the reliability and objectivity of their analysis system. Additionally Hughes *et al.* (2002) identified that a further 15% of studies used inappropriate statistical analysis techniques in order to evidence the consistency or the repeatability of the data collected, whilst many authors reported using techniques such as Pearson's correlation coefficient and ANOVA's; techniques previously questioned by Bland and Altman (1986). The survey confirmed that many performance analysis discipline researchers found reliability testing difficult, particularly with the identification of the correct statistical analysis techniques to evaluate the level of reliability.

A continuation of the survey conducted by Hughes *et al.* (2002), regarding the reliability studies reported and undertaken in recent performance analysis

papers presented at the conferences World Congress of Notational Analysis of Sport III (Hughes, 2001), Science and Football IV (Spinks, Reilly & Murphy, 2002), and 2 World Congress' of Performance Analysis VI (O'Donoghue & Hughes, 2004), VII (Dancs, Hughes & O'Donoghue, 2006), revealed that 48% of the papers still did not report any reliability analysis data (Table 1). This is an overwhelming amount of studies that seemingly disregard attention to the repeatability of the data collection process used, and the reliability of the data reported, and used to make inferences to general populations and sporting performances.

Table 1. *Statistical processes used in reliability studies published at performance analysis conferences between 1998-2006.*

Reliability Statistic	Number of Studies	Percentage of Studies
None	35	48
Correlation	6	8
Method of errors	23	32
Chi-square	4	5
t-test	0	0
ANOVA	0	0
Cronbach's alpha	0	0
Kappa	5	7
Total	73	100

The type of reliability statistics most appropriate to be used is dependent on the scale of measurement of the performance indicator. There are four main scales of measurement; nominal, ordinal, interval and ratio (Vincent, 1999). Nominal and ordinal scales are categorical scales of measurement variables, which use named values. Categorical scales of measurement, nominal and ordinal use named values to represent their data, the difference being that nominal are different values, whereas ordinal have a defined order. In performance analysis, nominal values are subdivided into two further categories. Those where there are some pairs of values that are

'neighbouring' and those that are not. For example, a neighbouring nominal value could be the classification of time-motion, where neighbouring values of stationary and walking, walking and jogging *etc.* exist.

When assessing the reliability of categorical nominal values a number of statistics can be applied. Hughes and Franks (2004) proposed percentage error to be the simplest and most intuitive method for the assessment of agreement between two measurements of nominal variables. However recently caution has been highlighted toward using this statistic to measure global reliability of analysis. The calculation of this percentage error may disguise the true level of agreement between the two data sets (O'Donoghue, 2010). Using percentage error for frequency nominal values, expresses the sum of the absolute difference in frequencies as a percentage of the sum of the mean frequency values reported by the two observations. Using this total percentage error conceals errors that become cancelled out due to the totals being used. This type of statistics is best used to measure the reliability of individual performance indicators (Cooper *et al.*, 2007; O'Donoghue, 2010). Percentage error, when applied correctly is advantageous in its simplicity of interpretation, highlighting the percentage of time when two observers disagreed. However it does not take into account the possibility of agreement occurring by chance. Cohen (1960) presented a chance-corrected measurement of agreement known as kappa that can be applied to chronologically ordered sequences of values. It is generally thought to be a more robust measure than simple percent agreement, since kappa calculates expected agreement with exclusion of the possibility of agreement occurring by chance. This value is expected to be lower than percentage agreement, as it removes the frequencies of agreement by chance.

Kappa has also been used in time-motion analysis studies to determine the fraction of observation time that two independent observers agree on the activity performed by a subject adjusted for the expected fraction of observation time where they could be expected to agree by guessing (McLaughlin & O'Donoghue, 2002). One of the limitations of using kappa to analyse the proportion of observation time where two observations agree with

each other is that a minor difference in the time at which each observation commences will reduce the strength of agreement achieved. It is often seen as a harsh reliability statistic, due to the fact that anything other than exact agreement on a value will be treated as a total disagreement. For example, a disagreement between running and sprinting will be treated the same way as a disagreement between sprinting and stationary movement. It is also seen as a harsh statistic in relation to instantaneous events. With the acceptance of two types of nominal values within performance analysis, those that have no relation to each other, and those that can be viewed as pairs. When assessing reliability of these neighbouring nominal values, a weighted kappa statistical analysis can be applied. This weighted kappa, applies partial credit to neighbouring to those values with a neighbouring pair during assessment of agreement (Cohen, 1968; Sim & Wright, 2005; Robinson & O'Donoghue, 2008; O'Donoghue, 2010).

Hockey: The Context

Hockey is similar to other field-based invasive games and has often been juxtaposed with football. Fox (1984) grouped hockey with lacrosse and football among sports requiring 70% anaerobic and 30% aerobic contribution to energy expenditure. Later, Sharkey (1986) classified the game as bordering the aerobic side (40% anaerobic, 60% aerobic) of the energy continuum, stating that the game, with its potential for continuous activity, appears to be aerobically more demanding than previously thought. It is appropriate to view the game at the elite level as aerobically demanding with frequent through brief anaerobic efforts superimposed. Hockey does however, have some unique features, the design of the stick and the rules governing the use of it. Thus allowing the use of only the flat side of the stick give the game an inbuilt asymmetry and forces players into un-ergonomic postures whilst dribbling a ball. Consequently raised physiological demands of the game are imposed, as the players are forced to pay greater attention to body positions in relation to both the ball and opponent (Reilly & Borrie, 1992). All games are now played on artificial turf, reducing the rolling resistance of the ball, as compared to grass and other sports (Hughes, 1988; Reilly & Borrie, 1992), and increasing the number of touches per game (Hughes, 1988).

Hockey has been analysed and described by many since the inception of time-motion analysis. Earliest records indicate that from a manual subjective time-motion analysis of regional hockey players, Espenschade (1936) identified that outfield players covered between 2.1 and 2.5 km during a game. Since this investigation was undertaken, there have been significant changes in the game of hockey itself, not least the rulings concerning offside players.

Lothian and Farrally (1994) identified from individual player analysis of one Women's National League match, that the majority of time was spent walking. In fact for one individual player, this accounted for almost half the match. A large range for the time spent in high intensity activity (17.5% - 29.2%), meant that some players undertook almost twice the amount when compared with

others, also true for the frequency of involvement in hockey related activities with values ranging from 54 - 90 times each match, accounting for only 3.6% of total time. Further scrutiny identified mean duration of each high intensity activity period was 5.22 ± 0.61 s with corresponding low intensity periods of 18.22 ± 3.8 s, with some players spending much greater time in high intensity activity than others. The maximum duration that each player was involved in a single period of high intensity activity ranged from 17 - 62 s and low intensity from 66 - 196 s. With the mean periods of high intensity activity lasting between 4.73 - 6.82 s, it could be suggested that the ATP-CP system is the predominant system for energy provision with little accumulation of lactate in these periods to generate the intense burst of action required (Åstrand, Rodahl, Dahl & Strømme, 2003; Pulkkinen, 2001). However literature based on recovery from multiple sprints such as rugby and football, has found an increase in blood lactate suggesting that anaerobic glycolysis is present during very short burst (up to 6 s) of high intensity activity with limited recovery. Consequently, an accumulation of lactate following periods of repeated sprint activity is expected. Some of this lactate could however be resynthesised during the longer low intensity recovery periods. Significant differences were also identified in the time spent in high intensity activities between the first and second halves indicating levels of fatigue. However changes in the substitution rules since publication of this study allowing rolling substitutions to be made, may reduce the effects of fatigue on work-rate in hockey. No overall trends were apparent in any aspects of the movement analysis when related to playing position with the exception of midfielders being involved in significantly more ($p < 0.05$) changes of activity than other players. This would suggest that top-level hockey demands that players work as a unit and as such there are no distinct positional variations in terms of the physiological demands placed upon the players. However, the small numbers in each group ($n = 4$) did not allow for positional differences to emerge indicating that the data reported merely identifies individual player differences and that these results are not necessarily indicative of top-level hockey as a whole.

Since the publication of previous profiles of work-rate, several rule changes have been implemented that have altered the game and altered the playing demands imposed on players. In the season beginning 1996, the off-side rule was removed, allowing players to enter the attacking circle, without having to either make an attacking movement or be behind a defender. The removal of the opportunity to substitute players during penalty corners occurred in 1998.

Using a unique “two pass” approach for time-motion analysis of field hockey, Robinson *et al.* (2001) investigated the effect of fatigue upon game performance. Analysis of the game data in five minute sub-divisions allowed for trends in work-rate to be investigated. No significant differences were found for the amount of high intensity activity performed between successive five minute periods during the first half. However in the 2nd half, players were observed to perform initial bursts of high intensity movement that was maintained for 15 min. Thereafter, in spite of continued fluctuations, an overall decrease of 0.07% per minute in the time spent performing high intensity activity was observed. Analyses of such values for time spent in high intensity activity and distances covered, may provide an indication of fatigue. However such measurements only reflect the nature of movements contained in each five minute period, which can be affected by match play situation, set pieces, injury time and stoppage time. Observations concerning absolute distances covered during single five minute periods identified that a defender covered a minimum of 231.8 m and a forward covered a maximum of 662.2 m. The distances covered during five minute periods, was found to be positively correlated with the percent of high intensity activity performed. Therefore mean distances covered for each five minute period demonstrated very similar trends to those described for percentage of time engaged in high intensity activity. These values may provide indications of fatigue, however, such measurements reflect only the nature of movements contained within each five minute period and therefore are additionally influenced by match play situations, set pieces, injury and stoppage times. Measurements of the speed, at which these high intensity periods were performed, would irrespective of the proportionate contributions of each, provide a more accurate indicator of fatigue. Robinson *et al.* (2001) identified fatigue to be

associated with a decline in the amount of high intensity activity performed, lower distances covered, and a reduction in the movement velocities measured during the five minute segments of the game. However, frequent and short duration declines in these variables are a facet of the game of hockey due to its intermittent nature, and are also influenced by the match play situations, stoppage times, injury times and set piece play, and are not necessarily truly indicative of fatigue.

Boddington *et al.* (2002) aimed to reassess the work profile of women's hockey and present findings on the modern contemporary game. Calculating time spent and mean displacements during the game, the authors reported that hockey players spent 97.4% of total game time in low intensity activity (standing $1.5 \pm 0.3\%$; walking $82.3 \pm 2.1\%$; jogging $13.7 \pm 1.6\%$). The remainder (2.6%) was attributed to cruising and sprinting, at $1.9 \pm 0.4\%$ and $0.7 \pm 0.1\%$ respectively. Player displacement throughout the game was deemed to be less than 4 km, with a mean displacement of 3901 ± 522 m. These findings are in distinct contrast with values previously reported, Boddington *et al.* (2002) highlight a much larger amount of time spent in low intensity activity (97.4%), when compared against Lothian and Farrally (1994) value of 70.8%. Admittedly there have been some significant rule changes in the intervening years. However it is thought these rule changes would have increased the speed of the game, causing an increase in the reliance on more high intensity activity rather than less. What is unknown from the publication by Lothian and Farrally (1994) is exactly when the game analysis was completed. Rules governing the substitutions of players was altered and implemented in 1992, that allowed for players to be swapped on and off the field at any time during the game ("rolling substitutions"). The other plausible reason for the marked differences are that Boddington *et al.* (2002) sampled movement displacement every 15 s calculating speed during each period and subsequently categorising each period of activity into a locomotion activity based on pre-determined speeds of movement. Whilst this could be accepted as a more reliable data capture method than the subjective assignment of movement category that has been used by other studies, unfortunately, the movement displacement and speed were determined from sampling at 15 s

intervals and thus failed to include the movements performed in the previous 14 s of play. In a sport previously identified as being fast, free-flowing, and intermittent in nature, with players continually changing their motion (Boyle *et al.*, 1994; Lawrence & Polglaze, 2000), it could be suggested that this severely underestimates the actual movement and changes in speed demonstrated by an individual during game play.

