The physical demands of elite men's field hockey and the effects of differing substitution methods on the physical and technical outputs of strikers during match play

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A thesis submitted to the

Auckland University of Technology

in fulfilment of the degree of

Masters of Health Science

February 2008

School of Sport and Recreation

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DEDICATION

To my beautiful daughter Isis, for every minute that I missed spending with you while writing this thesis I will repay with a hundred hugs, a hundred kisses and a hundred silly songs.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the following individuals who have contributed to the completion of this thesis.

To Tista, your patience with me during my many late nights and boring weekends will not go unrewarded. I promise to learn Dutch and make up for lost time. To my supervisor Andy, thanks for tolerating my stubbornness and for choosing your moment to make suggestions and provide support. To Kevin Towns (KT), thank you for providing a working environment of opportunity, challenge and responsibility – you are the best coach I have ever or will ever work with. To the Men's Blacksticks players, you guys are fantastic and I thank you for putting up with all the inconveniences of the project and for making me one of the team, I doubt I will come across an opportunity to work with such a group of athletes again. To Pete Pfitzinger, Martin Dowson, Graeme Robson, Patria Hume, Tracey Paterson and Karoline Cheung, your influence on my career has been enormous and I will always be ready and willing to repay your support and loyalty. To my family, especially Grandad, who passed during the late stages of this thesis, this is another volume for the shelf, another reason to be proud of being a Lythe. To SPARC, your generous funding and support has provided me with great opportunity and is much appreciated. And finally to Mickie, thanks for coming to check on me as I toiled late into the night. You may be little but you are a big part of the family.

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

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ABSTRACT

Research has indicated that teams who cover greater distance during matches and complete more basic tasks such as passes, tackles and shots are more successful. Identifying means of increasing these physical and technical outputs is therefore a significant opportunity for performance enhancement. There has been limited research performed on hockey, especially at the elite level. An issue that is even more relevant given that in the past 15 years the sport has undergone some significant rule changes including the introduction of unlimited substitutions. With sixteen players able to be used per match and eleven players on the field at any one time the coach can make substitutions as frequently as desired to try and maximise the overall performance of the team. The objectives of this thesis were to use methods of performance analysis to measure the physical and technical outputs of players during elite hockey and to specifically measure the impact of differing substitution strategies on the physical and technical outputs of strikers during match play.

Three striker conditions were assessed; three strikers with no substitutions, four strikers with a moderate amount of substitutions; and, five strikers with a large amount of substitutions. Five matches between the New Zealand men's hockey team and Tasmania state representative team were played over eight days. Physical outputs of players were measured using portable GPS units and heart rate monitors and technical aspects of match play were measured using team performance statistics and a set of technical criteria which awarded points to strikers for each contribution they made to the game based upon a scale of effectiveness.

Average total distance covered during 70 minutes by a position was 8160 ± 428m of which 479 ± 108m (6.1%) was performed at speeds greater than $19 km.h^{-1}$. Within this high intensity distance were 34 ± 12 sprints per player with an average duration of 3.3s. Average match HR was 85.3 ± 2.9% HR_{max} and average peak HR was 96.3 ± 2.7% $HR_{max.}$ Distance covered decreased by 6.2% between the 1st and 2nd halves and there was a trend of decreasing distance in both halves when total distance was broken into five-minute time periods.

When assessing the impact of substitutions on the performance of strikers it was found that there were no significant differences in physical outputs between conditions with total distance (S5 = 8414 ± 125m, S4 = 8422 + 34m; S3 = 8282m) and distance covered at speeds greater than $19 km.h^{-1}$(S5 = 701 ± 46m, S4 = 685 ± 28m, S3 = 723m) being similar. Substantial differences were found in technical outputs between the substitution conditions with more strikers and greater substitutions offering a better total output than less strikers and fewer substitutions (S5 = 241 ± 35, S4 = 207 ± 38, S3 = 173) but statistical significance between conditions was also not found.

In conclusion, the results suggest that although substitutions are not a means to increase the physical work of strikers they do appear to be a way to enhance the contributions that strikers are making to the game.

THESIS OUTLINE AND STRUCTURE

This thesis is presented as five chapters and seeks to investigate the physical demands of elite men's field hockey using a variety of performance analysis methods. Of primary interest during this investigation, is the potential effect that differing substitution strategies have on the outputs of strikers and consequently the team. Chapters one and two present an introduction and review of literature. Chapter three quantifies the physical demands of elite men's hockey using data obtained from five elite-level matches. Chapter four investigates the impact of differing substitution strategies on the overall physical and technical outputs of strikers during match play. A small amount of introduction and methodological information is repeated during chapters three and four to ensure that they are both stand-alone studies. Finally, chapter five provides a summary of limitations, practical applications and directions for future research.

CHAPTER 1: INTRODUCTION

Performance analysis is a technique for analyzing physical, technical and tactical aspects of match performance and is becoming an increasingly integral part of the coaching process in elite sport. Performance analysis has a number of applications including tactical and technical evaluation, analysis of movement and physical demands and development of predictive models (Hughes, 2004). The link between technology and performance analysis is very strong with most analysts utilising a spectrum of commercially available and custom made gadgets as well as a variety of software packages. All combine to create a pool of information to be used by coaches with their players, to explore their own or their opponents' strengths and weaknesses in technique, tactics and movement (Hughes, 2004). One such piece of technology that is becoming increasingly applied to a range of sporting applications is portable GPS receivers. Satellite tracking GPS units can now be worn during competition and training to provide detailed information about movement patterns and physical activities of athletes. As yet however, the usefulness of this application of GPS remains unclear as there has not been sufficient published data to establish reliability, validity and practicality.

Monitoring athletes during competition to develop an understanding of physical and technical demands has evolved considerably since the early methods were pioneered in the 1950's and 60's (Pollard, 2002). Indeed, current systems and methods have become extremely sophisticated and are now being applied to a range of sports and none more so than soccer. The volume of research that has been developed in the last 30 years is immense and most analysts refer to soccer when seeking to develop concepts and enhance their own performance analysis methods. Hockey is a sport that shares many tactical and structural similarities with soccer (allowing for good comparisons). Compared to soccer however, the volume and quality of research investigating various aspects of performance in hockey is limited. There have been but a few studies that have provided information on elite performance, especially in the last 10-15 years since in the introduction of some significant rule changes that have altered the pace and nature of the game (Boyle, Mahoney, & Wallace, 1994; Ghosh, Goswami, Mazumdar, & Mathur, 1991; Johnston, Sproule, McMorris, & Maile, 2004; Paun, van der Ploeg, & Stern, 2008; Spencer et al., 2004). This paucity of research suggests that there is significant opportunity to gain knowledge and possibly improve performance through analysis. One such area of opportunity is substitutions. One of the aforementioned recent rule changes in hockey was to allow unlimited substitutions during match play and a coach has five substitute players that can be used as regularly as desired. The coach must manipulate this process to maximise the impact to physical performance, technical performance and ultimately the team's success. The documented increase in the physical outputs of substitute players in soccer (Mohr, Krustrup, & Bangsbo, 2003) plus consistent findings that physical and technical outputs decreased towards the end of soccer matches (Bangsbo, Norregaard, & Thorsoe, 1991; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2008) suggests that a manipulation of substitution players in hockey will reduce fatigue and may in turn increase physical and technical outputs and consequently performance.

This project aims to investigate the physical and technical demands of elite men's hockey. A variety of performance analysis methods will be employed during this investigation, including the use of portable GPS units and a set of specifically developed criteria to assess the technical and tactical contributions of strikers during match play. By studying the impact of substitution frequency on overall output and performance an improved understanding of the issues can be gained which can lead to the establishment of efficient substitution systems and models to use in competition.

The general objective of this project is to increase understanding of the physical demands of elite men's hockey. Specifically, the aim is two-fold:

1. To quantify the physical demands of elite men's hockey over several matches
2. To investigate the impact of striker substitutions on overall physical and technical outputs of players during match play

CHAPTER 2: LITERATURE REVIEW

LITERATURE REVIEW - PART 1 : PERFORMANCE ANALYSIS

Performance analysis is a technique for analyzing physical, technical and tactical aspects of match performance. It uses a systematic process that aims to provide information for the purposes of conditioning and coaching. To be useful, performance analysis must support the coaching process and it requires a coupling of information between match observations and the training process.

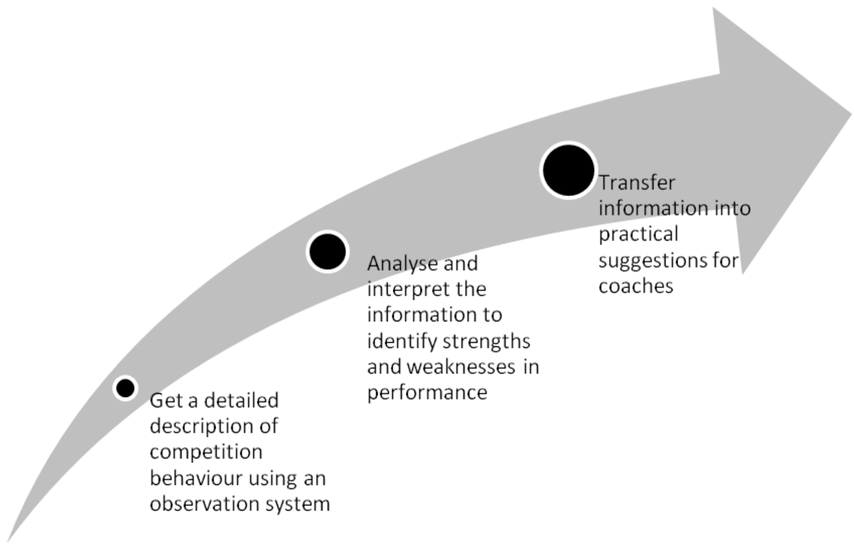


Figure 1: Coach-focused process of performance analysis

A three-step process to ensure an appropriate coupling between analysis and coaching has been proposed by Lames and Hansen (2001). In the first step, a detailed description of the competition behaviour is required using an observation system of appropriate quality. Secondly, the information is analysed and interpreted to identify strengths and weaknesses in performance. Finally, the results of the diagnosis are transferred into practical considerations by identifying a list of possible objectives for training (figure1), (Lames & Hansen, 2001).

Although basic performance analysis methods existed in American baseball as early as 1912 the birth of current methods came in 1950 when pioneering analyst Charles Reep collected match information to plan strategy for his local professional soccer team (Pollard, 2002). Reep's rudimentary methods were subsequently used in a widely cited paper from Reilly and Thomas (1976) who observed and documented the physical outputs of players during soccer match performance. While watching video footage of the match the investigators dictated to an audio tape a recording of their observations using five categories of motion (standing, walking, cruising, running and sprinting). This information along with pitch positions and time spans for each movement allowed the calculation of distances covered and further details regarding work rates to be measured for the first time (Reilly & Thomas, 1976).

Since then a variety of systems and methods have been used to document time and motion activity including manual charting, audio recording, video recording, satellite tracking and computer tracking. Such analysis has been used to provide a general insight into the physiological demands and movement patterns of athletes during match-play in a variety of team sports including field hockey (Paun et al., 2008; Spencer et al., 2004), rugby league (Coutts, Reaburn, & Abt, 2003; Kay & Gill, 2003) rugby union (Deutsch, Kearney, & Rehrer, 2007; Deutsch, Maw, Jenkins, & Reaburn, 1998; Duthie, Pyne, & Hooper, 2003a, 2005), touch rugby (O'Connor, 1994), Australian rules football (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004), soccer (Rienzi, Drust et al. 2000; Bangsbo, Krustrup et al. 2003; Mohr, Krustrup et al. 2003; Di Salvo, Baron et al. 2007) and futsal (Barbero-Alvarez & Castagna, 2006; Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008).

Cinematographic Tracking

The classic methods of motion analysis that were used in the early studies utilised a coded map of the playing area with measurements and markings to help estimate positions on the field and distances covered. Activities were subjectively rated according to intensity by researchers who watched video footage of the match using categories described and defined in table 1. They gave a commentary of events which was recorded on audio tape and later transcribed. The method was validated by recording the locomotion of the same player and counting stride frequencies in each motion category (with the distance per stride at each category of activity having been previously calibrated) (Carling, Williams, & Reilly, 2005). These cinematographic methods relied mostly on the skills of the observers and required a long period of time to obtain and analyse the data. Despite these apparent drawbacks, use of this method remains common. Reasons for the continued popularity include cost and the fact that manual processing of video footage allows opportunity for other information to be collected such as specific activity categories to allow for the unique movements of their sport that do not appropriately fit into the generic movement velocity groupings (Tables 1 and 2).

Table 1: Movement classifications based on observation

Motion Category	**Definition as defined by (Dawson et al., 2004; Spencer et al., 2004)**	**Definition as defined by (Deutsch et al., 2007)**
Standing	Motionless	Standing or lying on the ground without being involved in pushing or any other match activities. This can include small movements when such movements are not purposeful
Walking	Motion, but with both feet in contact with the ground at the same time at some point during the gait cycle	Walking forwards or backwards slowly with purpose. One foot is in contact with the ground at all times
Jogging	Motion with an airborne phase, but with low knee lift	Running forwards slowly to change field position, but with no particular haste or arm drive
Striding/ Cruising	Vigorous motion with airborne phase, higher knee lift than jogging (included skirmishing movements of rapid changes of motion, forwards / backwards / laterally).	Running with manifest purpose and effort, accelerating with long strides, yet not at maximal effort (3/4 pace)
Sprinting	Maximal effort with a greater extension of the lower leg during forward swing and a higher heel-lift relative to striding.	Running with maximal effort. This is discernible from cruising by arm and head movements.

Bloomfield has suggested that popular categories of motion and activity are too narrow to appropriately describe the specific demands of each position in soccer (Bloomfield, Polman, & O'Donoghue, 2004). They proposed a detailed analysis through a method involving fourteen modes of timed-motion, three ‘other’ non-timed movements, fourteen directions, four intensities, five turning categories and seven 'on the ball' activity classifications. The system is known as the 'Bloomfield Movement Classification' (BMC). Although a good strength of inter-observer agreement was reported for most activities it required 4-6 hours to code a single 15-

minute segment of a match for one player. This makes such a system extremely difficult to utilise in elite non-professional competition as without significant analysis personnel, there would be too much delay in providing information to coaches.

Table 2: Specific movement categories

Specific categories of movement used in Rugby (Deutsch et al., 2007)	Specific categories of movement used in Basketball (McInnes, Carlson, & Mckenna, 1995)	Specific categories of movement used in Soccer (Bloomfield et al., 2004)
Utility: shuffling sideways or backwards to change field position. Usually a defensive or repositioning movement. This does not include aimlessly walking slowly backwards. Jumping: jumping in a lineout or to catch a ball in play. Rucking/mauling: attached to an active ruck or maul. Once the ball exits the ruck or maul, or the referee calls the end of the play, the player is no longer considered to be engaged in rucking/ mauling, and is deemed to be standing still. Scrummaging: attached to an active scrum. As above, once the ball exits or the play is stopped, the scrum is no longer active	Jump: an attempt to leave the floor to make a shot, block or intercept etc Shuffle: low intensity shuffle, moderate intensity shuffle, high intensity shuffle (rapid lateral foot movement, usually in a squat position)	Movements: slow down, slide, fall, get-up, impact Running directions: forwards, sideways, backwards, diagonal, arc Action: receive, pass, turn, dribble, shot How: right foot, left foot, header, back-heel, other Touches: 1-3, 4-6, 7-10 >10. Turns: 0-90^{o}, 90-180^{o}, 180-270^{o}, 270-360^{o}, >360^{o}

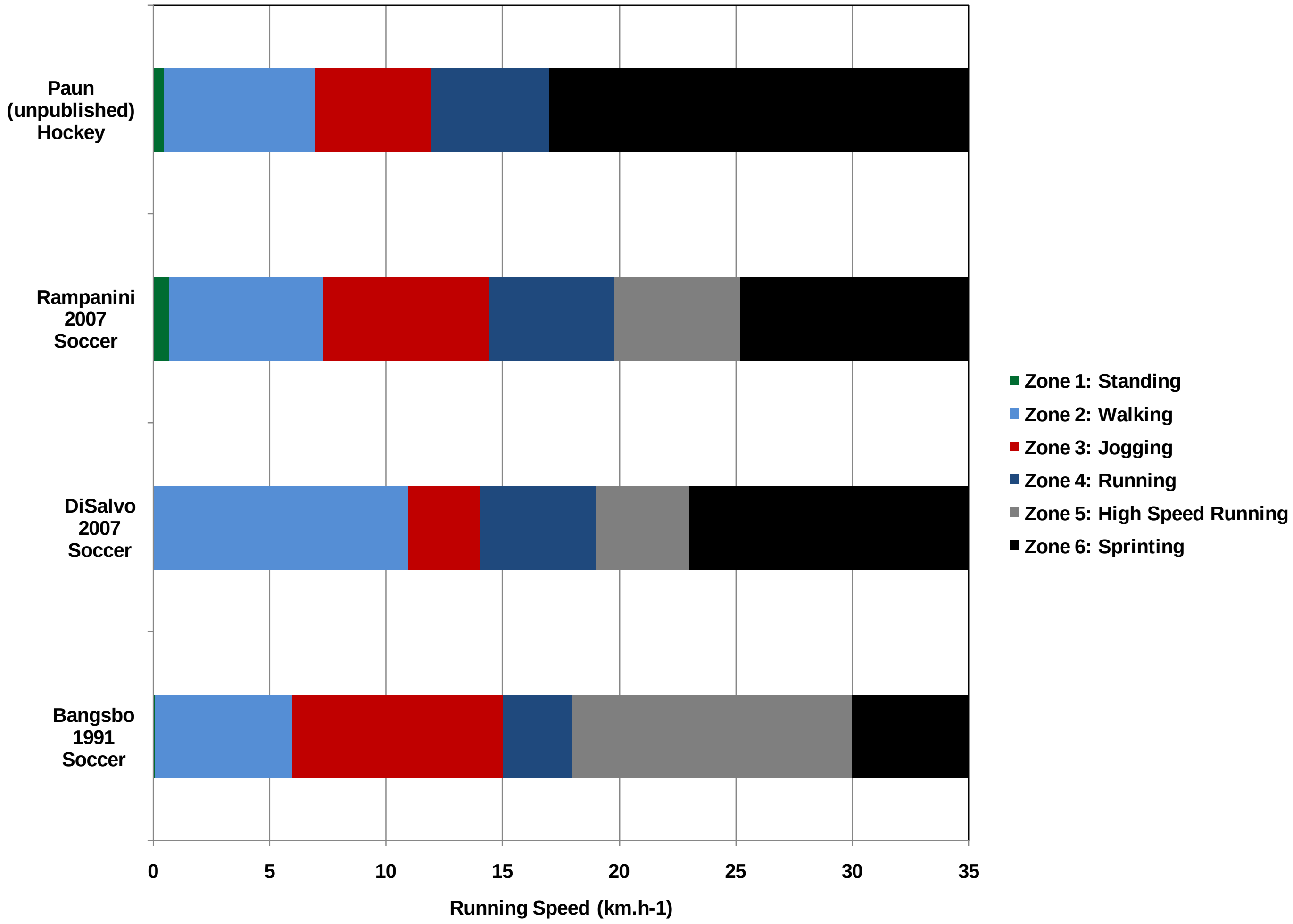


Figure 2: Comparison of speed zone classifications

As systems and methods of documenting motion have become more automated, the categorisation of locomotion using absolute speed limits has occurred. As can be seen in figure 2 the speeds used vary from study to study in particular at the top end of the speed continuum. Typically, the top speed zone is considered to be sprinting and frequency and duration of sprints are often a key measurement variable. In a study of elite men's hockey Paun et al (2008) recorded a sprint when players ran faster than 17 km.h^{-1} whereas in studies of soccer much higher thresholds of 23 km.h^{-1} (Di Salvo et al, 2007), 25.2 km.h^{-1} (Rampanini et al, 2007) and 30 km.h^{-1} (Bangsbo, 1991) were used (Bangsbo et al., 1991; Di Salvo et al., 2007; Paun et al., 2008; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). The number of zones used also differs with some using six and some five.

(Bangsbo et al., 1991; Di Salvo et al., 2007; Paun et al., 2008; Rampinini et al., 2007)

Automated Tracking Methods

Expensive and sophisticated computer tracking methods have been recently developed that allow the movement of players to be semi-automatically or automatically quantified. Two commercial systems, Prozone (www.pzfootball.co.uk) and Amisco (www.amisco.eu), used extensively in European professional soccer, track players by determining the x, y coordinates of the players position at the start and end of discrete activities. This coordinate data is obtained with manual input using footage from 6-8 fixed-view cameras and a scaled map of the pitch onto which the film footage is superimposed. The validity and reliability of these systems has not been extensively reported although some simulated soccer match movements have been shown to have high accuracy (Di Salvo, Collins, McNeill, & Cardinale, 2006).

Information describing other automated systems is now also appearing in the literature with increasing regularity (Barros et al., 2007; Fernandez & Caixinha, 2004; Figueroa, Leite, & Barros, 2006a, 2006b; Mauthner, Tilp, Koch, & Bischof, 2007). Fernandez and Caixinha (2004) used mathematical modelling to track soccer players during training and competition. They calibrated the playing area using 15 triangles and mapped the coordinates of player movements using translation, rotation and scaling parameters. With a 25Hz sample frequency the mean error was calculated as 4.2% (Fernandez & Caixinha, 2004). Barros et al (2007) used a computer tracking method to compare the distances covered during soccer matches by Brazilian and English professional players. The system used four static cameras which covered the whole playing field with some overlap (the overlapped regions are used for synchronization and to solve cases when one player was blocked from view by another). This configuration provided enough reference points and guaranteed that the size of the players in the image were big enough to discriminate noise and the interested components of the scene. The process used a tracking algorithm which identified players as “blobs” using size, shape and colour and detected their correct trajectories by movements of these blobs (Barros et al., 2007). Mauthner et al (2007) tracked the activities of beach volleyball players using the particle filter concept where movements are tracked using colour changes. Although the process was fast and relatively free from human input only one player could be tracked with each camera and validity/reliability data was not reported (Mauthner et al., 2007). All of these studies suggest that automated methods are providing reliable and accurate information and are therefore appropriate for performance analysis. It is important to note however that all required a high level of computer power and expertise.

Global positioning systems are another method being used in sport to analyse movement patterns and workloads in team sports. Although position and speed data can be obtained within minutes of the match being completed a primary drawback to the use of these devices is that they remain quite bulky and require the athlete to carry them during the course of the performance. Despite these drawbacks a number of investigators have used GPS devices to track team sport activities (Barbero-Alvarez & Castagna, 2006; E. Hennig & Briehle, 2000; Hewitt, Withers, & Lyons, 2007; Paun et al., 2008; Pino, Martinez-Santos, Moreno, & Padilla, 2006). For example, Hennig and Briehle (2000) tracked the movement patterns of elite soccer players using portable Garmin GPS devices (weight ~250 grams) which were worn by the players in an elastic waist band (E. Hennig & Briehle, 2000). Pino et al et al (2006) measured the distances covered by 2nd division Spanish professional soccer players using FRWD F 500 GPS devices during a practice match (Pino et al., 2006). Barbero and Castagna et al (2006, 2008) performed two studies using SPI10 GPS devices (GPSports Pty, Canberra, Australia). The first was on male professional futsal players during outdoor practice matches and the second was on male professional soccer players during a friendly training match (Barbero-Alvarez & Castagna, 2006; Barbero-Alvarez et al., 2008). Hewitt et al (2007) measured the match performance of female Australian soccer players during international competition (Hewitt et al., 2007). Finally, Paun et al (2008) measured the physical work-rates of elite male Australian hockey players using GPSports SPi10 units. (Paun et al., 2008) They reported an overall difference of less than 2% between GPS determined and actual distances in the speed range of 5-27km.h^{-1}. Despite the apparent high volume of research, all of these studies were reported as technical reports or conference abstracts and only Paun et al (2008) provided detailed methodology and any validity or reliability data. If the information provided by Paun (2008) is indeed indicative of the reliability of GPS units then it suggests that they are an appropriate automated method for tracking athletes and the increasing number of investigations suggests that the methodology has developed a popular following. This then suggests that there is a potential application to match analysis if devices can be made to fit within the rules of competition and be acceptable for players to wear during official matches.

NOTATIONAL ANALYSIS – TECHNICAL AND TACTICAL PERFORMANCE

A key area of performance analysis relates to the technical and tactical performance of players during match-play. A performance indicator is a selection, or combination, of action variables that aims to define some or all aspects of a performance (Hughes & Bartlett, 2002). A variety of researchers have developed methods to measure technical and tactical qualities during competition (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Rowlinson & O'Donoghue, 2006; Suzuki & Nishijima, 2005). Elferink-Gemser et al (2004) assessed performance characteristics of youth field hockey players as a means of talent identification and looked at a variety of physical characteristics, technical skills and tactical knowledge. Measures included sprint performance, interval endurance capacity, dribbling performance and hitting ability. Tactical knowledge was also assessed in questions about general tactics both when in possession of the ball, and when not in possession of the ball. They showed that the elite players fared better than the sub-elite players on technical and tactical variables and that elite players had developed these skills by the age of 14 (Elferink-Gemser et al., 2004). This agreed with Williams et al (2000) who found consistent differences between skilled and less skilled players (Williams, 2000) when administering similar tests on youth soccer players suggesting that the measurement of technical and tactical variables can provide useful information which may be able to discriminate between players and predict performance outcomes.