Spencer *et al.* (2004) tried to redress the lack of information regarding the movement patterns of elite level field hockey, by the analysis of one game from an International tournament. Analysis revealed that International men's hockey players spent most of the time engaged in low intensity activity, with standing, walking and jogging accounting for 95% of player game time. This value is markedly different from values reported by Lothian and Farrally (1994). The difference is likely due to the variations in movement classification, as Lothian and Farrally classed hockey related skills as high intensity, even when performed at a low intensity. However, similarities exist to that identified by Boddington *et al.* (2002), who merely reported displacements, categorised into locomotion speeds for players without references to any skill related activity. The remaining 5% of player game time was spent in high intensity activity of striding and sprinting, with mean sprint durations of 1.8 ± 0.4 s, again an obvious difference when compared with Lothian and Farrally's report of 3.1 ± 0.3 s. But the results of Spencer *et al.* (2004) are aligned to those previously reported in other team sports such as football (2.0 s; Bangsbo *et al.*, 1991), rugby (2.0 s; Docherty *et al.*, 1988) and Australian Rules football (2.4 s; Dawson, Hopkinson, Appleby, Stewart & Roberts, 2004). The mean number of sprints performed was 30 ± 14 , with a mean recovery time of approximately 120 s. However, this does not provide a true indication of the sprinting requirements of the game. As with all team sports and the unpredictable nature of intermittent activity, sprinting is not evenly distributed and therefore there maybe occasions of intense periods of repeated sprint activity, that are vital to the outcome of the game. This suggests that high intensity activities should not solely be investigated using 'total-game' mean statistics, but that they should be treated also as individual actions. Positional differences were reported for numbers of RSA performed,

with the maximum of 1 performed by defenders, whereas attackers performed 2 - 4. In addition to this, Spencer *et al.* (2004) also noticed that 4 of the 17 RSA consisted of 6 - 7 sprints, representing an intense period of RSA. In acknowledgment, it has been suggested that a test protocol designed to overload the player, specific to men's hockey, may include 6 - 7 sprints with less than 21 s recovery between sprints of 4 seconds in duration.

Summary

Intermittent sports, such as field hockey, require a high degree of physical fitness (Reilly & Seaton, 1990). Previous time-motion analysis indicates that in women's field hockey, about 20% of the game is spent in high-intensity activity, such as running and sprinting (Lothian & Farrally, 1994). High-intensity activities of short duration (5 s) are truncated with low intensity activities such as walking and jogging (18 s). Game skill requirements and added postural stress (semi-crouched posture) are superimposed on the work-rate demanded by the game and its pattern of play, and make the demands of field hockey unique (Reilly & Seaton, 1990). It is therefore appropriate to view a field hockey game as aerobically demanding, with frequent, though brief, anaerobic efforts added (Reilly & Borrie, 1992). High-intensity efforts rely predominantly on the immediate (ATP-PC) and short-term (anaerobic glycolysis) anaerobic energy systems. The aerobic energy system is important during prolonged intermittent exercise. Manifestly, the energetics of field hockey require an interaction of all three energy systems, with each system playing a significant yet specific role in energy supply during the game, dependent on individual playing position demands (Reilly & Borrie, 1992; Dawson *et al.*, 1993; Lemmink & Visscher, 2006).

Chapter III – Validation Study

Validation of Trak Performance as a time-motion analysis system

Introduction

For effective coaching and athlete training to be undertaken, accurate and reliable performance data is a fundamental critical requirement. In field sports, this data has not traditionally been readily available, and has often been provided by subjective assessments and judgments by coaching staff (Schokman *et al.*, 2002). Performance analysis of the game can assist to provide this information in a more accurate and reliable manner. One of the most commonly reported uses of this information is to identify physiological demands of the game to provide a more detailed understanding of the game for specificity of training regimes (Reilly & Thomas, 1976; Withers *et al.*, 1982; Mayhew & Wenger, 1985; McKenna *et al.*, 1988; Deutsch *et al.*, 1998).

Various methods of time-motion analysis (TMA) have been documented, many of which have been criticised in terms of the validity and reliability of the data that they report. This is somewhat disconcerting as the usefulness of any TMA relies upon the extraction of valid and reliable data from real sport performances. Systems have been produced that have furthered hand-notation and labor intensive digitisation techniques towards more user-friendly, computer-based, real-time tracking technologies to more accurately reflect movements of players during team game situations. Technological advancements have led towards automatic data collection of such movement data using GPS, image recognition and three-dimensional motion capture (Liebermann *et al.*, 2002). However many of these techniques are expensive, inaccessible or have cumbersome, preclusive equipment, that inhibit them from being used in field-based settings.

Some of these systems still require an element of human manipulation to extract data and as such possess some operator error (O'Donoghue, 2004), with limited research published comparing their use against recognised automated criterion measures. The validation of these systems is fundamental when proposing new methods for the identification of time-motion variables of team sports.

Accuracy of these 3D motion capture systems has reached sub-millimetre precision for focused captures such as at the hand (Metcalf, 2009). Because of their high level of accuracy and ability to compute 3D coordinates, these motion capture systems are widely adopted in biomechanical studies (Williams, Schmidt, Disselhorst-King & Rau, 2006). The purpose of the current study therefore was to undertake criterion validity testing of the data collected using Trak Performance (TP) (Sportstec International, Australia), the proposed method of data collection for the main study, against a 16-camera Vicon 3D (Vicon, OMG Plc, UK) motion capture system in simulated field hockey.

Method

Participants

Members of the University of Worcester 1st XI women's hockey team volunteered for, and participated in, the study. Six elite-level collegiate hockey players ($n = 6$) with mean age of 19.2 (± 1.5) years participated in the validation study. The Departmental Ethics Committee approved the project via a checklist (Appendix 2), and written informed consent was obtained from the individual volunteer participants (Appendix 3).

Procedure

Participants played 5 games of 5 minutes competitive '3-on-3' hockey in an indoor area measuring 10 x 8 m. During this time both data collection methods, Vicon and Trak Performance (TP) were used. Further information about the individual procedures are detailed below:

Vicon – 3 dimensional motion capture

Reflective markers were placed on the crown of baseball caps worn by each player. A small block of wood was also issued a reflective marker and used to assist in the synchronisation of the two data capture methods. All markers were tracked using a 16-camera Vicon MCAM2 3D (Vicon, OMG Plc, UK) motion capture system with Vicon Workstation software (Vicon, OMG Plc, UK), at 60Hz.

Initial data processing was conducted using the Vicon Bodybuilder software, where each reflective marker was identified and labeled. The trajectories for each marker were checked for continuous recognition around the data capture area for the entire five minute period of play. Once each player had been labeled, a movement file for each individual player was exported. Each file was opened in Excel 2004 for Mac (Microsoft Corporation, USA). Each exported Vicon ASCII file reported x,y,z coordinates for the marker attributed. Further data calculations were made to identify distance covered and speed at each data point. The speed of individual player movement was categorised into the following speed zones: stationary (0.0 - 0.1 km/hr), walking (0.1 - 6.1

km/hr), jogging (6.1 - 10.1 km/hr), striding (10.1 - 14.4 km/hr) and sprinting (14.4 - 32.3 km/hr) (adapted from Boddington *et al.*, 2002).

Trak Performance computer based tracking system (TP)

A fixed camera (Sony HVR-Z1, Sony Corporation, Japan) with 0.5 wide-angle lens was positioned in an elevated position at the end of the indoor arena, to obtain an overall view of the whole playing arena for post event player tracking to be undertaken. The entire duration of the five competitive games was recorded continuously.

A computer-based tracking (CBT) method was applied for the data collection. The specific CBT system used, Trak Performance (TP) (Sportstec Limited, Australia), utilises a scaled version of the playing pitch on which individual player movements are traced. The scaled pitch is calibrated so that a given movement of the mouse pen corresponds to the linear movement of the player. The software allows for the tracking of one individual at a time and utilizes the following basic algorithm (Edgecomb & Norton, 2006).

$$\text{linear distance} = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$$

where x_1 = horizontal x coordinate at time 1; x_2 = horizontal x coordinate at time 2; y_1 = vertical y coordinate at time 1; y_2 = vertical y coordinate at time 2. The x and y coordinates and distances are in computer pixels.

The observer was seated directly in front of the computer monitor (Samsung 206BW, Korea), with a portable laptop MacBook Pro (Apple Inc, USA) with Trak Performance (Sportstec Limited, Australia) and a graphics tablet (Wacom Intuous A3, Japan) (Figure 1). Video footage from the validation study was replayed through a computer via the video software QuickTime Pro (Apple Inc, USA) so as to allow for full-screen viewing. The observer tracked each player continuously with the drawing tablet stylus, using the ground markings visible as reference points.



Figure 1. *Set-up of computer-based tracking system TP, monitor and tablet input device.*

The CBT system, Trak Performance, allowed the derivation of the following variables in real-time; total distance travelled by player, time spent in allocated speed zones, and mean speed displayed on screen updated second-by-second. This information was also recorded and saved to files to allow for later analysis (Edgecomb & Norton, 2006). This data was exported into Excel 2004 for Mac (Microsoft Corporation, USA), where further calculations were applied to categorise speed into one of five locomotion categories defined as stationary (0.0 - 0.1 km/hr), walking (0.1 - 6.1 km/hr), jogging (6.1 - 10.1 km/hr), striding (10.1 - 14.4 km/hr) and sprinting (14.4 - 32.2 km/hr) (adapted from Boddington *et al.*, 2002).

Statistical analysis

The speed category and distance components from both data collection methods were compared using weighted kappa for level of agreement between the two samples of categorisation of movement using Excel 2004 for Mac (Microsoft Corporation, USA). Kappa level of agreement values were interpreted using Altman (1991) strength of agreement values (Table 2). Independent samples *t*-test were applied to test for significant differences between mean distance covered and mean speed for both data collection methods using SPSS v17.0 (SPSS Inc, Chicago, USA).

Table 2. *Interpretation of kappa values (Altman, 1991).*

Kappa	Strength of agreement
$\kappa \geq 0.8$	Very good
$0.6 \leq \kappa < 0.8$	Good
$0.4 \leq \kappa < 0.6$	Moderate
$0.2 \leq \kappa < 0.4$	Fair
$\kappa < 0.2$	Poor

Results

Independent samples *t*-test statistical analysis revealed significant differences between the mean distances covered as reported by both data collection methods (Table 3). The 3D motion capture method (Vicon) reported a significantly greater mean distance covered when compared to TP (Trak) data collection method ($t = 7.346$, $p < 0.05$), representing a mean percentage difference of $20.27 \pm 14.79\%$ between the two data collection methods during simulated 3 v 3 hockey games. The same statistical analysis was conducted on the mean speed variable and identified significant overall differences, with Vicon reporting a significantly greater mean speed compared to the Trak analysis ($t = 4.008$, $p < 0.05$).

Table 3. *Distance covered (m) and mean speed (km/hr) of players in simulated hockey games as calculated by both data collection methods (mean \pm SD).*

	VICON	TRAK
Mean Distance covered (m)	227.20 \pm 42.29	181.02 \pm 45.01
Mean Speed (km/hr)	2.8 \pm 0.2	2.1 \pm 0.4

When the raw speeds of movement data from each method were categorised into the 5 locomotion categories, the methods agreed on the categorisation of locomotion activity in $88.63 \pm 1.22\%$ of cases. Inspection of the remaining 11.37% of cases in which categorisation was not in absolute agreement, revealed that $9.26 \pm 1.56\%$ were classified one category higher, $1.87 \pm 0.74\%$ one category lower, $0.21 \pm 0.05\%$ two categories higher and $0.02 \pm 0.03\%$ lower by the TP compared to the 3D data collection method (Figure 2). A weighted kappa level of agreement analysis reported a value of 0.7, interpreted by Altman (1991) to be of good agreement (Table 2).

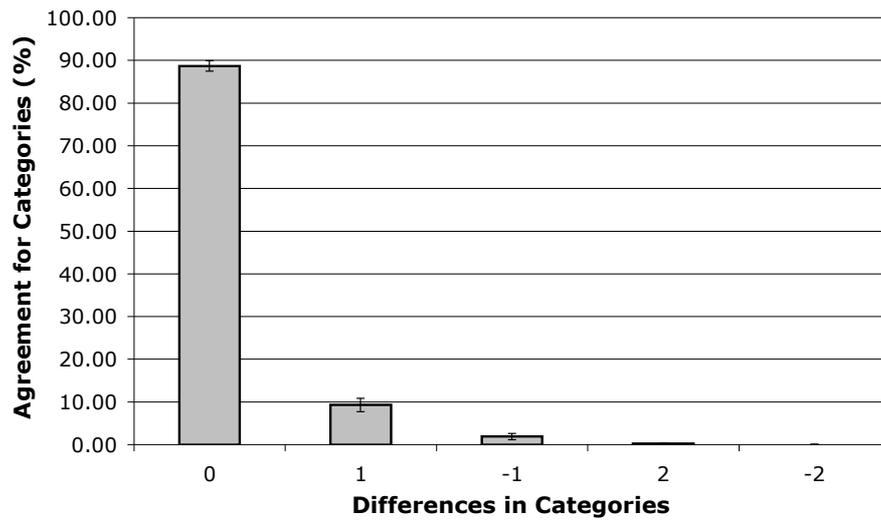


Figure 2. *Percentage of agreement of categorisation of locomotion activity between both data collection methods and degree of deviation from agreement (mean \pm SD).*

Discussion

The first objective of the thesis involved the investigation of the validity and reliability of using Trak Performance, a computer based tracking system, for the capture and analysis of time-motion data in elite women's field hockey. In order to gather data to address this objective, a simulated hockey game play study was undertaken in which 2 teams of 3 players competed in an indoor arena of 10 m by 8 m, whilst simultaneously being digitally video recorded and tracked using an automated and extremely precise 3D motion capture system. The computer based tracking system Trak Performance analysis system was then used, post-event, to trace player movement from the digital video recording and the results compared to those obtained from the 3D Vicon system as the 'criterion' method of motion capture.

The accuracy of 3D motion capture system (Vicon) has long been acknowledged and adopted in the biomechanical discipline, with the ability for within sub-millimetre precision for focused captures on small movements such as the hand (Williams *et al.*, 2006; Metcalf, 2009). However the expensive and cumbersome equipment required for such detailed and accurate analysis precludes itself from use in any other discipline. The acknowledged accuracy of 3D motion capture was fundamental in its implementation in comparison against the data collection method TP. Although precision to the sub-millimetre scale was not required, it was felt that this data normalised to the same level of accuracy to the other data collection method would provide a suitable 'Gold-Standard' for comparisons to be made.

Expanding the normal capture area of the 3D motion capture system to encompass the 10 x 8 m indoor arena, did not have any effect on its own functioning, with calibration reporting the system to be accurate within 1 millimetre. Significant differences were identified from statistical analysis on the mean distance covered as reported by both data collection methods. The analysis revealed that the 3D motion capture method (Vicon) reported a significantly greater total distance covered and greater mean speed during the simulated game as compared to the TP (Trak) method (Table 3).

Methodological differences in the point of player tracking, 3D motion capture a marker on the crown of the head of each player, and TP a midway point between both feet on the floor, provide some justification in the significant differences identified by these tracking methods, which will be discussed further. This difference in the point of tracking caused great concern on initial method investigation. The 3D motion capture system, being optics based, requires direct line of sight with the reflective markers which can easily be broken. The possibility of occlusion is partially overcome by the use of multiple cameras, but to reliably track all markers especially in a larger capture area, the most prominent positioning was vital. The optimal placement of the retroreflective marker was deemed to be on the crown of the head as it was least likely to be occluded by other players from view of the cameras for the 3D motion capture method during the simulation of play. A subsequent investigation was undertaken to see if the TP system could track the player using the same location, however the design of TP requires the ground positioning of the player to be tracked, so that there is no discrepancy between where the player is and where they are perceived to be from the angle of view. In this particular case, had the head of the player been tracked within the TP software, there would have been a considerable amount of time that the player would be deemed to be out of the playing area.

As the Vicon system measures the movement of the reflective marker on the head, and TP measures actual movement between the feet, any vertical movement of the head would be attributed to the total distance covered during the simulation (Table 3). The small playing area could also allow players to reach for the ball without moving their feet, which Vicon would track as displacement, but TP would not acknowledge. Further increases in the distance covered attributed from the Vicon motion capture could derive from the extra movement undertaken when players take up a hockey related stance (Reilly & Seaton, 1990). These additional movements, although initially small, when coupled together could provide reasoning for such discrepancies. Despite significant differences in the overall average speed (Table 2) reported by both methods, analysis of the degree of discrepancies for locomotion categorisation reveals more appealing results (Figure 2). Data reported

highlights that total agreement in classification of locomotion to be between 87-90%. The remaining cases where categorisation was not agreed by both methods, revealed that 11.13% of cases differed by one category either higher or lower, resulting in 0.21% (± 0.05) of cases categorised either two higher and 0.02% (± 0.03) two lower, with a good kappa level of agreement. Edgecomb and Norton (2006) reported issues with systematic errors occurring from small sideways movements of the cursor when tracking player's around a playing area, and noted that these errors were more pronounced at lower movement speeds. This would provide reasonable allowance for these discrepancies in categorisation.

A report by Roberts *et al.* (2006) in which a comparison of objective hand notation of movement was compared to 2-dimensional coordinate based digitising method highlighted that the notational method reported a 27.5% greater amount of time spent in work than the digitisation method, equating to an 8 minute difference. In contrast the discrepancies of the current study of between 10 - 13% disagreement in categorisation seems considerably smaller.

Assessment of the use of the Vicon system prior to study commencement revealed that it was not possible to use the Vicon system in a larger area such as a sports hall. Issues with the reflection of the cameras from the floor and interference with the lighting system were experienced. The use of the Vicon system in the purpose built laboratory, but with the largest possible tracking arena, was the only option in which this Vicon method could be used. It would appear however, that the small indoor arena of 10 x 8 m has impinged on the validity of this analysis. The 3 'v' 3 simulated hockey game in this relatively small arena did not elicit any sprinting behaviour from the players. This is unfortunate, as it has previously been noted that it is difficult to observe any discernible differences between the running locomotion's of striding and sprinting (Withers *et al.*, 1982).

Chapter IV – Reliability Study

Reliability of Trak Performance as a time-motion analysis method

Introduction

Performance analysis, like many other areas of sports science, is a discipline where reliability of measurement is critically important. The significance of the repeatability and accuracy of any data gathering system used for performance analysis is paramount, stated as a central facet to performance analysis by Hughes *et al.* (2002). It has been acknowledged that this importance is more significant when new equipment and methods are being used to produce evidence of systematic testing and reliability (Hughes, 2008b). It is also important that the reliability of these systems is demonstrated in a manner that is compatible with the intended subsequent analysis of data (Hughes *et al.*, 2002), time-motion analysis systems are no exception to this (O'Donoghue, 2008).

Unless automatic player tracking systems are used (Liebermann *et al.*, 2002), most methods will still require at least some level of manual data input, where a human operator becomes part of the measurement instrument. This can result in movement data being entered inaccurately due to the subjective nature of human movement recognition, variable observer reaction to events being performed by the subject and indeed different interpretations of performance indicators relating to work-rate and movement by different observers (O'Donoghue, 2008). For example, McLaughlin and O'Donoghue (2002), found that one observer had a tendency to record 10% more time spent performing high intensity activity than the other observer used in an inter-operator reliability study involving 28 subjects. However Hughes *et al.* (2002) found that from analysing 72 research papers, 70% of investigations did not report any reliability study.

Assessing the reliability or measuring the consistency of data is usually determined via a test-re-test method. Where the first measurement of data is compared against subsequent information collated in the same manner (Vincent, 1999). In performance analysis independent observations of the same performance are used (O'Donoghue, 2010). Even when fully automated systems are used (Vicon 3D motion capture and GPS), there may still be errors due to incorrect labeling, occlusion or limitations in the system used. Therefore, reliability evaluation is essential so that the information produced and detailed can be interpreted with the full knowledge of the level of measurement error involved. (O'Donoghue, 2007).

Hughes *et al.* (2004) proposed that the simplest and most intuitive method for assessing agreement between two measurements was percentage error. Calculating the sum of the absolute difference in frequencies as a percentage of the sum of the mean frequencies recorded by two operators. However this total percentage error can conceal disagreements that are above the acceptable limit, cancelling each other out, because during the calculation of percentage error only the totals were used (O'Donoghue, 2010). The kappa statistic (Cohen, 1960) has also been identified to be more rigorous in this assessment of agreement, and has been used in time-motion analysis studies to calculate the agreement of independent observers adjusted for when agreements could occur by chance (McLaughlin & O'Donoghue, 2002; O'Donoghue *et al.*, 2005; Robinson & O'Donoghue, 2008). Kappa has been recognised as a harsh reliability statistic, as any disagreement with disregard to the magnitude, is deemed a disagreement. O'Donoghue (2010) state that within the performance analysis discipline there are two forms of nominal scale which should be accounted for in statistical analysis. Those that have neighbouring values and those that do not. Kappa treats these neighbouring values as disagreements, the same way it would treat other values, whereas weighted kappa (Cohen, 1968), applies credit to those values that are neighbouring.

The nature of this reliability assessment warrants the acceptance of neighbouring values in locomotion categories that border each other. Using the weighted kappa statistic (Cohen, 1968), partial credit of agreement will be given towards paired values associated between stationary and walking, walking and jogging, jogging and striding, and striding and sprinting.

Method

Video Footage Collection

The movement of all outfield players of group matches played on Number One pitch (n = 18) of the Womens European Nations Cup 2003 were recorded by two digital video cameras onto MiniDV tapes. The video footage was collected using two Sony DCR-TRV50E (Sony Corporation, Japan) digital video cameras mounted on Manfrotto Aluminium Studio Pro tripods, positioned at the half-way line on a raised platform approximately 10 m away from the sideline, at an elevation of approximately 20 m. Permission was obtained from the television broadcasters (RTVE, Spain) for media access to the tournament arena and facilities. From the camera positions provided, full pitch coverage was not obtainable, so the filming parameters were altered. Both cameras were panned simultaneously from an initial central position in order to track all outfield players' movement on the pitch.

The footage from each camera was individually captured via firewire (IEEE 1394) into a video analysis software package SportsCode Elite (Sportstec Limited, Australia) using a portable laptop MacBook Pro (Apple Inc, USA) at 25 frames per second. The digital recordings of both cameras were synchronized to 1/25th precision by observing first stride movement of the player at the forefront of the field visible by both cameras. Each half view of the pitch was then stitched together, to allow for viewing of all outfield players. This video file was then exported out to be an independent single video file for viewing as a QuickTime file.