Typical technical performance variables include passes, shots, tackles, mistakes made, possession etc. A variety of authors have discussed such variables and their relationship to performance (Hunter & O'Donoghue, 2001; Rampinini et al., 2008; Rowlinson & O'Donoghue, 2006; Suzuki & Nishijima, 2005). For example, Suzuki and Nishijima (2005) proposed a scale that evaluated defensive performances during international soccer competition. Items in the following categories were evaluated on a five point scale; distances between attackers and defenders, angles between attackers and defenders and the number of players in the tactical defending area (Suzuki & Nishijima, 2005). Although findings from the match data were not discussed the authors reported that they were able to successfully measure game and player performance using a 9 item, multi-dimensional model. Rowlinson and O'Donoghue (2006) developed a manual notational analysis system to record positive and negative applications of a set of defensive and offensive skills during professional and international men's soccer. The performance of eight players was analysed during three UEFA Champions League performances and three FIFA World Cup performances each to identify which level of soccer is of the highest quality (Rowlinson & O'Donoghue, 2006). It was found that the level of performance was similar but that World Cup performances had greater variability. Also, in a study of 22 matches from the 1995 men's Rugby Union World Cup, Hunter and O'Donoghue (2001) assessed positive and negative aspects of attacking and defensive play, changes in possession and methods used to gain territory. Winning and losing sides were found to differ in the number of occasions that a team entered into the opposition's last third of the field and the frequency of attacks by which the team went around the opposition (Hunter & O'Donoghue, 2001). Finally, Rampanini et al (2008) measured technical performance during elite Italian soccer matches and compared them to team success. Players from more successful teams completed more short passes, tackles, dribbles and shots than less successful teams. In summary, the measurement of technical activities during soccer match play had identified that there are relationships with player ability and team performance. Although no information has been presented on technical aspects of elite hockey the development of methods to identify and appropriately measure such variables therefore seems warranted.

KEY ISSUES AND THEMES IN PERFORMANCE ANALYSIS

Reliability

The reliability of performance analysis methods are critical to the application of their findings. Despite this, reliability information is not always adequately reported. McInnes et al (1995) measured the activity and movement patterns during male elite basketball. One match quarter was analysed twice for four players with a spacing of three weeks from the original analysis. Method errors for the different categories of movement (standing and walking, jogging, running, striding, sprinting, shuffling, jumping) ranged from 4.9-10.6% (mean = 7.0%) for the total percent time spent in each category and from 3.9-11.7% (mean = 9%) for the duration of each period of high intensity (McInnes et al., 1995). Similar errors were reported by Duthie et al (2003) who sought to determine the level of agreement in an individual observer's repeated time motion measurements during rugby. Ten players were analysed twice during a full match using visual observation. Match activities were categorized as stationary, walking, jogging, striding, sprinting, static exertion, jumping lifting and tackling. An experienced rugby analyst conducted the experiment and there was one month between each analysis. The reliability of the total time spent in movement categories of stationary, walking, jogging, striding, sprinting and static exertion ranged from 5.8%-11.1% TEM (mean 8.3%) which the author accepted as being moderate reliability. The reliability of mean duration in each category was slightly better with TEMs of 7.1-9.3% (mean 7.7%). The movement category of jogging had the best reliability measures whereas both stationary and higher intensity categories had the poorest reliability (Duthie, Pyne, & Hooper, 2003b).

O'Donoghue (2004) used 15 minute segments of 10 matches to analyse the movements of 60 professional soccer players. Movements were classified as either high or low intensity and the durations of these movements were recorded. Tests of inter-observer reliability and intra-observer reliability were conducted revealing that there was significant systematic bias between observers for the percentage time spent performing high intensity activity ($P<0.01$) and between the first and second observations ($P<0.05$) with higher values being recorded during the first observation (O'Donoghue, 2004).

Spencer et al (2004) analysed the movements of male hockey players during an international match. By observing video footage of the match the observers visually categorized players movements into standing, walking, jogging, striding and sprinting. To assess reliability, half the match was analysed twice for five players. TEM values of 5.9-10.2% (mean = 7.8%) were reported for the frequency of movement and 5.7-9.8% (mean 8.1%) for duration of movement(Spencer et al., 2004).

Finally, Burgess et al (2006) used Trak Performance Software (SportsTec Pty Ltd) to measure the movements of Australian professional soccer players. Intra-observer TEM was reported as 4.6% when five match halves were reviewed on two separate occasions but no measure of validity has been reported (Burgess, Naughton, & Norton, 2006). Collectively, these papers suggest that errors of 5-10% are typical and that the accuracy and reliability of observational measurement techniques decrease as the movement speed of athletes increases. This decrease during higher speed activities is a significant issue as it is often this movement category that is of greatest interest to coaches and scientists. It suggests that observational methods that allow for greater accuracy and reliability at high speed are very necessary.

Positional Differences

The desire for position specific training has significantly driven the investigation into the positional demands of sports. In rugby, there are clear differences in the physical characteristics and physiological demands of the different positions (Deutsch et al., 2007; Duthie et al., 2005; James, Mellalieu, & Jones, 2005). Specifically, forwards are heavier and taller than backs. Forwards spend significantly more total time in high-intensity work than backs, because of their greater involvement in rucking, mauling, and scrimmaging but backs perform two to three times more high-intensity running than forwards. Overall work performed (quantified by HR patterns and blood lactate levels) is lower for the backs than the forwards (Deutsch et al., 2007). Backs tend to be leaner, shorter faster, more aerobically fit relative to body mass and more explosive (greater vertical jump) than their forward counterparts. Forwards produce better absolute results when measured for strength and aerobic endurance, but when expressed relative to body mass, the results favour the backs (Deutsch et al., 2007; Duthie et al., 2005).

In soccer, it appears that genetic characteristics affect the orientation of individuals towards particular playing positions. Stroyer et al. (2004) demonstrated that young elite soccer players in their late puberty are highly specialized both according to playing level and position on the field (Stroyer, Hansen, & Klausen, 2004). Comparing soccer players from four professional European leagues, Bloomfield et al. (2005) found differences between the age, stature, body mass and

BMI of players in different positions which suggests that players of particular size and shape may be suitable for the demands of the various playing positions, a suggestion that was recently supported by Di Salvo et al (2007) who found that distances covered by central defenders in high speed running and sprinting speed zones to be significantly lower that all other positional groups and that external midfielders had significantly higher outputs than other positional groups in the high speed running category. (Bloomfield, Polman, Butterly, & O'Donoghue, 2005; Di Salvo et al., 2007). Generally, midfield players cover a greater distance at a jog, attackers cover greater distance at a sprint and defenders cover greater distances when moving sideways or backwards than other positions (Tumilty, 1993). Bangsbo et al (1991) supported this notion when they reported that there were no statistically significant differences between positions in the amount of distance covered at high intensity (Bangsbo et al., 1991).

In hockey, it appears that there are small differences between the physical characteristics of different positions although there is inadequate published data on modern players to confirm this generalisation. However, reported match work rates do differ between positions. Johnston et al (2004) reported midfielders having highest HRs (167 ± 5 $b.min^{-1}$) with defenders the lowest (147 ± 13 $b.min^{-1}$) although the work (cruising and sprinting) to rest (standing, walking, jogging) ratios were similar across positions with defenders 1:6.1, midfielders 1:7.3, and attackers 1:5.2 (Johnston et al., 2004). Spencer et al (2004) found differences in match playing time and motion frequency between positions. Inside-forwards played the most match time, (18 min more than the half-backs). Of the motion data, most notable was the higher number of sprints performed by the inside forwards and strikers (39 ± 1 and 42 ± 15, respectively) compared with the fullbacks and halfbacks (18 ± 1 and 22 ± 7, respectively). Inter-position differences in motion frequency were also recorded for striding and jogging (Spencer et al., 2004).

Effect of Level of Competition and Style

The way a team plays or its “style” of play significantly impacts on the intensity with which players perform (Tenga & Larsen, 2003). Although comparisons of player physical outputs between one style of play and another have not been performed in hockey some limited research does exist for soccer which can be drawn on for general comparison. Rienzi et al (2000) compared the anthropometric and work rate profiles of South American players during international competition against a sample of English players during premier league matches. They reported that the English players performed at a higher intensity and covered significantly greater total distance during match-play than their South American counterparts (Rienzi, Drust, Reilly, Carter, & Martin, 2000). It was discussed that the English professional league was played in such a way that players must constantly work hard to make a receive passes and to regain possession whereas the international competition has a different tactical emphasis with teams seeking to retain possession and attack when opportunity arises. The uncertainty from the research was that it is unclear what contributions style (South American v English) and level (elite professional v international) made to the eventual effect size of 1.3. Yamanaka et al (1988) studied three levels of competition and suggested that top level players spend less time at high movement intensities than lower level players. Their data suggested that the number of changes in movement mode decreased as the level of competition progressed from inter-college to national league to professional Japanese players (Yamanaka, Haga, & Shindo, 1988). A similar suggestion was made by Burgess et al (2006) after finding that semi-professional Australian players covered greater distances and performed at higher intensities than data from the English Premier League (although some of this disparity may be due to the fact that the respective data was gained using different methods) (Burgess et al., 2006). It remains to be seen whether sub-elite, elite and international hockey shows a similar trend to the findings of the above studies.

Effect of Multiple Matches

Professional seasons are long and condensed and matches in elite level soccer and hockey are frequently scheduled in close proximity to each other. Consequently fatigue over a series of matches may occur. During international hockey tournaments such as the Olympic Games teams are required to play 7 matches within a period of 10-12 days with either 24 or 48 hours between and in potentially difficult environmental conditions. To assess the effect of this tight scheduling Spencer et al (2002) recorded the work outputs of male hockey players during three international matches played over four days. The percent of total match time spent standing significantly increased across all three matches and the percent time spent jogging significantly decreased from match 1 to match 2 and from match 1 to match 3 respectively. Furthermore, the percent time in striding/high intensity running significantly increased from match 1 to match 3 and from match 2 to match 3 (Spencer et al., 2004). Similarly Odetoyinbo et al (2007) and colleagues reviewed the performances of twenty-two English premier league soccer teams who played three matches across five days. Total distance covered was similar, as was the distance covered at high intensity. However they did report a significant decrease in distance covered at high intensity in possession of the ball across the three matches (Odetoyinbo, Wooster, & Lane, 2007).

METHODS OF PERFORMANCE ANALYSIS DATA COLLECTION

GPS: The Global Positioning System

The complete Global Positioning System (GPS) provides 24-h, all-weather navigation and surveying capability worldwide. Currently 27 satellites are in medium Earth orbit (2000-35,786 km above earth), transmitting signals allowing GPS receivers to determine the receiver's location, speed and direction. Devices using GPS technology are now commercially available for cars, boats, hikers, runners and team sport athletes. One such commercial product is produced by Australian company, GPSports Systems Pty. Ltd. They market two generations of a GPS tracking unit (GPSpi10 and GPS Spi Elite) for use with team-sport athletes to monitor their training and competition. Both units are carried by an individual in a padded back-pack just below the neck (figure 3) and sample at 1Hz (position is recorded every second). A growing body of published research exists on the use of GPS devices for the measurement of physical activity but only very limited research to date has applied GPS to team sport time motion analysis.

Figure 3: GPS SpiElite device being fitted to a player

Validity of GPS Measurement

Although in a non-team sport context, the reliability and validity of portable GPS devices has been reported previously. Schutz and Chambaz (1997) reported high correlations between actual speed and speed values generated by GPS during walking and running (2-20 km.h-1) and cycling activities (20-40km.h-1) with little bias in the prediction of velocity. The overall error of prediction (s.d. of difference) averaged 0.8 km.h^{-1} (Schutz & Chambaz, 1997). Schutz and Herren (2000) repeated this study using walking and running speeds ranging from 2.9 – 25.2 km.h^{-1} and found similar results with speed accuracy standard deviations of 0.08km.h^{-1} (walking) and 0.11 km.h^{-1} (running) (Schutz & Herren, 2000). Larsson and Henriksson-Larsen (2001) reported high correlation coefficients between actual and GPS values for distance, speed and position when monitoring activities during orienteering (Larsson, 2003). Portas et al (2006) compared the distance and velocity provided by GPS units and electronic timing lights during a linear running protocol at varying velocities. For GPS-estimated distance, mean % error was calculated. For velocity a log-transformed linear regression was conducted with the standard error of the estimate for each unit expressed as % CV. The error for GPS distance measurements varied by the velocity of the trial. The mean % error was highest during running at 22.5km.h-1 (5.64%; 2.82m) and the lowest (0.71%; 0.36m) at the slowest velocity of 6.45km.h-1. The % CV for the GPS-estimated velocity was 1% for each of the three units (95% CI 0.8% to 1.2%) (Portas, Rush, Barnes, & Batterham, 2006).

Edgecomb and Norton (2006) compared the results from computer-based tracking and GPS (SPI10, GPSports Pty) tracking when performing basic sport specific running activities. Both systems were compared to actual distances as measured by a calibrated trundle-wheel. Twenty eight trials were performed where players travelled at various speeds around circuits of different lengths and geographical layouts (ranging in distance from 125m to 1386m with an average of 283m). Paired T-tests were used to determine differences between GPS distances and actual distances. Relative technical error of measurement (TEM%) was used to calculate intra-tester reliability. The GPS and actual distances were highly correlated (r=0.998) although there was a significant difference between the GPS distance and the actual distances ($t = 5.27$; $df = 58$; $p < 0.001$). Over the 59 trials the average error of the GPS system was +4.8 ± 7.2% with an absolute error of 6.3 ± 6.0%. Triplicate repeat measures of the distance a player travelled for a range of circuits demonstrated a TEM of 5.5% (intratester reliability). The correlation between the triplicate measures was highly significant ($r = 0.989$) (Edgecomb & Norton, 2006). Thus information suggests that GPS units have good accuracy during basic linear movements but that accuracy decreases as speed increases. No reliability information is available for activities involving rapid change of direction such as those occurring during team sports.

Heart Rate

The use of HR monitoring with athletes has progressively increased since the early 1980's when the first wireless HR devices were developed (Achten & Jeukendrup, 2003; Laukkanen & Virtanen, 1998). From this point onwards, (the objective measure of) HR began to replace (the subjective measure of) perceived exertion as the common global measure of physiological strain. Strong reported validity for these devices, most notably those devices from Scandinavian company Polar (Polar Electro Oy, Finland) has also seen them feature heavily in exercise-based fitness research (Goodie, Larkin, & Schauss, 2000; Kinnunen & Heikkila, 1998; Laukkanen & Virtanen, 1998; Vuori, 1998; Wajciechowski, Gayle, Andrews, & Dintiman, 1991) as a means of providing an accurate, reliable, non-obtrusive and socially acceptable method of quantifying activity and training load (Achten & Jeukendrup, 2003; Gilman, 1996).

Outside of the monitoring of supplementary aerobic training, the application of HR monitoring for team sport athletes is a more recent phenomenon. The proliferation of competition HR analysis in team sports has been helped by the development of a HR recording system (Team Polar, Polar Electro Oy, Kempele, Finland) that does not require athletes to wear a watch receiver (only a chest strap that has an internal memory). This allows for the safe recording of HR in body contact situations where the wearing of a watch may be considered inappropriate and may be against the rules of the sport.

The use of HR as a measure of exercise intensity relies on a consistent relationship between HR and oxygen consumption. Arts and Kuipers (1994) stated that there was such a strong linear relationship between power output, HR and oxygen consumption that one could easily be predicted from the other (Arts & Kuipers, 1994). However, in runners (Lambert et al 1998) and cyclists (Palmer et al 1994, Jeukendrup et al 1998) it has been shown that competition HRs do not provide as valid an approximation of oxygen consumption as they do during training with factors such as dehydration, heat stress and mental stress elevating HR without affecting oxygen uptake and exercise intensity (Bangsbo, Mohr, & Krustrup, 2006; Jeukendrup & Van Diemen, 1998; Lambert, Mbambo, & St Clair-Gibson, 1998; Palmer, Hawley, Dennis, & Noakes, 1994). The extent of the elevation of HR during competition in team sports has not been reported but with low heat stress, appropriate hydration strategies and high fitness levels it can be assumed that the effect of cardiac drift on HR is minimised. Additionally, it has been suggested that psychological factors have more influence on HR at rest or at low intensities whereas at higher intensities the emotional influence on HR is somewhat neutralized by the higher workload (Boyle et al., 1994).

A number of studies have described the competition HRs of team sport athletes (Table 3). Rodriguez-Alonso et al (2003) reported the HR of female basketball players during international and national level matches. Mean HRs were 94.6% (international) and 90.8% (national) of maximum as measured in a progressive shuttle test (Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce, & Terrados, 2003). Similarly, Abdelkrim et al (2006) and McInnes et al (1995) reported mean HRs of 91% and 89% respectively during elite male basketball competition (Abdelkrim, El Fazaa, & El Ati, 2007; McInnes et al., 1995). Krustup et al (2005) reported mean HRs in elite women's soccer players during professional competition. Players averaged 87% of maximum as measured during a maximal laboratory treadmill test .(Krustrup et al., 2005) Mean HRs of 160 b.min^{-1} and 81% of HR_{max} have been found in male Gaelic football players (Florida-James & Reilly, 1995; Reilly & Keane, 2001). O'Connor (1999) reported mean HRs of 178 beats per minute during elite touch rugby (O'Connor, 1999) and Hollander et al (1994) reported HRs between 88 and 95% of maximum during elite competitive water polo (Hollander, Dupont, & Volkerijk, 1994).

Table 3: Competition HR during team sports

Author	Sport	Details	Mean Competition HR
(Boyle et al., 1994)	Hockey	Ireland Male Elite	159 b.min^{-1}
(Paun et al., 2008)	Hockey	Australian Male Elite	176 ± 13 b.min^{-1}
(Platanou & Geladas, 2006)	Water Polo		156 ± 18 b.min^{-1}
(O'Connor, 1999)	Touch Rugby	Australian Male Elite	178 b.min^{-1}
(Reilly & Keane, 2001)	Gaelic Football	Ireland Male	160 b.min^{-1}
(Florida-James & Reilly, 1995)	Gaelic Football	Ireland Club Male	81% HR_{max}
(Krustrup et al., 2005)	Soccer	Danish Professional Female	87% HR_{max}
(McInnes et al., 1995)	Basketball	Australian Professional Male	89% HR_{max}
(Abdelkrim et al., 2007)	Basketball	Tunisian Male Elite	91% HR_{max}
(Rodriguez-Alonso et al., 2003)	Basketball	Spanish Female International	94.6% HR_{max}
(Barbero-Alvarez et al., 2008)	Futsal	Spanish Professional Male	90% HR_{max}

Mean match HRs during elite male club and representative hockey have been reported as 159 $b.min^{-1}$ (Boyle et al., 1994) 155 $b.min^{-1}$ (Johnston et al., 2004) and 176 $b.min^{-1}$. (Paun et al., 2008) It is unclear why the absolute HR values of Paun et al (2008) are substantially higher than those of Boyle et al (1994) and Johnston et al (2004). The relatively small number of subjects in the respective studies and lack of information regarding HR_{max} means that variation in individual HR may be responsible for some of this difference.

HR Sample Interval

The intermittent nature of team sports means that the exercise intensity is constantly changing. Spencer et al (2004) reported that international hockey players change intensity on average every 5.5 seconds (Spencer et al., 2004). This is consistent with findings in Gaelic football (McErlean, Cassidy, & O'Donoghue, 2000) and soccer (Reilly & Thomas, 1976; Yamanaka et al., 1988). To use HR as a measure of intensity in such team sports therefore requires a high frequency of sampling to capture this regular change of intensity. Ali et al (1991) compared the HR traces of soccer match performance using 5, 16 and 60 second sample intervals and found that all sample intervals provided significantly different representations of the activity to each other and that a 5 second sample interval was most appropriate for an intermittent sport (Ali & Farrally, 1991b). The use of a 5 second HR sample is consistent across the literature in soccer (Capranica, Tessitore, Guidetti, & Figura, 2001; Krustrup et al., 2005; Tessitore, Meeusen, Piacentini, Demarie, & Capranica, 2006), hockey (Boyle et al., 1994; Johnston et al., 2004) basketball (Abdelkrim et al., 2007; Rodriguez-Alonso et al., 2003) and rugby (Deutsch et al., 1998) and has been mathematically demonstrated to be adequate for analytical purposes (McCarthy & Ringwood, 2006).

Expression of HR Data

As demonstrated in table 3, methods of reporting of HR data during team sport competition are inconsistent. Much of the early notational analysis research simply reported average HR and most did not reference to actual or predicted maximum HR (HR_{max}). Although mean and non-referenced HR data is useful it results in a substantial loss of specific information (Helgerud, Engen, Wisloff, & Hoff, 2001). Clearly, the addition of laboratory or field measures of actual HR_{max} and the division of competition HR data into zones, time periods, and/or playing position makes the analysis more applicable and meaningful.

Investigators in soccer, basketball and Gaelic football have divided the match HR data into time segments so as to make comparisons between work rates and physiological load over the course of the match (Bangsbo, Norregaard et al. 1991; Rodriguez-Alonso, Fernandez-Garcia et al. 2003; Krustrup, Mohr et al. 2005; Abdelkrim, El Fazaa et al. 2007). Abdelkrim et al (2007) reported average HR for each quarter of a basketball match, Krustup et al (2005) divided a 90-minute soccer match into 15 minute segments and Rodriguez-Alonso (2003) and Bangsbo (1991) compared data between the first and second halves. It is commonly reported that work rates and HRs decrease by ~5% in the second half of soccer matches (Ali & Farrally, 1991a, 1991b).

Deutsch et al (1998) divided match HR of male under-19 rugby players into four zones; maximal (>95% HR_{max}), supra-threshold (85-95% HR_{max}), anaerobic threshold (75-84% HR_{max}), and sub threshold (<75% HR_{max}). Match HR's were reported as the average percentage of match time that each position spent in the respective HR zones (Deutsch et al., 1998). Johnston et al (2004) and Paun et al (2008) used the same zones to analyse the match HR of elite male hockey players and also reported average percentage of match time that each position spent in the respective HR zones (Johnston et al., 2004; Paun et al., 2008). McInnes et al (1995) divided the match HR's of professional male Australian basketball players into six zones; >95% HR_{max}, 91-95% HR_{max}, 86-90% HR_{max}, 81-85% HR_{max}, 75-80% HR_{max}, <75% HR_{max}. In these various studies the authors have divided HR into zones to capture activity in various intensity categories. Establishment of clear zones allows for comparative analysis to occur with data that is reference to HR_{max} and therefore able to be used for comparison.

Technical and Tactical Outputs

Given the expense of automated systems, much performance analysis research continues to use methods that involve human observation. Given that such methods involve a degree of subjectivity, there is a need to train system operators and have clear procedures so as to avoid data being entered inaccurately, variable observer reaction to events, and different interpretations of performance being made (Bloomfield, Polman, & O'Donoghue, 2007b). The possibility of error was identified by McLaughlin and O'Donoghue (2001) who found that one observer had a tendency to record 10% more of a certain activity than the other observer in an inter-operator reliability study involving 28 subjects (McLaughlin & O'Donoghue, 2001). However, conversely, Bloomfield et al (2007) found good reliability of measurement of soccer match performance (Bloomfield et al., 2007b) and Deutsch et al (2007) reported TEM values of 1.6 to 4.6% for a range of technical skills during rugby match-play

(Deutsch et al., 2007) suggesting that observational methods can provide reliable data.

One problem for a reliability study is the determination of the extent to which events have been missed. Another problem consists of analysts coding events incorrectly. The only way of dealing with these potential problems is to have a single analyst perform the classifications, to ensure the operational definitions are well thought out and understood, and to check all analysts' codes for a match against a gold standard (James, Taylor, & Stanley, 2007).

Summary

Much has changed since the early notational analysis methods of Reep (Pollard, 2002) and there is now a steadily increasing array of performance analysis methods being applied to modern sport. Observational methods are still an extremely popular method of gaining analysis data even though it is over 30 years since the first significant publication was made using such a system (Reilly & Thomas, 1976). Sophisticated, automated tracking systems have been developed that provide detailed match information without significant manual input but these systems remain very expensive and used predominantly by professional soccer and rugby clubs in Europe. Another less expensive automated device, the GPS receiver, is showing promise from a practical perspective.