Video analysis

From the games collected for the principle study, five randomly selected samples of periods of five minutes were used for the reliability analysis. All analysis was conducted in the same manner as was to be used within the principle study. Each five minute sample was analysed twice by the same observer to establish intra-reliability.

A computer-based tracking (CBT) method was applied for the data collection. The specific CBT system used, Trak Performance (TP) (Sportstec Limited, Australia), utilises a scaled version of the playing pitch on which individual player movements are traced. The scaled pitch is calibrated so that a given movement of the mouse pen corresponds to the linear movement of the player. The software allows for the tracking of one individual at a time and utilises the following basic algorithm (Edgecomb & Norton, 2006).

$$\text{linear distance} = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$$

where x_1 = horizontal x coordinate at time 1; x_2 = horizontal x coordinate at time 2; y_1 = vertical y coordinate at time 1; y_2 = vertical y coordinate at time 2. The x and y coordinates and distances are in computer pixels.

The observer was seated directly in front of the computer monitor (Samsung 206BW, Korea), with a portable laptop MacBook Pro (Apple Inc, USA) with Trak Performance (Sportstec Limited, Australia) and a graphics tablet (Wacom Intuous A3, Japan) (Figure 3). Video footage was replayed through a computer via the video software QuickTime Pro (Apple Inc, USA) so as to allow for full-screen viewing. The observer tracked the player continuously with the drawing tablet stylus, using the visible ground markings as reference points.



Figure 3. *Set-up of computer-based tracking system TP, monitor and tablet input device.*

The CBT system, Trak Performance, allowed the derivation of the following variables in real-time; total distance travelled by player, time spent in allocated speed zones, and mean speed displayed on screen updated second-by-second. This information was also recorded and saved to files to allow for later analysis (Edgecomb & Norton, 2006). This data was exported into Excel 2004 for Mac (Microsoft Corporation, USA), where further calculations were applied to categorise speed into one of five locomotion categories defined as stationary (0.0 - 0.1 km/hr), walking (0.1 - 6.1 km/hr), jogging (6.1 - 10.1 km/hr), striding (10.1 - 14.4 km/hr) and sprinting (14.4 - 32.2 km/hr) (adapted from Boddington *et al.*, 2002).

Statistical analysis

Paired samples *t*-test were applied to the mean distance covered, and time spent in individual locomotion categories for both samples of data via SPSS v17.0 (SPSS Inc, Chicago, USA). Weighted kappa and non-weighted kappa statistical analysis was applied to the two samples of data for assessment of agreement in chronological categorisation of movement using Excel 2004 for Mac (Microsoft Corporation, USA), interpreted by Altman (1991) (Table 2).

Results

Table 4 shows the differences in the total distance covered by the player samples used in the re-analysis process for the determination of reliability of the use of the Trak Performance. Paired samples *t*-test conducted on these two variables did not identify any significant statistical differences between the two analyses (0.70 ± 0.11 vs 0.62 ± 0.11 , $t = 1.91$, $p > 0.05$).

Table 4. *Distance covered from re-analysis (mean \pm SD).*

	Analysis 1	Analysis 2
Mean Distance covered (km)	0.70 ± 0.11	0.62 ± 0.11

Figure 4 graphically represents the time spent in individual locomotion categories as reported from the initial analysis and then the re-analysis of the same randomly selected five minutes of play from 5 games. Paired samples *t*-test conducted on the data revealed no significant differences between the percentages reported by both analyses; stationary ($t = 0.537$, $p > 0.05$), walking ($t = -1.697$, $p > 0.05$), jogging ($t = 0.642$, $p > 0.05$), striding ($t = 1.431$, $p > 0.05$) and sprinting ($t = 0.785$, $p > 0.05$).

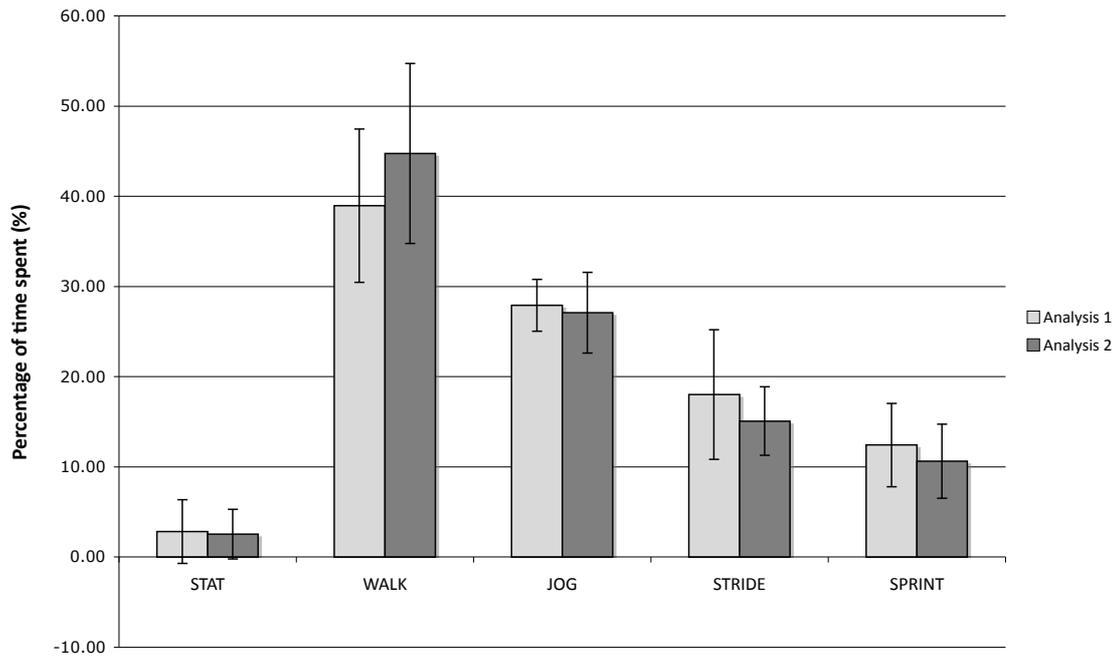


Figure 4. *Percentage of time spent in locomotion categories from re-analysis.*

An initial kappa calculation recognised a proportion of the number of times categorised were agreed, P_0 , of 0.47. However the expected proportion of categorisation agreements where they could be expected to agree by chance, P_C , of 0.32 (Table 5). This meant that the kappa value, κ , 0.21, would be interpreted as fair agreement (Altman, 1991). However some of these disagreements were due to minor differences in categorisation (Figure 5), therefore a weighted kappa calculation is more appropriate.

Table 5. *Number (s) agreements in categorisation on re-analysis.*

Observation 1	Observation 2				Total
	Stationary	Walking	Jogging	Striding	
Stationary	14	27	7	-	48
Walking	15	346	137	76	574
Jogging	-	164	143	108	415
Striding	-	119	138	206	463
Total	29	656	425	390	1500

Table 6. Value (s) for agreement in categorisation.

Observation 1	Observation 2			
	Stationary	Walking	Jogging	Striding
Stationary	1	0.5	-	-
Walking	0.5	1	0.5	-
Jogging	-	0.5	1	0.5
Striding	-	-	0.5	1

Calculation of a weighted kappa, using the values for agreement above (Table 6) and the numbers of agreement in categorisation (Table 5) recognise that the number of times categories were agreed, P_0 , of 0.67. However the expected proportion of categorisation where they could be expected to agree by chance, P_C , of 0.14. This meant that the weighted kappa value, κ , 0.61, would be interpreted as good agreement (Altman, 1991) (Table 2).

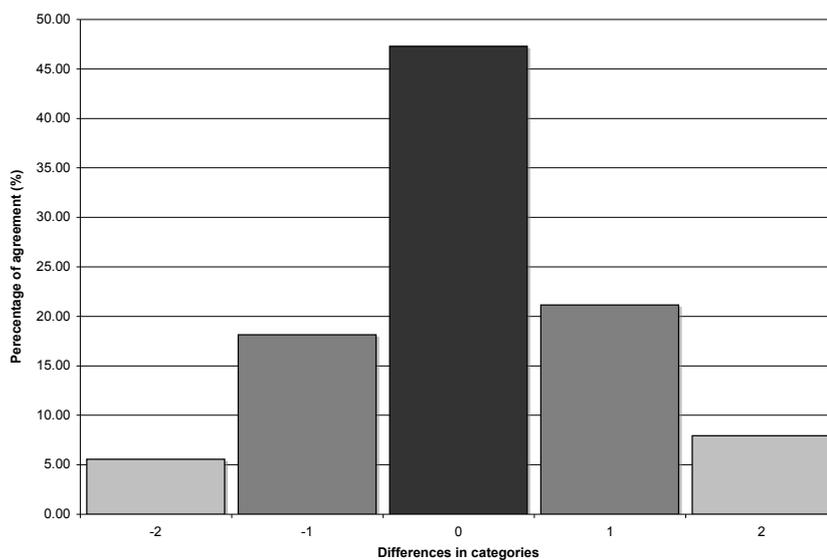


Figure 5. Percentage agreement for the categorisation of movement into individual locomotion categories.

Discussion

Before examining the findings from any time-motion analysis study, research has identified that the reliability of any system used must first be established (Hughes *et al.*, 2002; O'Donoghue, 2007). Assessment of the reliability of the time-motion analysis in the current study was conducted by re-analysis of previously analysed samples. In which five minutes, from five separate games, were re-analysed on separate occasions. A comparison of the analysis for the percentages of time spent in individual locomotion activities revealed no significant differences in any of the 5 categories, providing an indication that the two analyses were not more than 95% different (Figure 4).

However kappa values reported indicated only a fair level of agreement between the two analyses ($\kappa = 0.21$), this is not a convincing indication of the reliability of using TP as a method for time-motion analysis. It has been indicated previously that kappa level of agreement for reliability is a harsh statistic, causing anything other than an exact agreement to be treated as total disagreement. When reducing continuous movement into discrete categories, some variation is inevitable between the bordering categories. For example, kappa treats a disagreement between running and sprinting the same way as a disagreement between sprinting and stationary movement. Perhaps a statistic that allows less bias for bordering categories would produce a more favorable level of agreement. Figure 5 indicates the benefit of this, with 86.53% of movement categorisation falling between -1 and +1 categories from the original assessment.

More recently, the use of the kappa statistic as an interpretation of reliability has been questioned. The use of a weighted version of kappa has been suggested for the assessment of reliability performance analysis studies. Using a matrix to alter the weighting of agreements, weighted kappa treats some neighbouring classifications as partial agreements, and not total disagreements, with the resultant a possibly increase in the level of agreement. Analysis of the reliability of the TP as method for time-motion

analysis using this method indicates ($\kappa = 0.61$) a good level of agreement between the two observations (Altman, 1991).

Table 4 provides evidence of the consistency of TP as a method for time-motion analysis in measuring distance covered, with statistical analysis unable to detect any significant difference in the results for distance covered over the reassessment period of analysis. In their comparison of tracking systems for measuring player movement, Edgecomb and Norton (2006) reported average differences in distances measured and actual distances of 5.8 - 7.3%, suggesting systematic errors that associated with TP, whereby a general overestimation of distance occurs. Revealing that small sideways movement of the cursor around the pitch during player tracking can over estimate distances, especially at lower movement speeds.