As the measurement of physical performance becomes increasingly common the gain in knowledge from such measurement diminishes. This has shifted the recent focus of performance analysis to technical aspects of match play. A wide variety of literature has been presented measuring both success and frequency of simple tasks and the performance of complex tactical skills.

Such investigations require valid and reliable data collection procedures and statistically sound processing and analysis methods. Recent literature suggests that these methodological issues are currently being investigated. Of similar importance is the maintenance of the strong link between performance analysis and the coaching process. Producing research that is responsive to the needs of coaches and athletes and that provides information in a timely manner to support training and competition should still be the fundamental principle behind performance analysis.

LITERATURE REVIEW – PART 2: THE PHYSICAL DEMANDS OF ELITE MEN'S HOCKEY

Introduction

Hockey has been classified as a goal-striking invasion game (Hughes & Bartlett, 2002) and it originated in primitive form, thousands of years before the first Olympic Matches in 776 B.C. After that, the match evolved through roman-influenced Europe and developed derivatives in Germany (Kolbe), Holland (Het Kolven) , France (Hocquet) and Ireland (Hurling). The first hockey association was formed in 1873 and international field hockey contests were played by men as early as 1895 (Anders & Myers, 1999; Reilly & Borrie, 1992). At present there are 64 ranked women's teams and 68 ranked men's teams in the world and hockey is a formal sport in both the Commonwealth Games and Olympic Games.

Game Format

Hockey is played between two teams of eleven players, including a goalkeeper. The field of play is rectangular (90m long and 55m wide) and a match consists of two, thirty-five minute halves. The object of the match is to hit the ball (approx 9 inches in diameter) into the opponents goal using specially shaped sticks that are 36-42 inches in length. A significant rule of hockey is that for a goal to be scored the ball must touch an attacking player's stick inside of the attacking circle (a 16yard semi-circle around the goal). Additionally, penalty corners, which are a significant goal scoring set-piece opportunity are awarded for infringements by the defenders inside the circle. These two factors make getting the ball into the circle a significant objective for the attacking team.

The positions of hockey can be divided into five categories; goalkeepers, fullbacks, halves, inside forwards and strikers and each have specific roles and activities. Although there are many options, a typical team formation is shown below with a goal keeper, two fullbacks, three halves, two inside forwards and three strikers (please refer to figure 4). Hockey has had two significant modifications. In the 1970's the playing surface changed from grass to artificial turf which altered the pace and style of the game considerably. More recently, rule changes have also been introduced to modify the pattern of the game. The two most significant changes (mid-1990s) have been to allow unlimited substitutions (a maximum of 16 players can play in each match and can rotate as frequently as they like) and the removal of the offside rule (which has created attacking space and led to more goals being scored per match). These changes were initiated to promote fast-paced, continuous play.

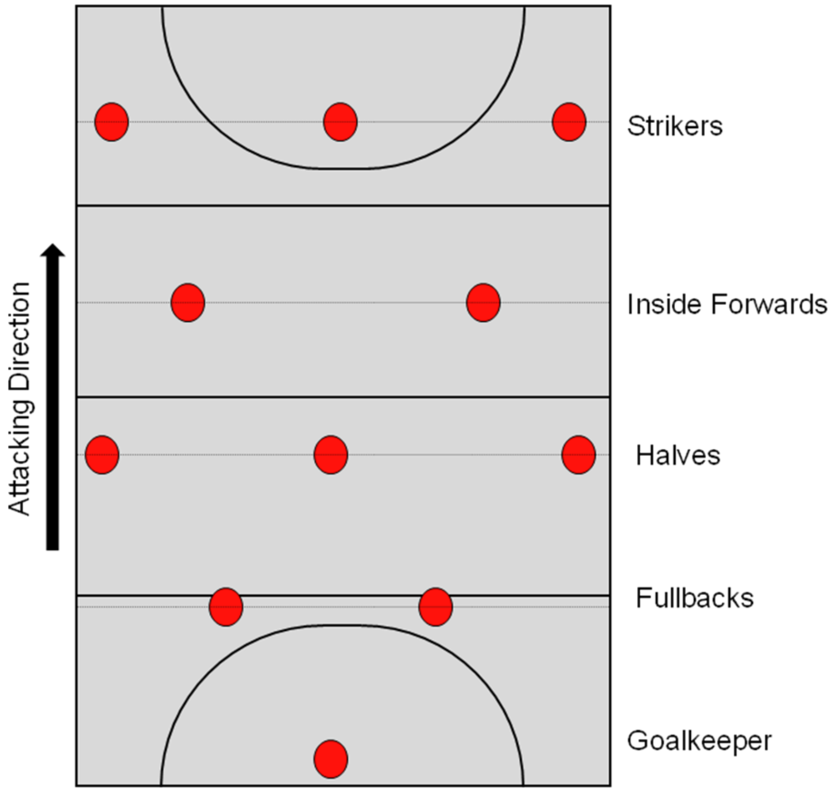


Figure 4: Typical field positions in hockey

The Physiology of Hockey

There are many factors that contribute towards success in team sports. Foremost among these is game technical skill and the cognitive ability to make correct decisions. In addition, players must possess certain physical qualities. They require high aerobic and anaerobic power, good agility, joint flexibility and muscular development, and be capable of generating high torques during fast movements (Reilly, Bangsbo, & Franks, 2000). The predominant metabolic pathways during hockey match-play are aerobic and the metabolic responses are broadly analogous to those encountered in endurance exercise.(Reilly et al., 2000) Although aerobic metabolic pathways provide the dominant energy route, anaerobic activity is highlighted during the more crucial moments of the match and contribute directly to winning possession of the ball and to the scoring or conceding of goals. Hockey is referred to as an intermittent sports due to the pattern of repeated short bursts of high intensity activity interspersed with active and passive recovery. Such a pattern requires lactate removal and rapid regeneration of phosphocreatine (PCr) stores to allow for sustained performance (Tomlin & Wenger, 2001). Muscle strength is relevant to striking the ball and to tackling and tolerating physical impacts with other players. Anaerobic power is also important in accelerating the body during short movements and changing direction quickly. Players who can sustain a high work-rate throughout a match gain an advantage over equally skilled players whose energy can approach depletion towards the end of a game or after a series of high intensity efforts, resulting in reduced performance (Reilly et al., 2000).

Published research on the physical demands of men's hockey is limited, especially relating to recent and elite competition. A summary of studies to date is presented in Table 4. Wein (1981) provided some early data quantifying the distances covered during hockey matches in the 1972 World Cup. The range of distances was 5.14km to 8.82km with an average of 5.61km but scant details of methodology were given and it is unclear if the data included of players who played for less than 70 minutes (Wein, 1981). It seems that with such a large spread of reported distances that this could have been the case.

Following this early work from Wein (1981), Ghosh et al (1991) reported descriptive information from an Indian national team training camp that saw 54 junior and senior players involved in a series of fitness assessments and trial matches. Average VO_2max was 54.4 ml.kg.min^{-1} for the junior players and 53.8 ml.kg.min^{-1} for the senior players. To gain an insight into match intensity blood lactate samples and HRs were recorded. Blood lactates, taken two minutes after the end of a match were between 4 and 6 mmol.l^{-1} and mean match HRs were 143.4 ± 15.3 b.min^{-1} for the junior players and 156.6 ± 15.1 b.min^{-1} for the senior players (Ghosh et al., 1991). Although the post-match lactate sample is not necessarily indicative of match intensity it does provide a general gauge and in conjunction with the HR data suggests a moderate to high level of physical load.

Boyle et al (1994) found a similar HR response when studying the work rates of international hockey representative players in Ireland despite the subject characteristics being substantially different to those of Ghosh et al (1991). Players were taller, heavier and had higher VO_2max than those of the Indian sample group. HR was recorded at 5 second intervals during club competition and referenced to HR's measured during a laboratory test of maximum oxygen consumption. Mean HR during match play was 158.6 ± 8 b.min^{-1} and average oxygen consumption was estimated as 77.9%±7.3 VO_2max (Boyle et al., 1994). However only nine subjects were monitored (one player per game for nine games) and no individual playing position had two sets of data. Similarly, Johnston et al (2004) only reported the findings from single measurements on 15 elite male hockey players in the Scottish National League. One player was filmed per match for 15 weeks consisting of five defenders, five midfielders and five attackers. Using the video footage, activities were subjectively categorized as standing, walking, jogging, striding and sprinting so as to establish work to rest ratios and profiles of match play. Players spent the majority of time stationary (4.0%) or engaged in low intensity activity (walking 50.9%, jogging 29.6%) with only a small portion of the match in high intensity activity (cruising 10.1%, sprinting 4.7%). Mean HR was 155 ± 12 $b.min^{-1}$ and players spent 64% of match time above 75% of HR_{max}. The mean ratio of high intensity (cruising and sprinting) to low intensity (standing, walking, jogging) activity was 1:5.7 ± 0.6 with minimal positional differences. Players performed 30 ± 6 sprints with an average sprint duration of 5.7 seconds (Johnston et al., 2004). This is the first published study to describe the temporal characteristics of hockey and although the calibre of the matches was only moderate, the information provides a useful categorisation of the time spent in different locomotion categories. The finding that the overwhelming proportion of time was spent either stationary, walking or jogging suggests that the game consists of short bursts of high intensity work superimposed onto an aerobic framework. The additional finding that players on average performed 30 sprints of 5.7 seconds per match indicates that the ability to perform and recover rapidly from high intensity activity is a key physical quality for elite hockey players.

Findings from a higher level of competition were reported by Spencer et al (2004) who used video analysis to monitor the activities of the Australian Men's team during an international match. While watching video playback the researchers subjectively identified and placed player motions into categories of standing, walking, jogging, striding and sprinting using the locomotion criteria of Bangsbo et al (1991) (Bangsbo et al., 1991). The mean match time of each player was 48 minutes with only three players being involved for the entire 70-minute duration. Low intensity activities of standing walking and jogging accounted for approximately 94% of match time (7.4% standing, 46.5% walking, 40.5% jogging). Only 5.6% of match time was spent performing high intensity running which compares favourably with the findings of Boyle et al and suggests little difference between the proportion of time spent in intensity categories at international level as compared to elite domestic level. Notable position differences were reported with respect to high intensity activity with inside forwards and strikers performing more sprints than fullbacks and halfbacks. The motions of all players were grouped into a team motion category and the flow of this motion was assessed during 5 minute periods throughout the match. It was reported that as a half progressed there were increases in the amount of standing and walking that occurred. For example, compared with the initial 5 minute period in the second half, the subsequent 30 minutes saw a significant increase in percent time spent walking and standing and a significant decrease in percent time jogging. Mean sprint duration was 1.8 seconds with an average of 30 ± 12 sprints per player. Although the number of sprints recorded per player per game is identical to that reported by Johnston et al (2004) the sprint duration is substantially lower (1.8s v 5.7s) which is likely due to different criteria used to log the start time of the sprint. Using typical speed testing data from an elite population, an average sprint of 5.7s suggests a distance of 40-50m per effort. Such a sprint duration is rare during hockey match play (Lythe, 2006) with average sprint durations of 1-3 seconds being much more typical of time-motion studies of team sports so the findings of Spencer et al (2004) seem to be more realistic.

Another common point of discussion in time motion studies is changes in motion category i.e. moving from one category such as walking to another category such as jogging. Spencer et al (2004) reported that a match consisted of 780 motions or a change in activity every 5.5 seconds (Spencer et al., 2004). Paun et al (2008) reported 901 ± 116 motion changes when assessing the HR and physical outputs of Australian national league players using portable GPS units. The greater number of motions than reported by Spencer et al once again suggests different criteria/more motion categories were used to create this statistic especially when you consider that data from subjects in Paun et al only consists of an average of 64 minutes of match time. Paun et al (2008) monitored six players over four practice matches each during preparations for the Australian Hockey League. Average total distance covered by players during their time on the pitch was 6419 ± 838m. Players spent 89% of match time engaged in low or moderate intensity activity (standing, walking and jogging) with the remaining 11% in high intensity activity. An average of 36 ± 9 sprints were performed per player per match with a mean duration and distance of 2.5 ± 1.7s and 12.4 ± 9.9m (Paun et al., 2008) (refer to Table 4). Despite methodological differences the proportion of time spent in motion categories and the sprint frequency and duration compare well to those of Spencer which suggests a similar quality of physical performance by the two subject groups. Mean HR of 176 ± 13bpm is higher than those reported by Ghosh et al, Boyle et al and Johnston et al although with no HR_{max} data to refer to for each subject group it is not possible to say if the groups had differences in actual HR intensity.

Collectively these studies indicate that elite male hockey has a relatively low overall match intensity with 80-90% of game time being spent performing low intensity movements. However there are approximately 850 motion changes and 30 sprints of two seconds duration performed by each player during a game. Even though recent data from Spencer et al (2004) (1 match x 14 players), Spencer et al (2005) (3 matches x 10 players) and Paun et al (2008) (4 matches x 6 players) has provided a good snapshot of the physical demands of elite hockey at elite domestic and international level there is still a need for another comprehensive set of data that covers all playing positions, over multiple matches at a high level of competition.

In summary, there is only a small amount of published literature on the physical demands of hockey and no literature exists describing both technical and tactical aspects of match performance. The early studies of Ghosh et al (1991) and Boyle et al (1994) provided some basic information prior to the rule changes and Johnston et al (2004) added more recent data to this. The papers have been surpassed by Spencer et al (2004) and Paun et al (2008) who have presented updated information on such an elite group.

Table 4: Time and motion data from elite men's hockey

Reference Details	Subject Group	Player Characteristics	Time Motion
(Ghosh et al., 1991)	54 Indian national level players 25 junior (18.8 ± 0.6 years) 29 senior (25.1 ± 2.1 years) Unspecified number of intra-squad trial matches	Height = 172.8 cm (junior), 171.7 cm (senior) Mass = 59.6 ± 6.6 kg (junior), 60.9 ± 4.8 kg (senior) VO_2max = 54.4 ml/kg/min (junior), 53.8 ml/kg/min (senior)	Blood lactates taken 2 minutes after a match were 4.2 ± 1.9 (junior), 5.6 ± 2.0 (senior) Mean HR during match was 143.4 ± 15.3 (junior), 156.6 ± 15.1 (senior)
(Boyle et al., 1994)	9 Irish International players (26 ± 4.5 years) 1 club match per player	Height = 177.3 cm, Mass = 75 ± 5.4 kg , Body fat = 12.4% VO_2max = 61.8 ml/kg/min	Mean HR during match play = 158.6 ± 8
(Johnston et al., 2004)	15 Scottish domestic players (19.5 ± 2.5 years) 1 national league match per player	Height = 179 ± 0.1 cm, Mass = 80 ± 2.5 kg	Percent of time spent in locomotive states = standing 4.0%; walking 50.9%; jogging 29.6%; cruising 10.1%, sprinting 4.7% Mean HR during match = 143.4 ± 15.3, Peak HR during match = 183 ± 11bpm Percent of time spent in HR zones = <75%, 37 ± 18.8 ; 75-85%, 26.1 ± 11.8; 85-95%, 34 ± 17.4; >95%, 4 ± 3.0. Work to rest ratio = 1:5.7 (±0.6) Mean sprints per player = 30 ± 6 with average duration of 5.7 seconds

Table 4: continued

(Spencer et al., 2004)	14 Australian International players (26.0 ± 3 years) 1 international match	Mass 76.7 ± 5.6 kg, VO_2max = 57.9 ± 3.6 ml/kg/min Mean match time per player = 48 minutes Percent of time spent in locomotive states = standing 7.4%; walking 46.5%; jogging 40.5%; striding 4.1%, sprinting 1.5% Average number of motions (changes in mode) per match = 780 Sprints performed by position = strikers 39; inside forwards 41; fullback 18, half 22
Spencer et al 2005	14 Australian International players (26.0 ± 3 years) 2 international matches	Mass 76.7 ± 5 kg Mean match time per player = 56, 57 minutes Percent of time spent in locomotive states = standing 11.2%/15.5%; walking 47.7%/48.3%; jogging 34.8%/29.4%; striding 5.1%/5.8%, sprinting 1.2%/1.0%
(Paun et al., 2008)	6 Australian domestic players (26.2 ± 3.9 years) 4 national league matches per player	Height = 178.6 ± 3.8cm, Mass = 78.2 ± 14.8kg VO_2max = 53.7 ± 4.9 ml/kg/min, Body fat = 12.8 ± 5.9% Mean match time per player = 64 minutes Mean total distance covered = 6419 ± 838m Mean number of changes in tempo per match = 901 ± 116 Mean number, distance and duration of sprints performed (above 17km.h-1) = 36 ± 9, 12.4 ± 9.9m, 2.5 ± 1.7s Mean HR during match play = 176 ± 13bpm, HR was above 85% HRpeak for 60% of the match

LITERATURE REVIEW – PART 3: FATIGUE

A consistent point of interest in the topical literature is the change (usually a decrease) in activity between the early parts of the match and the later parts of the match. In soccer, decreases in distance covered between the first half and second half are commonly reported (Bangsbo et al., 1991; Mohr et al., 2003; Reilly & Thomas, 1976) although the significance and the nature of these decreases has shown some variation. For example, Burgess et al (2006) found that professional Australian players covered less low intensity distance but equal amounts of high intensity distance in the second half of matches and suggested that players conserved energy in the second half by performing less low intensity work which allowed them to maintain the high intensity running (Burgess et al., 2006). The decrease in physical work output inevitably impacts on a player's involvement in the match. Australian soccer players had a greater engagement with the match in the first half as compared to the second half as indicated by a decrease in the amount of player events (e.g. ball contacts) per minute (Burgess et al., 2006). This was supported by Rampanini et al (2008) who also found a significant decrease in involvements with the ball in professional soccer players (Rampinini et al., 2008).

DiSalvo et al (2007) found that although a longer distance was covered during the first half compared to the second half the difference was not significant (5709 ± 485m vs 5684 ± 663m). When data was divided into speed categories, significantly more distance was covered in the second half than the first at low intensities (Zone 1: 0–11 km/h; 3496 ± 148m vs 3535 ± 302m $p < 0.05$). However significantly more distance was covered in the first half compared to the second half at medium intensities (Zone 2: 11.1–14 km.h^{-1}, 851 ± 188m vs 803 ± 187m $p < 0.0001$; Zone

3:14.1–19 km.h^{-1} 894 ± 251m 865 ± 255m $p < 0.05$). However, no significant differences at submaximal (Zone 4: 19.1-23 km.h^{-1}) and maximal (23+) intensities were observed (Di Salvo et al., 2007).

Mohr et al (2003) reported two other interesting fatigue issues. Firstly, after the 5-min period during which the amount of high-intensity running peaked, performance was reduced by 12% in the following 5 min compared with the game average. Secondly, substitute players (n =13) covered 25% more distance during the final 15 min while performing high-intensity running than the other players who had been involved in the match from the start (Mohr et al., 2003).

In hockey, the mean time spent in high-intensity motions of activity has been reported to decrease significantly between the first and second halves of elite women's matches (8:14 ± 1:29s vs 7:03 ± 1:19s) (Lothian and Farrally, 1994). However, the athleticism of the elite men's game is a lot different to this study and the game has evolved considerably since this study was conducted nearly 14 years ago. A more recent study found no significant differences in percent time striding or sprinting in either half of an international hockey match (Spencer et al., 2004). However, average team motion decreased in intensity after the first five minutes of each half of the match. The percent time spent jogging for most 5-min periods in the first half and all periods of the second half was significantly less when compared with the first 5-min period in the first and second half, respectively. As a result of this reduced activity level, the percent time spent standing and walking increased significantly for most 5-min periods in both halves of the match, when compared with the first 5-min period of play in each half (Spencer et al., 2004).

Although physical fatigue is the most likely reason for the observed reductions in physical work rate it could be argued that in some cases the reductions are related to the fact that the outcomes of matches had already been decided. This is supported by the observation that the tactics of a team are frequently observed to change when a score is significantly in their favour or against their favour (Ali & Farrally, 1991b; Lago & Martin, 2007; Mohr, Krustrup, & Bangsbo, 2005). Although tactics can lead to players working below their physical capacities, it is likely that performance can be improved through the use of physical conditioning. Indeed a relationship between improvements in physical condition and match performance has been reported. Krustup et al (2003) have demonstrated in both referees and elite level soccer players that increases in fitness translate to increases in physical work outputs during matches (Krustrup et al., 2003). Similarly Helgerud et al (2001) demonstrated that an eight week training programme which increased VO_2Max from 58.1 to 64.3 ml/kg/min improved soccer match performance variables significantly. Distance covered (20%), average work intensity (3%), number of sprints performed (100%) and involvements with the ball (24%) during a match increased in male elite junior players as a result of interval training at 90-95% of HR_{max} (Helgerud et al., 2001).

Mechanisms of Fatigue

Hockey like many team sports can be described as an interval sport, requiring intermittent bouts of high-intensity activity interspersed with periods of submaximal effort. The occurrence of fatigue or reduced physical performance during match play is probably a complex interplay of a number of contributing factors and seems to occur at three different stages:

(1) randomly, after intense periods of high intensity activity, (temporary fatigue);

(2) early in the second half; (temperature fatigue); and,

(3) in the later stages of the match (depletion fatigue)

Different physiological mechanisms are responsible for these types of fatigue; temporary fatigue may be related to disturbed muscle ion homeostasis, impaired exercise ability in the first few minutes after half-time could be explained by a markedly lowered muscle temperature at the start of the second half and the decrement in the last stages of a match may be caused by a depletion of muscle glycogen or dehydration (Mohr et al., 2005). There are also recent suggestions that central nervous system (CNS) is involved in feelings of tiredness, lethargy, and mood disturbances. Evidence has accumulated over the past 20 years to support a significant role of the brain in the aetiology of fatigue during strenuous exercise but to date this has not yet been applied to intermittent team sport activity (Meeusen, Watson, & Dvorak, 2006).

Temporary Fatigue

The causes of temporary fatigue may be linked directly to levels of muscle glycogen, the accumulation of blood lactate, pH level or the breakdown of phosphates. To assess this in a sporting context Krustup et al (2006) assessed the extent to which sprint performance is impaired after intense exercise periods during a soccer match. Fourth division Danish players performed a repeated sprint test immediately after a short-term intense period during the match and at the end of each half (Krustrup et al., 2006). It was shown that after intense periods in the first and second halves, the players' sprint performance was significantly reduced (mean sprint time during 5 x 30m sprints with 25s rest was longer ($p < 0.05$) after intense periods in the first (1.6 ± 0.6%) and second halves (3.6 ± 0.5%). However, at the end of the first half the ability to perform repeated sprints was recovered. The mechanisms for these changes were unclear however as only weak correlation was found between lactate and decreased sprinting performance. Additionally lactate concentrations during the match were rather low (blood lactate being 6.0 ± 0.4 and 5.0 ± 0.4 mM for first and second halves respectively) compared with those found at exhaustion after high-intensity laboratory-based exercise (Bangsbo et al., 1992; Gaitanos, Williams, Boobis, & Brooks, 1993). Thus, it is unclear if elevated lactate and lowered muscle pH cause fatigue during a team sports. Another mechanism, that of depleted phosphates has also been suggested.

Low muscle PCr concentrations may contribute to temporary fatigue, since high intensity activity places heavy demands on this energy system and performance in intense intermittent exercise has generally demonstrated to be elevated after a period of creatine supplementation (Cornish, Chilibeck, & Burke, 2006; Dawson et al., 1997). It has been shown that after intense periods during match-play the decrease in PCr is correlated with impairment in sprint ability (Krustrup et al., 2006). However, PCr was only lowered by 25% (20 $mmol^{-1}kg^{-1}$ d.w.), which in part could be due to the fast recovery of PCr and the approximately 20s delay in collecting the muscle biopsy in this study. Because of rapid muscle PCr resynthesis it is likely that the reported values significantly underestimate the PCr breakdown during match-play. Dawson et al (1997) demonstrated the significant impact of repeated sprint efforts on the nature of PCr replenishment. They reported that 30 s after a single 6 s sprint, PCr stores had recovered to approximately 70% of their resting concentration. However, after 5x6 s sprints, with only 24 s of recovery between each effort, PCr stores recovered to only 45% of resting levels. After 3 min of recovery, the repletion of PCr stores was essentially complete when a single sprint was performed, but only approximately 80% complete when repeated sprints was performed. The rate of PCr repletion after repeated short sprints is not slower than after a single short sprint but it simply takes longer after repeated than single short sprints because of a greater level of PCr depletion (Connolly, Brennan, & Lauzon, 2003; Dawson et al., 1997). Despite this, PCr may have been significantly lower in individual muscle fibres, since stores have been reported to be almost depleted in individual fibres at the point of fatigue after intense exercise (Søderlund & Hultman, 1991). However no changes were observed in muscle PCr in the final phase of the Yo-Yo intermittent recovery test (Krustrup et al., 2003). Subjects were able to continue performing with rather low concentrations of PCr which argues against a potential inhibitory effect on performance during intense intermittent exercise.