It has been previously stated that for an analysis system to be deemed objective, the results from the system should remain consistent regardless of the individual operator. It is proposed that the TP method of data collection, due to the lack of subjective categorisation removes the most common issue between operators of agreement in the categorisation of movement into specific locomotion categories. The continuous nature of the tracking procedure for TP requires the play being analysed to be manually tracked around the pitch and movements to be traced onto a scaled diagram of the pitch. Therefore an intra-operator reliability study identifies the consistency of the player tracking and not the ability to correctly categorise movements from subjective observations. Further questions have also been raised, as to whether intra-operator reliability studies merely report increased awareness and familiarity of the match observed, and not the reliability of the assessment. The continuous tracking method of TP does not allow such familiarisation of the game to occur.

It is the opinion of the current author, from the data portrayed, that the TP motion tracking method provides a superior and reliable method for the analysis of time-motion, than others reporting the use of subjective

observations to categorise locomotive movement. Subjective categorisation of movement has two inherent problems. Initially the correct identification of the movement category from observation and, as equally important, the estimation of distance covered from average stride length or average speed. The TP method calculates both players' speeds and distances covered by individual displacements recorded by the tracing of players' movements around a scaled image of the pitch. The TP method removes the observational categorisation of movement, and replaces with grounded mathematical computations of displacement at regular intervals of one second.

Chapter V – Method

Video Footage Collection

The movement of all outfield players of group matches played on Number One pitch (n = 18) of the Womens European Nations Cup 2003, from 12 International teams: Netherlands, Spain, Germany, England, Ukraine, Ireland, Scotland, France, Azerbaijan, Russia, Italy and Wales, were recorded by two digital video cameras onto MiniDV tapes. The video footage was collected using two Sony DCR-TRV50E (Sony Corporation, Japan) digital video cameras mounted on Manfrotto Aluminium Studio Pro tripods, positioned at the half-way line on a raised platform approximately 10 m away from the sideline, at an elevation of approximately 20 m. Permission was obtained from the television broadcasters (RTVE, Spain) for media access to the tournament arena and facilities. From the camera positions provided, complete full pitch coverage was not obtainable, so the filming parameters were altered, in that both cameras were panned simultaneously from an initial central position in order to track all outfield players' movement on the pitch.

The footage from each camera was individually captured via firewire (IEEE 1394) into a video analysis software package SportsCode Elite (SCE) (Sportstec Limited, Australia) using a portable laptop MacBook Pro (Apple Inc, USA) at 25 frames per second. The digital recordings of both cameras were synchronised to 1/25th precision by observing first stride movement of the player at the forefront of the field visible by both cameras. Each half view of the pitch was then electronically stitched together, to allow for viewing of all outfield players. This video file was then exported out as an independent single video file for viewing as a QuickTime movie file (QT) (Figure 6).

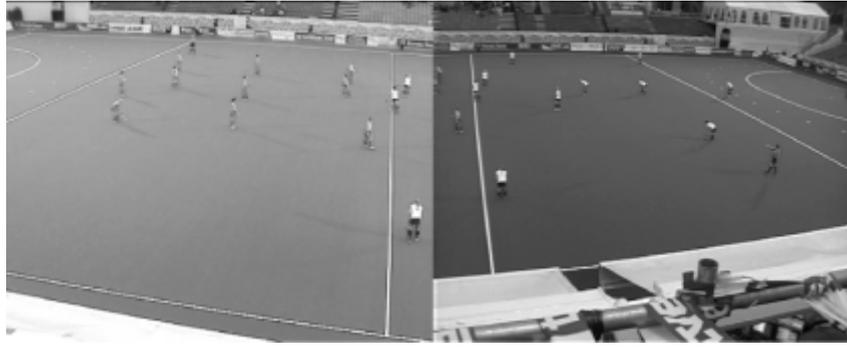


Figure 6. Exemplar of 'stitched' videos from which time-motion analysis player tracking was conducted.

Computer-Based Tracking System

A computer-based tracking (CBT) method was applied for the data collection. The specific CBT system used, Trak Performance (TP) software (v2.2.2) (Sportstec Limited, Australia), utilises a scaled version of the playing pitch on which individual player movements are traced. The scaled pitch is calibrated so that a given movement of the mouse pen corresponds to the linear movement of the player. TP allows for the tracking of one individual at a time and utilises the following basic algorithm (Edgecomb *and* Norton, 2006).

$$\text{linear distance} = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$$

where x_1 = horizontal x coordinate at time 1; x_2 = horizontal x coordinate at time 2; y_1 = vertical y coordinate at time 1; y_2 = vertical y coordinate at time 2. The x and y coordinates and distances are in computer pixels.

The CBT system, simply instructed the computer to take the current position, in x-y pixels on the screen at any time slice, and to calculate the linear distance travelled since the x-y position determined at the previous time slice. Using the pitch calibration factor to convert pixels into metres, according to the playing field dimensions and screen resolution. TP allowed the derivation of the following variables in real-time; total distance travelled by player, time spent in allocated speed zones, and mean speed displayed on screen updated second-by-second. This information was also recorded and saved to

files that allowed the entire sequence of player movements and summary statistics of game events to be plotted.

Data Collection Procedure

A stratified random sample of three players from one team in each match were analysed, these included one midfielder, one defender and one forward; giving a total sample size of $n = 54$ players from the 18 matches. The observer was seated directly in front of the computer monitor (Samsung 206BW, Korea), with a portable laptop MacBook Pro (Apple Inc, USA) with Trak Performance (Sportstec Limited, Australia) and a graphics tablet (Wacom Intuous A3, Japan). Video footage was replayed through a computer via the video software QuickTime Pro (Apple Inc, USA) so as to allow for full-screen viewing. Each player's movement patterns were followed from the video replay and tracked using a Wacom graphics stylus onto the tablet continuously throughout each game, using visible ground markings as reference points into the software TP. When a player was substituted or moved positions, the replacement player in the position being analysed was followed for the rest of the tracking process, consequently focusing on the playing positions and not the individual athletes (Dawson *et al.*, 2004).



Figure 7. *Set-up of computer-based tracking system TP, monitor and tablet input device.*

This information was also recorded and saved to files to allow for later analysis (Edgecomb & Norton, 2006). This data was exported into Excel 2004 for Mac (Microsoft Corporation, USA), where further calculations were applied to categorise speed into one of five locomotion categories defined as stationary (0.0 - 0.1 km/hr), walking (0.1 - 6.1 km/hr), jogging (6.1 - 10.1 km/hr), striding (10.1 - 14.4 km/hr) and sprinting (14.4 - 32.2 km/hr) (adapted from Boddington *et al.*, 2002).

Data processing

Individual tracking files were exported from the TP software and imported into Excel 2004 for Mac (Microsoft Corporation, USA). Calculations were made on the initial raw data of time, speed and distance, to categorise the speed into one of the aforementioned speed categories and the variables of distance covered, time spent in locomotion categories, duration of activities, sprinting characteristics including repeated sprint activity and work to rest ratios were calculated using the formula presented in Appendix 6.

Statistical analysis

A series of multivariate analysis of variance (MANOVA) with post hoc Tukey test adjusted alpha statistical tests were conducted to investigate positional differences on the following variables; percentages of time spent and distance covered in each locomotion activity, number of sprint bouts and duration of sprint bouts, repeated sprints activity dynamics and percentage of activity performed pre and post sprints using SPSS v.17.0 (SPSS Inc, Chicago, USA). A number of one-way ANOVA were used to investigate positional differences for the total number of sprints performed, the rest time between sprints, total distance covered and work to rest ratios.

Chapter VI – Results

Time-motion characteristics of women's hockey

Analysis of the games identified a mean total distance covered by outfield players of 9.1 ± 1.6 km, of which 4.6 ± 0.4 km and 4.1 ± 1.3 km was covered in low intensity and high intensity activity respectively. On average players were standing for $3.9 \pm 2.4\%$ of total game time. Low intensity modes of stationary, walking ($42.6 \pm 7.6\%$) and jogging ($28.2 \pm 3.0\%$) accounted for approximately three-quarters of total game time ($74.7 \pm 9.0\%$). High intensity running accounted for $25.3 \pm 9.0\%$ of total game time; this was composed of $14.9 \pm 3.5\%$ striding and $10.3 \pm 6.0\%$ sprinting. All of these individual performance indicators contribute to an overall work to rest ratio of $1:3.5 \pm 1.8$.

The mean duration of locomotion activities of the game are presented in Table 7. Longest activity durations were found in the stationary and walking locomotion's, surprisingly the 3rd longest duration was sprinting.

Table 7. *Duration of locomotion during field hockey game (mean \pm SD).*

	Locomotion category (s)				
	Stationary	Walking	Jogging	Striding	Sprinting
Mean duration (s)	4.8 ± 1.5	3.7 ± 0.4	2.0 ± 0.1	1.7 ± 0.1	2.5 ± 0.3

Analysis of the individual sprint characteristics identified that mean distance covered whilst sprinting was 12.7 ± 1.7 m. A considerable variation was identified in the time between sprints with an average of 26.7 ± 11.5 s, with these intervening periods predominantly being spent in the locomotion category of jogging with an average speed of approximately 2 m/s (7.7 ± 0.55 km/hr).

As would be expected from a continuous motion tracking method, the overall greater percentage of activity that occurs prior (71.62 ± 5.98) to and after (68.29 ± 3.93) a sprint event is a lower intensity level running of striding. The results also indicate that there are occasions when a player is required to sprint directly from walking (3.89 ± 2.42) and a greater percentage of times from jogging (24.47 ± 5.11). Figure 8 also indicates that players return to lower intensity activity such as walking (4.42 ± 2.14) and jogging (27.23 ± 3.04) after sprinting.

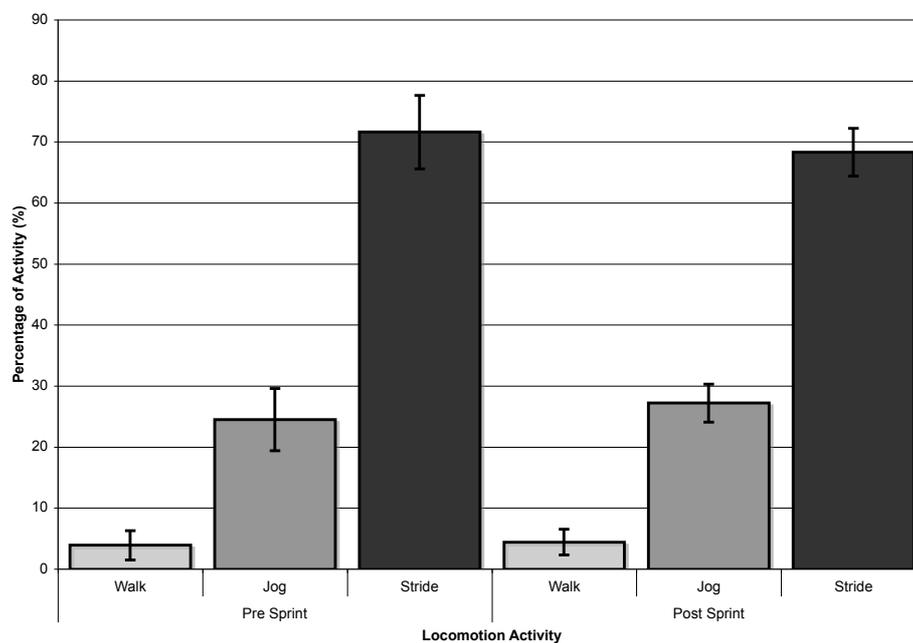


Figure 8. *Percentage of locomotion activity pre and post sprint (mean \pm SD).*

Investigation of data in respect to repeated sprint characteristics revealed that on average 12 ± 9 occurrences were identified during a game. With each of these having on average 3 ± 1 sprints per bout, a mean recovery intervening period of 15.4 ± 3.5 s and each individual sprint being of approximately 12 m in length.