Another theory related to temporary fatigue may be related to an accumulation of potassium in the muscle (Bangsbo, 1996; Nielsen et al., 2004). During exercise, potassium is released from the intracellular to the extracellular space of skeletal muscle and into the bloodstream. Accumulation of potassium has been suggested to cause fatigue due to impaired membrane excitability (Nielsen et al., 2004). At the point of exhaustion after intense short-term exercise the interstitial potassium concentration is elevated to around 12 $mmol.l^{-1}$ (Mohr et al., 2004; Nielsen et al., 2004) which according to in vitro studies is high enough to depolarize the muscle membrane potential and reduce force development (Cairnes & Dulhunty, 1995). Repeated bouts of intense exercise also magnify the effect that potassium accumulation has on the muscle. When intense exercise is repeated the rate of muscle interstitial K+ accumulation is reduced in the initial phase of exercise and fatigue occurs at a lower interstitial potassium concentration. This finding suggests that it is not only the accumulation of K+ in the muscle interstitium that depresses the exercise performance, but also the degree of depolarization of the muscle sarcolemma as a consequence of the accumulation of potassium that contributes to fatigue development (Mohr et al., 2004). Thus, in addition to links with lactate accumulation and PCr depletion, temporary fatigue may be experienced in team sports as a consequence of accumulation of extracellular potassium and related electrical disturbances in the muscle cell.

Temperature Fatigue

Reduced work load has been observed in the initial phase of the second half during soccer and research suggests that a re-warming up period at the end of the half time break may be beneficial to performance (Mohr et al., 2004). The beneficial effects of the warm up appear to be largely attributable to increases in muscle temperature (Bishop, 2003). Suggested mechanisms include a decrease in muscle and joint stiffness, an increase in neural transmission rate, increases in the speed of muscle contraction and decreases in both the time to peak tension and half relaxation time (Bishop, 2003; Reilly & Gilbourne, 1997). Additionally central responses such as increases in HR and acceleration of VO_2 kinetics (due to higher O_2 availability to the working muscles at the onset of heavy exercise) are also significantly beneficial to performance provided that the warm up procedure does not deplete glycogen stores (Hajoglou et al., 2005) or increase thermoregulatory strain (Bishop, 2003).

Mohr et al (2004) investigated the changes in muscle temperature and subsequent effects on sprint performance during and after a soccer match. They reported that both muscle and core temperature decreased markedly during the half-time period when players recovered passively. Muscle temperature was lower at the start of the second half than before the start of the first half and a difference persisted for at least 5 min into the second half. The lower body temperatures prior to the start of the second half were associated with a significant impairment in sprint performance. In contrast to those who rested passively during half time period, a group that performed a period of re-warm-up at half-time maintained muscle temperature at the level obtained in the first half and sprint performance was not reduced. In addition, a correlation between a reduction in muscle temperature and change in sprint performance at half-time was found (Mohr et al., 2004). Together these findings show that sprint performance is related to muscle temperature and that it is possible that this impacts on performance at the start of the second half.

Depletion Fatigue

The final type of fatigue is experienced towards the end of the match when decreases in both physical and mental performance are frequently observed (Krustrup et al., 2006; Mohr et al., 2003). This fatigue may be caused by low muscle glycogen concentrations and/or dehydration. The energy depletion model of exercise performance holds that depletion of carbohydrate stores is a limiting factor in the ability to perform long term exercise. The findings that support this conclusion are (i) that fatigue during prolonged exercise is associated with depletion of liver (causing hypoglycaemia) or muscle glycogen stores, or both; (ii) that reversal of hypoglycaemia allows exercise to continue and (iii) that pre-exercise muscle glycogen supercompensation (carbohydrate-loading) or carbohydrate ingestion during exercise or both delays the onset of fatigue and improves exercise performance (Noakes, 2000).

Hornery et al (2005) sought to establish the extent of glycogen depletion in tennis and observed that muscle glycogen stores were almost depleted at half-time when the pre-match values were low (~200mmol kg dry weight). In that study, some players also started the match with normal muscle glycogen concentrations (~400mmol kg dry weight), with the values still being rather high at half-time but below 50mmol kg dry weight at the end of the match (Hornery, Farrow, Mujika, & Young, 2005). Others have reported that muscle glycogen stores are not always depleted in a soccer match but have suggested that a significant number of single muscle fibres, especially type II fibres, are depleted or partly depleted at the end of a match (Krustrup et al., 2006). Increased dietary carbohydrate intake in the days before competition increases muscle glycogen levels and enhances exercise performance in events lasting 90 min or more (Noakes, 2000). While the performance of a single high-intensity effort does not appear to be improved by carbohydrate loading, intermittent high-intensity performance may be enhanced (Hargreaves, Hawley, & Jeukendrup, 2004).

In soccer, carbohydrate ingestion has increased the amount of time spent at top velocities and improved the speed and agility and enhanced self-reported perceptions of fatigue during the second half of a match simulation protocol (Welsh, Davis, Burke, & Williams, 2002). Reilly et al (2001) studied the effect of ingesting a 5% glucose solution on Gaelic football players' work rates (using both 60 and 70 minute match durations). Players taking the energy drink had a higher frequency of discrete activities and walked for a shorter time during the match (35.4 vs 36.9% of total distance). A reduction in distance covered in the final 10 min was evident in both groups (Reilly & Keane, 2001). Rico-Sanz et al (1996) found a moderate correlation between the net muscle glycogen utilized and time to exhaustion during a soccer-specific test, thereby indicating a role for muscle glycogenolytic capacity in the onset of fatigue in soccer (Rico-Sanz et al., 1996). However the elevated values of glycerol, FFA and ammonia after exercise, also demonstrated the activation of other metabolic pathways for energy delivery (Rico-Sanz et al., 1996). Despite such findings the role of glycogen depletion and carbohydrate supplementation in hockey has not been studied. The relatively shorter duration of hockey matches theoretically allows players to sustain activity levels more easily (although the impact of multiple matches over a few days presents an additional challenge), but it is not clear whether carbohydrate supplementation is of benefit in this sport as it appears to be in soccer.

The effect of dehydration on prolonged, continuous moderate-intensity exercise has been investigated extensively. Without fluid replacement, there is a progressive decrease of systemic arterial, pulmonary arterial, right ventricular end-diastolic pressures and stroke volume, and a progressive increase in rectal temperature and HR (Coyle, 2004). In addition, dehydration equivalent to the loss of only 2% body mass is sufficient to impair endurance performance significantly in temperate environments (Coyle, 2004). The impact of dehydration on the intermittent high intensity exercise undertaken during participation in team sports has not been studied extensively. Hoffman et al (1995) examined the effects of dehydration on basketball performance and showed that fluid deficits of 2% of body mass had no significant effect on anaerobic power, vertical jumping height or goal-shooting ability of players during a simulated match of 40 minutes duration (Hoffman, Stavsky, & Folk, 1995). Conversely, measured performance of a soccer skill test under conditions where players could consume a carbohydrate drink before and during the activity and when they could not. Performance on the skill test decreased after 90 minutes of intermittent shuttle running when participants ingested no fluid as compared to when fluid was ingested and performance of the skill test was maintained. The ingestion of fluid throughout the protocol limited the increases in HR, ratings of perceived exertion, serum osmolality, sodium and cortisol concentrations as well as preventing the reduction in skill performance (McGregor, Nicholas, H.K.A., & Williams, 1999). The effects of dehydration on performance in team sports greater than 40 minutes and less than 90 minutes has not been reported and is clearly a worthy area of study.

Effect of Substitutions on Fatigue

The exchange of a fatigued player for a non fatigued player during a match may allow the overall intensity of play to be maintained. In hockey this is particularly significant as unlimited substitutions are allowed during the match. Although the use of substitutions may allow for traditional decreases in overall work-rate to be reduced or eliminated no research to date has examined such an interaction. Management of the substitution process also has the potential to impact on performances over a series of games as accumulated fatigue may be reduced through spreading the workloads evenly over an entire playing squad. Again, this interaction has not been investigated.

Summary

The intermittent high intensity demands of team sports potentially result in fatigue at three different stages of match-play. To date, most of the understanding of team sport fatigue has been drawn from research into soccer with only small contributions from other sports. Fatigue occurs randomly after intense periods of high intensity activity, (temporary fatigue); it has been shown to occur after the half time interval (temperature fatigue) and in the later stages of the match (depletion fatigue). Coaches have sought to minimise and prevent fatigue through the use of physical conditioning, nutritional and cooling strategies and through the use of substitutions. The use of multiple substitutions in sports such as basketball, hockey and rugby league is seen as a key method of maintaining physical work rate throughout a match. Surprisingly however, no research to date has investigated the effect of substitutions on the overall physical outputs of players.

CHAPTER 3: QUANTIFICATION OF THE PHYSICAL DEMANDS OF ELITE MEN'S HOCKEY

Recent rule modifications have significantly impacted on the nature of hockey. Firstly, the playing surface changed from grass to artificial turf in the 1970s which altered the pace and style of the game. Secondly, rule changes in the 1990's to allow unlimited substitutions and to remove the offside rule were initiated to promote fast-paced, continuous play. Despite a large number of team sport motion analysis studies being conducted on soccer (Bangsbo, Norregaard et al. 1991; Rienzi, Drust et al. 2000; Krustrup, Mohr et al. 2005; Di Salvo, Baron et al. 2007), rugby union (Deutsch et al., 2007; Duthie et al., 2003a, 2005), rugby league (Coutts et al., 2003; Kay & Gill, 2003) and Australian rules football (Dawson et al., 2004) there has been limited study of the physical demands of hockey since rule changes have been implemented, especially at the elite level.

A brief summary of studies from hockey is presented in table 5. Johnston et al (2004) studied elite male hockey players in the Scottish National League. Fifteen players were filmed, one player per match, for fifteen weeks providing fifteen sets of data. Players spent the majority of time stationary (4.0%) or engaged in low intensity activity (walking 50.9%, jogging 29.6%) with only a small portion of the match in high intensity activity (cruising 10.1%, sprinting 4.7%). Mean HR was 155 ± 12 and 64% of match time was spent above 75% of maximum HR. An average of 30 ± 6 sprints with an average sprint duration of 5.7 seconds were performed per match(Johnston et al., 2004). In elite players Spencer et al (2004) used a cinematographic observational method to describe the physical work rates of hockey players during an international test match. The mean match time of each player was 48 minutes.

Similar to the findings of Johnston et al (2004) low intensity activities of standing walking and jogging accounted for approximately 94% of match time (7.4% standing, 46.5% walking, 40.5% jogging). Mean sprint duration was 1.8 seconds with an average of 30 ± 12 sprints per player and the match consisted of 780 motions or a change in activity every 5.5 seconds (Spencer et al., 2004). Paun et al (2008) used SPi10 GPS units to measure the movement patterns and physiological demands of hockey match play in elite Australian domestic competition. Average time that each player spent on the pitch during each match was 64 minutes (the remaining time was spent resting on the sideline while substituted) and total distance covered by players during this time was 6419 ± 838m. Players spent 89% of match time engaged in low or moderate intensity activity (standing, walking and jogging) with the remaining 11% in high intensity activity. An average of 36 ± 9 sprints were performed per player per match with a mean duration and distance of 2.5 ± 1.7s and 12.4 ± 9.9m (Paun et al., 2008). Although these two recent studies have provided a basic understanding of the physical demands of men's elite hockey there are considerable methodological differences between them which makes comparison of data very difficult. There are also short-falls in both these studies most notably the small number of matches used by Spencer et al (2004) and the small number of players studied by Paun et al (2008). . Consequently there is a need to gain a large data set, covering all positions for a number of matches so as to adequately describe the demands of top level of competition. Therefore, the aim of this study was to measure physical outputs of hockey players during elite level competition and to determine the general and position specific physical demands placed upon players during match play.