Positional Specific Time-Motion Characteristic

Multivariate analysis of variance revealed significant differences in the following performance indicator variables. It is clear the demands imposed on defensive players are significantly different to both the midfield and forward playing positions. In fact significant differences were found in 17 of the performance variables investigated. Data indicates that the work-rate profile of a defensive player is less physiologically demanding than forward and midfield players, with defenders spending more time walking and less time in high intensity activity. Throughout the data portrays a relationship between the midfield and forward positions as a group in comparison to the defensive playing position (Table 8).

Table 8. *Significant positional differences in performance variables (mean \pm SD; post hoc Tukey with adjusted alpha).*

	Defenders	Midfield	Forward
Total distance (km) ^b	7.84 \pm 0.72	9.56 \pm 1.40***	9.75 \pm 1.70***
Distance walking (km) ^a	2.10 \pm 0.19	1.80 \pm 0.25***	1.74 \pm 0.15***
Distance striding (km) ^b	1.72 \pm 0.72	2.28 \pm 0.39**	2.37 \pm 0.30***
Distance sprinting (km) ^b	1.32 \pm 0.53	2.20 \pm 0.88**	2.55 \pm 1.02***
% time spent walking ^a	49 \pm 5	40 \pm 6***	39 \pm 7***
% time striding ^b	12 \pm 2	17 \pm 3***	16 \pm 3***
% time sprinting ^b	3 \pm 2	12 \pm 6**	13 \pm 7***
% time low intensity ^a	82.1 \pm 4.5	71.7 \pm 7.8***	70.4 \pm 9.1***
% time high intensity ^b	17.8 \pm 4.5	28.3 \pm 7.8***	29.6 \pm 9.1***
Rest between sprints (secs) ^a	37.6 \pm 12.7	23.1 \pm 6.4***	19.3 \pm 4.0***
Total no of sprints ^b	132 \pm 76	177 \pm 45*	203 \pm 42***
No of RSA bouts ^c	5 \pm 4	12 \pm 8	16 \pm 9***
Frequency of Walk bouts ^a	533 \pm 32	499 \pm 29**	492 \pm 36***
Frequency of Stride bouts ^b	311 \pm 60	390 \pm 62***	409 \pm 47***
Frequency of Sprint bouts ^b	127 \pm 49	176 \pm 45***	201 \pm 42***
Work:Rest ratio ^b	4.98 \pm 1.68	2.78 \pm 1.03**	2.85 \pm 1.95***

^adefenders>midfield and forward; ^bdefenders<midfield and forward; ^cdefenders<forwards

*p<.05, **p<.01, ***p<.001

Chapter VII - Discussion

Time-motion characteristics of women's hockey

Use of performance analysis has increased in recent years as an aid to enhance performance as well as for research purposes. There is a paucity of scientific research that has been undertaken in field hockey, some which can be viewed outdated due in part to developments within the game itself and the methods used by the researchers. Previous investigations concerned with identifying the physiological demands of sport have used time-motion analysis methods to collect their data, many of these methods have been documented and discussed in Chapter 2. Although several of which have been criticised, with questions raised concerning the validity and reliability of the data reported.

As demonstrated in previous chapters, time-motion analysis studies have been used to determine the frequency, duration and distribution of match time to different locomotive movements in many team sports. Observational time-motion analysis provides a subjective, non-invasive method for the quantification of work-rate during field based sports. This has previously been reported as the most effective method of assessing the physiological demands imposed on players during competition at the elite level (Duthie *et al.*, 2005). However recent investigations by Roberts *et al.* (2006) compared subjective analysis results against those determined by an image digitisation technique, highlighting the distinct over estimations when using subjective categorisation.

In an attempt to quantify the physiological demands of International Women's hockey with the underlying purpose of identifying whether position specific demands are evident, a new computerised time-motion analysis system, Trak Performance, was tested. In order to address the issue of validity when using TP, it was necessary to undertake a criterion validity assessment. This was conducted against a 16-camera Vicon 3D (Vicon, OMG Plc, UK) motion

capture system in simulated field hockey. Despite some methodological differences, weighted kappa analysis values indicated a good level of agreement between locomotion categories reported from the two methods. However the discrepancies between the distances covered are of more concern. These question whether the comparison of the two methods in the manners in which there were assessed is a true reflection of the capabilities of the Trak Performance. It could be said that a comparison with a method that is calibrated to within the nearest millimetre, and designed to analyse fine body movements, provides information at too high a frequency and provides too much detail. Other studies have compared the speed and distance of tracking based methods against movement through timing gates (Di Salvo *et al.*, 2006; Roberts *et al.*, 2006). This potentially would have been beneficial to conduct in comparison to Vicon. In regards to the ability to categorise movement, TP was found to have good agreement with the locomotion categories. Therefore, TP can be seen as a suitable method for the categorisation of motion. However due to the less than acceptable level of validity in the measurement of distance covered, data viewed regarding these measurements should be viewed with some caution. Despite this, reliability assessment of the method proved that the TP method was able to reproduce data from the analysis of the same games within a reasonable level of agreement. Therefore, this method provides a good alternative to the subjective categorisation methods which have previously been used.

The current study identified that players covered on average 9.1 ± 1.6 km and spent 74.7% of time in low intensity activity. High intensity running accounted for $25.3 \pm 9.0\%$, of which $10.3 \pm 6.0\%$ was spent sprinting. Work to rest ratios indicated activity profile of $1:3.5 \pm 1.8$. Analysis of the sprinting revealed that individual mean sprints were on average 12.7 ± 1.7 m in length with approximately 26.7 ± 11.5 s between each sprint at jogging intensity.

Values identified in the current study for time spent in low intensity activity contradict much larger values of 92.1% reported by MacLeod, Bussell and Sunderland (2007) and 97% by Boddington *et al.* (2002). The current study results however are more conducive with evaluations in a much earlier study

by Lothian and Farrally (1994) in which they determined that National hockey players spent between 70.8% and 82.5% of time in high intensity activity, however the game has significantly changed with regards to the rules.

In connection with these findings of time spent, mean duration of activity reported in individual locomotion categories has been found to be atypical of those reported by MacLoed *et al.* (2006). Some similarities are apparent with the mean duration of sprinting with the current reporting 2.53 ± 0.27 s and MacLoed *et al.* (2006) 2.9 ± 1.5 s, however this is considerable shorter in duration than reported by Spencer *et al.* (2004) of 4.1 ± 2.1 s. The mean sprint distance (12.72 ± 1.72 m) is also considerably less than the distance reported by Spencer *et al.* (2004). Their findings are more similar to elite soccer players of 30 - 40 m (Barros *et al.*, 1999).

Figure 8 provides an indication of the intensity of activity performed immediately prior to and directly after a sprint. With $71 \pm 5.98\%$ of activity before being striding and $68.29 \pm 3.93\%$ after being striding. This is in contrast to data reported by MacLoed *et al.* (2004) in which they found jogging to be the most dominant activity pre and post sprinting activity. With the continuous tracking method used for the collection of data in the current study, it is not surprising that the most common locomotion category performed immediately before and after sprinting activity is a lower level run of stride. Perhaps the current investigation should review this data further and identify how long these stride activities occur for prior to the sprint, to conclude whether this is a true reflection of the activity performed pre and post sprinting, and not just an obvious product of the method used. No further comparisons can be made in respect to authors as no such information has been provided in other publications of time-motion analysis.

Work:rest ratios are another important characteristic that can assist in the description of team based sports, providing a global indication of exercise intensity and recovery durations. Mean work: rest ratios of 1:3.5 (± 1.8) with range of 1:1.3 – 1:10.1. In a marked contrast to this MacLoed *et al.* (2006) reports a mean work:rest ratio for all players as 1:11.4. This work:rest ratio

would indicate that players would have on average twice the recovery duration between higher intensity activity, than reported for the current study. A large range in the work:rest ratio for the current study indicates possible positional differences in intensity of exercise performed. With some players performing, on occasion, almost equal amounts of work to rest; whereas others have significantly longer recovery durations. The lower range of work:rest ratios is more similar to values reported by McLean (1992) in their analysis of international rugby union of 1:1-1.9, indicating a significantly high intensity of work required. These ratios indicate the different level of demands that are imposed on players and therefore the differing reliance on the different energy systems. Players with higher ratios (1:10.1) have a greater dependency on the aerobic energy system, whilst lower ratios (1:1.3) require greater reliance on the creatine phosphate stores and an increased dependence on anaerobic glycolysis, causing a possible increase in fatigue and reduction in performance. It should be noted that the work:rest ratios reported in the current study are global work:rest ratios for the entire game. Perhaps a more thorough understanding of the work:rest ratios would be to analyse each individual activity session on their own, as undertaken by O'Donoghue (2005).

Although average time-motion data provides valuable information on the overall physiological demands on the game, it only provides a very limited appreciation for the demands of Repeated Sprint Activity (RSA). RSA has been acknowledged as an important feature of team games and refers to the need to perform repeated short duration sprints over a brief period of time (Dawson *et al.*, 1993, Spencer *et al.*, 2004). Current report findings evidence that this is also indicative of the women's game of field hockey, findings from the current study indicate that on average RSA bout activity, consisting of a minimum of 3 consecutive sprints with a mean recovery duration of less than 21 s, occurs 12 ± 9 times per game (Table 8). Within the RSA, the mean recovery duration between sprints is 15.42 ± 3.56 s. This is similar to values reported by Spencer *et al.*, (2004) in their analysis of male hockey. They reported a mean number of sprints as 4.2 ± 1.3 and a mean duration between sprints as 14.9 ± 5.5 s. However a marked contrast is found in the number of

RSA activities that occur during a game, with the current study noting 12 ± 9 and Spencer *et al.* (2004) recording only a total of 17 occurrences of RSA for all 10 outfield playing positions. It is unsure how these discrepancies could be accounted for, when the definition is clear and the other characteristics of RSA are remarkably similar.

Despite many researchers reporting global work-rate profiles in order to quantify physiological demands, it has long been noted that hockey is an intermittent sport that incorporate periods of high intensity exercise interspersed with periods of low intensity. Although average time-motion data provides valuable information on the overall physiological demands on the game, it only provides a very limited appreciation for the demands of RSA. RSA has been acknowledged as an important feature of team games and refers to the need to perform repeated short duration sprints over a brief period of time (Dawson *et al.*, 1993, Spencer *et al.*, 2004). Findings from the current study indicate this is also the case in women's field hockey, with an average RSA bout activity consisting of a minimum of 3 consecutive sprints with mean recovery duration of less than 21 s, occurring 12 ± 9 times per game. Within the RSA the mean recovery duration between sprints is 15.42 ± 3.56 s. This is similar to values reported by Spencer *et al.*, (2004) in their analysis of male hockey. They reported a mean number of sprints as 4.2 ± 1.3 and a mean duration between sprints as 14.9 ± 5.5 s. However a marked contrast is found in the number of RSA activities that occur during a game, with the current study noting 12 ± 9 and Spencer *et al.* (2004) recording only a total of 17 occurrences of RSA for all 10 outfield playing positions. The higher frequency of data collection for the current study could be the reason for these significantly higher values for RSA, as a slight variation in speed could assign this movement to a lower speed category when analysis is undertaken with TP. Whereas subjective observation may not be sensitive enough to acknowledge this slight reduction in speed and therefore not designate an alteration in locomotion category.

Positional differences were evident, with defenders covering significantly less distance over the game period than midfield and forward players (Table 8).

This is a marked increase on the value reported by Boddington *et al.*, (2002) in their analysis of hockey, in which they identified that players covered on average 3.9 ± 0.5 km. These discrepancies can likely be attributable to the differing methods used for data collection. The current study used continuous player movement tracking to calculate distance covered each second, whereas Boddington *et al.* (2002) used a 15 s sampling frequency to measure distance covered. However the 15 s sampling intervals provide complete disregard for the activity completed in the interim period of 14 s. In this interim time, even at an average walk speed of 3.76 km/hr a total of 14 m could have been covered, causing a severe underestimation in not just distance covered but all time-motion characteristics.

Hockey has been reported to incorporate periods of high intensity exercise interspersed with periods of low intensity. Work-rate profiles detailing the percentages of time spent in individual locomotion categories provide evidence that elite level women's hockey players spend a significant proportion of the game performing at sub-maximal levels ($74.75 \pm 9.01\%$). This sub-maximal activity constitutes standing still, walking and jogging and these individually account for $3.94 \pm 2.35\%$, $42.66 \pm 7.57\%$ and $28.16 \pm 3.01\%$ respectively. Positional differences were identified with the time spent in individual locomotion categories, highlighting that defenders spend a significantly greater percentage of time walking, less time striding and less time sprinting compared to both midfield and forward players (Table 8). No other study has related their findings in respect to playing positions, so comparisons for positional differences cannot be made.

A finding of the current study of MacLeod *et al.* (2007) used a subjective method of categorising movement into 6 categories; stationary, walking, jogging, cruising, sprinting and lunging, with no acknowledgement of the direction of movement. Lothian and Farrally (1994) conducted their analysis with a similar method to MacLeod *et al.* (2006), however the classification system used for the categorisation of locomotion activity was different, Lothian and Farrally (1994) used 9 discrete movements and classified low intensity activity as standing, walking, walking backwards/sideways and jogging, noting

that jogging backward/sideways cruising backward/sideways sprinting and activity with the ball as high intensity activity. Boddington *et al.* (2002) recorded player's positions at 15 s intervals to calculate displacement and then categorise into movement categories. The same methodological issue as highlighted in respect to distance covered is also applicable here. The continuous tracking nature of the TP method used for the present study allows for the players position to be recorded each second, although it did not allow for the breakdown of movement direction. With the player position sampled every second, the displacements each second were used to calculate speed and categorise movements into individual locomotion categories.

Caution is necessary in comparing recent data with reported results from literature because different technologies and categorisations were employed (Lothian & Farrally, 1994; Boddington *et al.*, 2002; Macloed *et al.*, 2006). Comparison of findings against those reported by Lothian and Farrally (1994) are not included to provide further substance to the current study, but only as an indication in the range of results identified and the differences caused by different methods of data collection. Several significant rule changes have taken place in the interim period since the publication of the Lothian and Farrally study in 1994 that exclude the information from consideration.

It is thought that the game information identified above provides a detailed review of the physiological demands imposed on players during elite level women's hockey games. This study represents findings from the largest participant sample size than any other investigation into the time-motion analysis of hockey. Fifty-four independent samples of elite game activity taken from a European Championship, using one randomly selected player from defense, midfield and forward playing positions, from 12 European teams, could provide an unbiased set of results to be used for the selection of sport specific fitness assessment and training. It should be noted however, that no acknowledgement was given to the playing conditions that these games were played in. The effect of competition status was controlled slightly, by the analysis of just the group games of the competition.

From the results discussed above, some positional differences have become evident. It is clear that the work-rate profile of a defensive player is less physiologically demanding than for forward and midfield players. This may highlight modern hockey tactics and the more fluid nature of attacking plays and versatility of players. Defensive players spend significantly more time walking, less time striding and less time sprinting than both midfielders and forwards. In connection with this, defenders spend significantly more time in low intensity activity, with on average at least 10% greater time than both midfielders and forwards. Correspondingly, defenders cover significantly more distance walking and less distance striding and sprinting, with total distance covered again significantly less than both midfield and forwards by almost 1500 m. In relation to sprinting activity, defenders complete a significantly lower number of sprints, with corresponding longer recovery durations between each sprint than both midfielders and forwards. Defenders also complete repeated sprints less frequently than midfielders and forwards. The work:rest ratio analysis revealed that defenders had almost twice as much recovery between high intensity activity than both midfielders and forwards. This is also reflected in the number of RSA bouts performed, where defenders complete less than half the amount of midfielders, and less than one third of the forwards.

A fundamental requirement for the designing of sport specific fitness assessment and training programmes is an in-depth knowledge of the physical demands placed upon players during competition at the highest level (Bompa, 2000). Maximum benefit from any training is achieved when the training stimulus imitates or overloads the physiological performance conditions (Deustch *et al.*, 1998). The acknowledged complex nature of hockey means that no one single test is capable of assessing all the facets of the game concurrently, and no single training drill could effectively mimic the game.

Overall time-motion characteristics reveal a significant dependence on the aerobic energy metabolism for the 75% of time spent in low intensity locomotion activity. As previously discussed the intermittent nature of hockey

reveals interdependence on both the phosphocreatine and anaerobic glycolysis metabolisms for high intensity activity. The relevant contributions for each of these are evident in the sprinting characteristics described above. The majority of positional definitions in the movement characteristics are evident between the defensive playing position and other outfield positions of midfield and forward which may highlight modern hockey tactics and the more fluid nature of attacking plays and versatility of players. Defenders had two-fold greater recovery time following sprinting than forwards. Sprinting only accounts for a small percentage of total game time with the dominating percentage of the game in low intensity exercise, supported by the aerobic energy system. Fitness assessment and training should therefore resemble the intermittent nature of the game with sprint recovery periods reflecting the different positional demands.

In accordance with the data it can therefore be suggested that linear sprinting speed, for all positions, be assessed over 15 m with an estimated target time of 3 s. Separate to this, the assessment of players' performance in repeated sprints ability should involve at least 3 sprints of 10 - 15 m with 5 s rest between each repeated sprint. Sprinting, however, only accounts for a small percentage (10.3%) of total game time, with the dominating percentage of 74.7% spent in low intensity exercise supported by the aerobic energy system. Therefore an appropriate measurement of aerobic capacity should be performed.

Training of elite level womens hockey players should closely reflect the demands of competitive match-play as identified above. With exercise intensities to mimic those experienced during the game. Although sprinting only accounts for approximately 10% of total match time, there should be evidence of this in training sessions.

Recommendations for further research

The personal learning acquired and the method-related and sport-specific knowledge created through completion of this programme of research training has led to the appreciation of a number of future research studies that could be used to further enhance knowledge and understanding in relation to time-motion analysis using Trak Performance and the gross movement patterns and demands of women's hockey.

Improvements to the studies presented in this thesis and further investigation of the validity and reliability of Trak Performance as an appropriate systems for the assessment of time-motion:

- *Using a larger tracking arena for simulated hockey games to enable validation of tracking process in all locomotion categories.*
- *Using prescribed movements patterns for players to follow.*

Further areas of research into the physiological demands of women's hockey could include:

- *Comparison of findings in respect to team ranking. Assessment would be done in a similar manner, but include the team rankings from the tournament in the results.*
- *Comparison of work-rate profile characteristics in respect of first and second half periods, in order to identify any possible fatigue effects and develop strategies for substitutions. Research has shown a marked decrease in high intensity activity being performed during the latter periods of the game (Robinson et al., 2001; Di Salvo et al., 2007).*
- *Effect of competition score-line on work-rate profiles in elite level women's hockey. To identify if significant changes exist when teams are winning or losing.*
- *In light of most recent rule change of the addition of the self-pass rules, which allows the ball to be played by the initiating free hit, centre pass or side-line ball player before it is received by another player, analysis of the effect that this has had on the physiological demands imposed on the player could be warranted.*

Chapter VIII – Conclusions

The following conclusions are drawn from synergy of the available research literature with the findings from the studies undertaken within this thesis and in direct relation to the stated aim and objectives.

Objective 1: Explore the validity and reliability of a new computerised time-motion analysis system and employ this method to identify the physical demands of elite women's hockey.

The current research supports that the TP motion tracking method provides a more superior method for the analysis of time-motion than others reporting the use of subjective observations to categorise locomotive movement. Further investigation into the validity and reliability of this method in a larger tracking area is proposed to satisfy current trends of kappa level of agreement. Overall demands of the elite level hockey were identified as intermittent in nature, with players on average covering 9.06 ± 1.58 km throughout the whole game. Approximately 75% of this was covered in low intensity activity (stationary, walking and jogging). Sprinting was calculated to be undertaken in approximately 10% of the total game time and on average players covered 12.72 ± 1.2 m during sprints. Repeated sprint activity was found to be important in the game, with RSA bouts occurring on average every 445 s, with an average of 12 performed in a game.

Objective 2: Identify position specific differences in time-motion analysis variables such as distance covered, time spent in locomotion categories, duration of activities, sprinting characteristics including repeated sprint activity and work to rest ratios.

Objective 3: Propose physiological characteristics of elite women's field hockey

The demands of the game, as identified in the current research show a change in contemporary motion characteristics. The time-motion analysis

conducted on elite level women's hockey reported main characteristics identifying that majority of game time (75%) was spent in low intensity activity. Mean work:rest ratios provide indication of significant differences between the requirements imposed on defenders compared to midfield and forward players. With defenders having on average almost twice the recovery time between work activities. Similar disparity was evident in total distance covered, an expected outcome with the work:rest ratios reported. A marked increase in the reliance on repeated sprint activity was found in relation to other publications, highlighting the need for this to be included in future time-motion studies. Distance covered throughout the entire game range from 7.84 - 9.75 km.

This thesis, therefore, has satisfied its overarching aim in that it has evaluated and used a innovative computer based time-motion analysis system to quantify the physiological demands of elite level women's hockey, and from the findings have made recommendations of the physiological requirement of elite level women's hockey.

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Appendices

Appendix 1. Reliability analysis conducted on published Performance Analysis studies (2001-2006).

Author (s)	Analysis Context	Statistical analysis
Hughes <i>et al.</i> (2001)	Soccer	Correlation
Muniroglu (2001)	Football	None
Tyryaky <i>et al.</i> (2001)	Soccer	None
Enisler <i>et al.</i> (2001)	Football	None
Hughes <i>et al.</i> (2001)	Soccer	Correlation
Ferit (2001)	Soccer	None
Eniseler (2001)	Soccer	None
Egesoy and Enyseler (2001)	Soccer	None
Stanhope (2001)	Soccer	None
Dooan <i>et al.</i> (2001)	Soccer	None
Larsen <i>et al.</i> (2001)	Soccer	None
Robinson <i>et al.</i> (2001)	Ladies Hockey	Percentage Error
Yalciner <i>et al.</i> (2001)	Womens Handball	None
Potter and Carter (2001)	Rugby Union	None
Carter and Potter (2001)	Rugby Union	None
McCorry <i>et al.</i> (2001)	Rugby Union	None

Author (s)	Analysis Context	Statistical analysis
Hughes and Blunt (2001)	Rugby Union	Chi-squared and Percentage Error
Liddle and Murphy (2001)	Badminton	Percentage Error and Correlation
Robinson <i>et al.</i> (2001)	Ladies Hockey	Percentage Error
Yamanaka <i>et al.</i> (2002)	Soccer	None
Abt <i>et al.</i> (2002)	Soccer	None
O'Connor (2002)	Touch Football	Correlation
Ohashi <i>et al.</i> (2002)	Soccer	None
Harley <i>et al.</i> (2002)	Football Referees	None
D'Ottavio and Castagna (2002)	Soccer Refereeing	None
Deutsch <i>et al.</i> (2002)	Rugby	None
Sasaki <i>et al.</i> (2002)	Rugby	None
Enomoto <i>et al.</i> (2004)	Water Polo	Percentage Error
O'Donoghue and Longville (2004)	Netball	None
Edwards and O'Donoghue (2004)	Netball	Kappa
McKeown and Murphy (2004)	Netball	None
O'Donoghue (2004)	Netball	Chi-squared

Author (s)	Analysis Context	Statistical analysis
Hale (2004)	Netball	None
Sainz de Baranda <i>et al.</i> (2004)	Soccer	Correlation
Taylor <i>et al.</i> (2004)	Soccer	Percentage Error
Hewer and James (2004)	Football	Percentage Error
Scoulding <i>et al.</i> (2004)	Soccer	Percentage Error
Shaw and O'Donoghue (2004)	Soccer	Percentage Error
Brown and Hughes (2004)	Football	Percentage Error
Fleig and Hughes (2004)	Football	Percentage Error
Jones <i>et al.</i> (2004)	Rugby Union	Percentage Error
Murakami <i>et al.</i> (2004)	Rugby Union	None
James <i>et al.</i> (2004)	Rugby Union	Percentage Error
Long and Hughes (2004)	Rugby Union	Percentage Error
Beck and O'Donoghue (2004)	Rugby League	Chi-squared
Ortega <i>et al.</i> (2004)	Basketball	None
Fernandes and Tavares (2004)	Basketball	Percentage Error
Devlin <i>et al.</i> (2004)	Basketball	Kappa

Author (s)	Analysis Context	Statistical analysis
Hayrinen <i>et al.</i> (2004)	Volleyball	None
Moreira and Tavares (2004)	Handball	Percentage Error
Godinho Sousa and Tavares (2004)	Handball	Percentage Error
Januario <i>et al.</i> (2004)	Coaching Analysis	Percentage Error
Portela Tosa <i>et al.</i> (2004)	Coaches Oral Intervention	Percentage Error
McLaughlin and O'Donoghue (2004)	Analysis of Physical Activity	Kappa
Seabra and Dantas (2006)	Soccer	Kappa
Snook and Hughes (2006)	Football	Percentage Error
Reed and Hughes (2006)	Rugby Union	Percentage Error
Hughes and Prober (2006)	Soccer	Chi-squared and Percentage Error
Choi <i>et al.</i> (2006)	Basketball	None
Gomez Ruano <i>et al.</i> (2006)	Basketball	None
Licen <i>et al.</i> (2006)	Basketball refereeing	None
Swalgin (2006)	Basketball	None

Author (s)	Analysis Context	Statistical analysis
Bazanov <i>et al.</i> (2006)	Basketball	None
Gomez Ruano <i>et al.</i> (2006)	Basketball	None
Taylor <i>et al.</i> (2006)	Soccer	Percentage Error
Tenga <i>et al.</i> (2006)	Soccer	Kappa

Appendix 2. University Ethics Checklist.

This form is intended as an initial checklist for individuals engaged in research activity at UCW. If you have answered **yes** to any of the questions below, a copy of your proposal should be referred to the appropriate Department for their consideration. The tutor with whom you discuss your topic should be able to help you with this.

Name of Student: Lucy Holmes

Provisional Title: A time-motion analysis of elite women's hockey – implications for fitness assessment and training

1. Does the study involve research with human participants who may not be able to give fully informed consent? (e.g. children, vulnerable adults, employees, those with a pre-existing relationship to the researcher). **NO**
2. Will the research involve the administration of any substances? (e.g. food substances, additives, alcohol etc). **NO**
3. Will invasive procedures be part of the research? (e.g. blood sampling, temperature probes). **NO**
4. Is there any foreseeable risk to the participant? (physical, social, psychological, emotional or financial). **NO**
5. Does the research involve access to, or the collection of, sensitive/confidential data from other organisations? **NO**
6. Will the study require information about unlawful activity? **NO**
7. Will the study involve prolonged, high intensity or repetitive testing? **NO**
8. Does the study involve deception? **NO**
9. Does the study involve NHS patients, staff or premises? **NO**
10. Does the study involve testing of animals? **NO**
11. Will financial inducements be offered? **NO**

Signature of student: 

Date:

Tutor's name: Dr Derek Peters

Signature:

Tutor to complete the following:

A copy of this proposal is being referred to the Department for further consideration:

YES / NO

***If YES – decision of Department * No further action required / Refer to UCW
Ethics Committee***

****delete as appropriate***

Appendix 3. Example of written and informed consent for validation study participants.



University
of Worcester

School of Sport
& Exercise Science

Video/Camera Recording
Participant Informed Consent Form
and Information Sheet

The purpose of the current is to undertake criterion validity testing of data collected using Trak Performance (TP) (SportsTec International) against data captured using a 16-camera Vicon MCAM2 3D motion capture system in simulated field hockey.

Reflective markers will be placed on headbands worn by players who will play 5 minutes of competitive '3-on-3' hockey in a 10x10m indoor area. The area will be recorded using a Sony HVR-Z1 HD video camera allowing manual player tracking with the TP software. Data collection procedures will be repeated until 50 player's samples have been collected to permit suitable validity and test-retest reliability analysis.

I, [REDACTED] agree that recording(s) can be made and data can be collected of this hockey session and any subsequent data be used for the purposes of this study.

[REDACTED]

15/2/07

Lucy Holmes
15/02/07

PRE-TEST QUESTIONNAIRE

Name: [redacted] Age: [redacted] D.O.B.: [redacted]

As you are to be a participant in this laboratory, would you please complete the following questionnaire truthfully and completely. The purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete an exercise test.

*Please delete as appropriate

1. How would you describe your present level of activity?

sedentary/moderately active/highly active* Give an example of a typical weeks exercise:

2. How would you describe your current level of fitness?

very unfit/moderately fit/trained/highly trained*

3. How would you consider your present weight?

underweight/ideal weight/slightly overweight/very overweight*

4. Smoking Habits

Currently non-smoker yes/no*

A previous smoker yes/no* of.....per day

If previous smoker, how long since stopping?years

A regular smoker yes/no* of.....per day

An occasional smoker yes/no* of.....per day

5. Consumption of alcohol

Do you drink alcoholic drinks? yes/no*

If yes, then do you:

Have the occasional drink? yes/no*

Have a drink everyday? yes/no*

Have more than one drink a day? yes/no*

Please indicate what type of alcoholic beverage you consume, i.e. beer, spirits, shandy

6. Have you had to consult your doctor within the last 6 months? yes/no* If yes please give brief details.

7. Are you presently taking any form of medication? yes/no* If yes please give details.

8. Have you suffered from a bacterial or viral infection in the last 2 weeks? yes/no*

9. Do you suffer, or have ever suffered, from

Asthma? yes/no*

Diabetes? yes/no*

Bronchitis? yes/no*

Epilepsy? yes/no*

High blood pressure? yes/no*

STRICTLY CONFIDENTIAL

10. Do you suffer, or have ever suffered from, any form of heart complaint? yes/no^{*}
11. Is there a history of heart disease in your family? yes/no^{*}
12. Do you currently have any form of muscle or joint injury? yes/no^{*}
If yes please give brief details. *Knee*
13. Have you had to suspend training in the last two weeks for a physical reason? yes/no^{*}
If yes please give brief details.
14. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you? yes/no^{*}

INFORMED CONSENT

Please read the following statements carefully. Please sign only when you have agreed with the statement and when you have had any relevant questions answered.

- I have read the information sheet for the above study and the full details of the tests have been explained to me (verbally and written). I am clear about what will be involved and I am aware of the purposes of the tests, the potential benefits and the potential risks.
- I know that I am not obliged to complete the tests. I am free to stop the test at any point and for any reason.
- I am responsible to report promptly any unusual feelings or discomfort during the exercise test.
- Tests results will only be used for the purposes of this module
- I have no injury or illness that will affect my ability to successfully complete the tests.
- I hereby give my full consent to take part in the study.

Signature of participant:

[Redacted Signature]

Date:

[Redacted Date]

Name of Test Supervisor:

[Redacted Name]

Signature of Test Supervisor:

[Redacted Signature]

Date:

[Redacted Date]

Appendix 4. Statistical analysis of reliability assessment data.

T-Test

Notes

Output Created			10-SEP-2009 14:02:35
Comments			
Input	Active Dataset	DataSet0	
	Filter	<none>	
	Weight	<none>	
	Split File	<none>	
	N of Rows in Working Data File		25
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.	
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.	
Syntax		T-TEST PAIRS = STRIDE_1 STAT_1 SPRINT_1 JOG_1 WALK_1 WITH STRIDE_2 STAT_2 SPRINT_2 JOG_2 WALK_2 (PAIRED) /CRITERIA = CI(.95) /MISSING = ANALYSIS.	
Resources	Elapsed Time		0:00:00.02
	Processor Time		0:00:00.02

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	STRIDE_1	18.0000	5	7.19340	3.21699
	STRIDE_2	15.0600	5	3.78985	1.69487
Pair 2	STAT_1	2.8000	5	3.51994	1.57417
	STAT_2	2.5400	5	2.74827	1.22906
Pair 3	SPRINT_1	12.4000	5	4.60326	2.05864
	SPRINT_2	10.6000	5	4.10366	1.83521
Pair 4	JOG_1	27.8800	5	2.86827	1.28273
	JOG_2	27.0600	5	4.47303	2.00040
Pair 5	WALK_1	38.9400	5	8.49164	3.79758
	WALK_2	44.7200	5	9.98208	4.46412

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	STRIDE_1 and STRIDE_2	5	.825	.085
Pair 2	STAT_1 and STAT_2	5	.970	.006
Pair 3	SPRINT_1 and SPRINT_2	5	.310	.612
Pair 4	JOG_1 and JOG_2	5	.782	.118
Pair 5	WALK_1 and WALK_2	5	.671	.215

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error	95% Confidence Interval		Mean	Std. Deviation	Std. Error
				Mean	of the Difference				
				Lower	Upper	Lower	Upper	Lower	Upper
Pair 1	STRIDE_1 - STRIDE_2	2.94000	4.59543	2.05514	-2.76598	8.64598	1.431	4	.226
Pair 2	STAT_1 - STAT_2	.26000	1.08305	.48436	-1.08479	1.60479	.537	4	.620
Pair 3	SPRINT_1 - SPRINT_2	1.80000	5.12981	2.29412	-4.56951	8.16951	.785	4	.477
Pair 4	JOG_1 - JOG_2	.82000	2.85605	1.27726	-2.72625	4.36625	.642	4	.556
Pair 5	WALK_1 - WALK_2	-5.78000	7.61393	3.40506	-15.23395	3.67395	-1.697	4	.165

Appendix 5. Illustration of formulae for calculations made on exported Trak Performance data.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
TIME	DIST	SPEED	EVENT		STATIC DIST	WALK DIST	JOG DIST	STRIDE DIST	SPRINT DIST		STATIC DIST	STATIC RUNNING TOTAL	COUNT	DURATION	AV. DIST PER SEC
EXPORT FROM TRAK PERFORMANCE	BLANK	IF(\$C3<0.108,\$B3,"")	IF(AND(\$C3>0.108,\$C3<6.12),\$B3,"")	IF(AND(\$C3>6.12,\$C3<10.08),\$B3,"")	IF(AND(\$C3>10.08,\$C3<14.04),\$B3,"")	IF(\$C3>14.04,\$B3,"")	BLANK	IF(F3="" ,0,F3)	RETURN IF(L4=0,0,L4+M3)	IF(L3=0,0,1)	RETURN IF(N5<N4,N4,"")	IF(O3="" , "" ,M3/N3)			