Table 5: Recent time and motion data from elite men's hockey

Reference Details	Subject Group	Key Findings
(Johnston et al., 2004)	15 Scottish domestic players (19.5 ± 2.5 years) 1 national league match per player	Percent of time spent in locomotive states = standing 4.0%; walking 50.9%; jogging 29.6%; cruising 10.1%, sprinting 4.7% Mean HR during match = 143.4 ± 15.3, Peak HR during match = 183 ± 11bpm Mean sprints per player = 30 ± 6 with average duration of 5.7 seconds
(Spencer et al., 2005)	14 Australian International players (26.0 ± 3 years) 3 international match	Mean match time per player = 48 minutes Percent of time spent in locomotive states = standing 7.4%; walking 46.5%; jogging 40.5%; striding 4.1%, sprinting 1.5% Average number of motions (changes in mode) per match = 780 Sprints performed by position = strikers 39; inside forwards 41; fullback 18, half 22
(Paun et al., 2008)	6 Australian domestic players (26.2 ± 3.9 years) 4 national league matches per player	Mean match time per player = 64 minutes Mean total distance covered = 6419 ± 838m Mean number of changes in tempo per match = 901 ± 116 Mean number, distance and duration of sprints performed (above 17km.h-1) = 36 ± 9, 12.4 ± 9.9m, 2.5 ± 1.7s Mean HR during match play = 176 ± 13bpm, HR was above 85% HRpeak for 60% of the match

METHODS

Five hockey matches were used for data collection. The matches were between the New Zealand Men's National Squad and the Tasmanian State Representative Team (Australia). The matches were played on a water-based turf between the 18th and 25th of February 2006 in consistent weather conditions (18-22.5°, 70-79% rH). The game schedule was match, match, rest, match, rest, match, rest, match. Three types of information were collected and used to calculate the physical and technical demands of elite men's hockey; GPS data, HR data and video footage. Eighteen members of the New Zealand Men's National hockey squad were used during these five matches. Seven players were professional, based in Europe for 6-7 months of the year, with the remainder amateur and based in New Zealand. Typical weekly training load was 20-25 hours per week consisting of hockey and conditioning activities. Descriptive statistics from the participant group are presented below (please refer to Table 6) with details of fitness testing procedures provided in Appendix 1. This study was performed as the team was in preparation for the 2006 Commonwealth Games. Ethics approval from the AUT ethics committee was gained prior to commencement of the study and written informed consent was obtained from each participant prior to commencing data collection.

Pilot Data

Preliminary GPS and HR data was collected during intra-squad trial matches and international matches between May 2004 and November 2005. Analysis of this data provided guidance for the design of the project by identifying variables that were significant to performance and that were considered valuable by the coaching staff and players.

Study Data Collection

A data collection assistant was on the sideline of each match noting and detailing exact timings for the match including start and end of each half, timing and details of substitutions, position changes of players and stoppages. These timings were then used to edit the GPS and HR so that data was presented for 10 positions (goalkeeper excluded) rather than for each individual player. Positional data was made up of the 70 minute sum of all players who were in that position during the match and only time spent on the pitch was included in analysis (referred to as position70 throughout the remainder of this document).

Table 6: Anthropometric and physiological characteristics of participants

Variable	Average ± SD	Range
Age (years)	24 ± 4.58	17.1 - 33.2
Height (cm)	180.1 ± 4.9	172 - 191
Body Mass (kg)	78.4 ± 6.5	68.8 – 94.6
International Caps	59.2 ± 69.3	0 - 198
MSFT Score (lengths)	147.3 ± 7.2	135 - 164
Estimated VO_2Max ($ml.kg^{-1}min^{-1}$)	64.9 ± 1.9	61.7 - 69.5
Peak Aerobic Speed ($km.h^{-1}$) [1]	16.5 ± 0.7	15.5 – 18.1
Maximal Running Speed ($km.h^{-1}$)	31.6 ± 1.2	29.3 – 34.4
3RM Bench Press (kg)	84.3 ± 9.5	70 – 102.5
Sum of Eight Skinfolds (mm)	61.4 ± 13.5	31.3 - 84.9

Physical Outputs

A GPS recording device (SPI Elite, GPSports Systems Ltd, Australia) was used to record the position coordinates of the player at a frequency of 1Hz (1 sample per second) and derived speed and distance information from the changes in position coordinates. A single unit was worn by each out-field player during all matches. The small (91mm x 45mm x 21mm) and light (75g) device was worn on the upper back in a neoprene harness under the shirt (Figure 3). The neoprene harness was fitted and correctly sized for each player prior to the match so as to

[1] Peak aerobic speed was taken as final stage running speed during MSFT

cause minimal discomfort and distraction. Following the conclusion of the match the data was downloaded using the manufacturer-supplied software (GPSports Team AMS v1.2.1.0). Raw data was then exported into Microsoft Excel for analysis.

GPS Data Analysis

GPS data was edited to only include time spent on the field of play and then separated into six speed zones (refer to table 7) in accordance with criteria used previously.

Table 7:Speed zones used for analysis of GPS match data

Speed Zone	Speed Range	Category Label
1	0-6 $km.h^{-1}$	Low intensity
2	6.1-11 $km.h^{-1}$	
3	11.1-14 $km.h^{-1}$	Moderate intensity
4	14.1-19 $km.h^{-1}$	
5	19.1-23 $km.h^{-1}$	High intensity
6	>23 $km.h^{-1}$	

* Modified from Di Salvo et al 2007 and Barros et al 2007

Heart Rate

In all matches players wore a HR monitor chest strap (Team Polar, Polar Electro Oy, Kempele, Finland) which recorded HR every 5 seconds. Following the conclusion of the match the data was downloaded using manufacturer-supplied software (Polar Precision Performance v4.03.043) and processed. Using substitution timings the HR data was edited so that the analysis did not include half time data, injury breaks or time spent off the field of play. By referencing to HR_{max}, the match HR data was divided into four zones as described by Deutsch et al (1998) and Johnston et al (2004) Please refer to table 8. Mean and peak HR's were also calculated.

Table 8: HR zones used for analysis of match data

HR Zone	**Percent of HR_{max}**
Low-Moderate Intensity	<75%
High Intensity	75-84%
Very High Intensity	85-95%
Maximal Intensity	>95%

Reliability and Validity of the SPI Elite GPS Device

Prior to the commencement of data collection, a series of tests were performed to assess the reliability and validity of the GPSports SpiElite devices. Moderate to high levels of validity were found for speed and distance measurements and also for inter-unit reliability. A summary of findings is presented below in table 9 and a detailed description of procedures is presented in appendix 1.

Statistics

Multiple paired T-tests with unequal variances were used to compare between periods of play (halves) and positions. Two-tailed levels of significance were set at $p < 0.05$. Linear regression was used to assess trends over periods of the match and to assess changes over the five matches.

Table 9: Summary of GPS SpiElite Reliability and Validity

Measure	**Methods**	**Findings**
Validity of Distance	Measurement of distance over two courses was compared to that gained using a meter wheel. Distance was measured at four movement speeds.	Accuracy decreased as movement speed increased. TEMs were 1.7-2.5% (walking), 4.9-5.0% (jogging), 6.0-6.8% (running), 8.6-9.0% (sprinting)
Validity of Speed	Measurement of speed over distances of less than 50m was compared to that gained using video tracking.	Running speeds from GPS units were not significantly different to measurements taken from video
Inter-unit Reliability of Distance Measurement	Two units were worn by the same player during a hockey match	CV ranged from 0.6 to 4.1% for the six different speed zones with the fastest speed zones having highest CV
Inter-unit Reliability of Speed Measurement	Two units were worn during repeated sprint training session	High level of reliability between units for distance, speed and duration of sprints

RESULTS

To assess whether the hockey matches used for this study were representative of international competition, physical and technical outputs were compared to data gathered previously from international test matches. Average total striker outputs (3 x position70) was 25171 ± 234m vs 25119 ± 293m and average total distance covered at speeds greater than 19km.h^{-1} was 728 ± 98m vs 701m ± 87m for previous vs present study data respectively. (Refer to Appendix 3).

Physical Outputs

The mean match time for each individual player was 51.9 ± 17.8 minutes which represents 74% of total match duration. Fullbacks averaged the highest number of minutes per match (64.8 ± 16.0) while halves, inside forwards and strikers averaged a similar number of match minutes (54.8 ± 22.4, 49.0 ± 14.4 and 50.4 ± 15.4 respectively). Mean total distance covered per position70 was 8160 ± 428m. The mean total distance covered by each individual player was 6798 ± 2009m. The major proportion of this distance was covered at low and moderate intensities with only 4.5% and 1.6% of total distance being covered at high intensity (speeds faster than 19 and 23km.h^{-1} respectively)(table 10). Using the position70 data, the majority of match time was spent in low intensity (60.9%) and moderate intensity (33%) activities (Figure 8). The distances covered by each position progressively increased as the player moved up the field from defence to attack. Fullbacks covered significantly less total distance than all other positions and significantly less distance in zones 3, 4, 5 and 6 than all other positions (figure 5).

Table 10: Average distance covered and percent of total distance covered in each speed zone by position70 (data are mean ± SD)

	Speed Range	**Total distance (m)**	**Percent of total distance**
Zone 1	0-6km.h-1	2410 ± 95	29.6 ± 0.8
Zone 2	6.1-11km.h-1	2585 ± 258	31.3 ± 0.9
Zone 3	11.1-14km.h-1	1424 ± 124	17.6 ± 0.5
Zone 4	14.1-19km.h-1	1232 ± 263	15.4 ± 0.7
Zone 5	19.1-23km.h-1	355 ± 110	4.5 ± 0.3
Zone 6	>23km.h-1	124 ± 69	1.6 ± 0.2
Total		8130 ± 360	

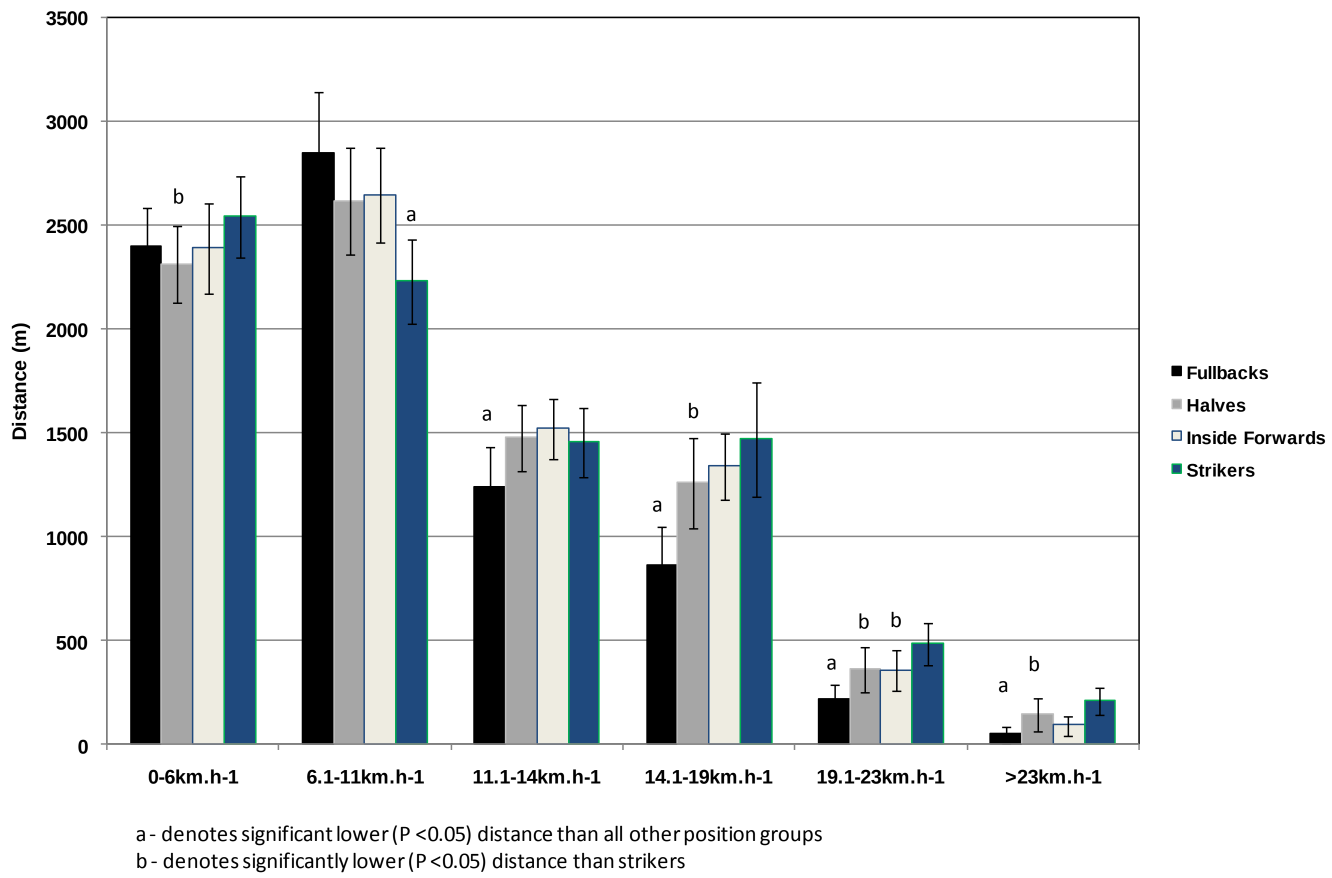
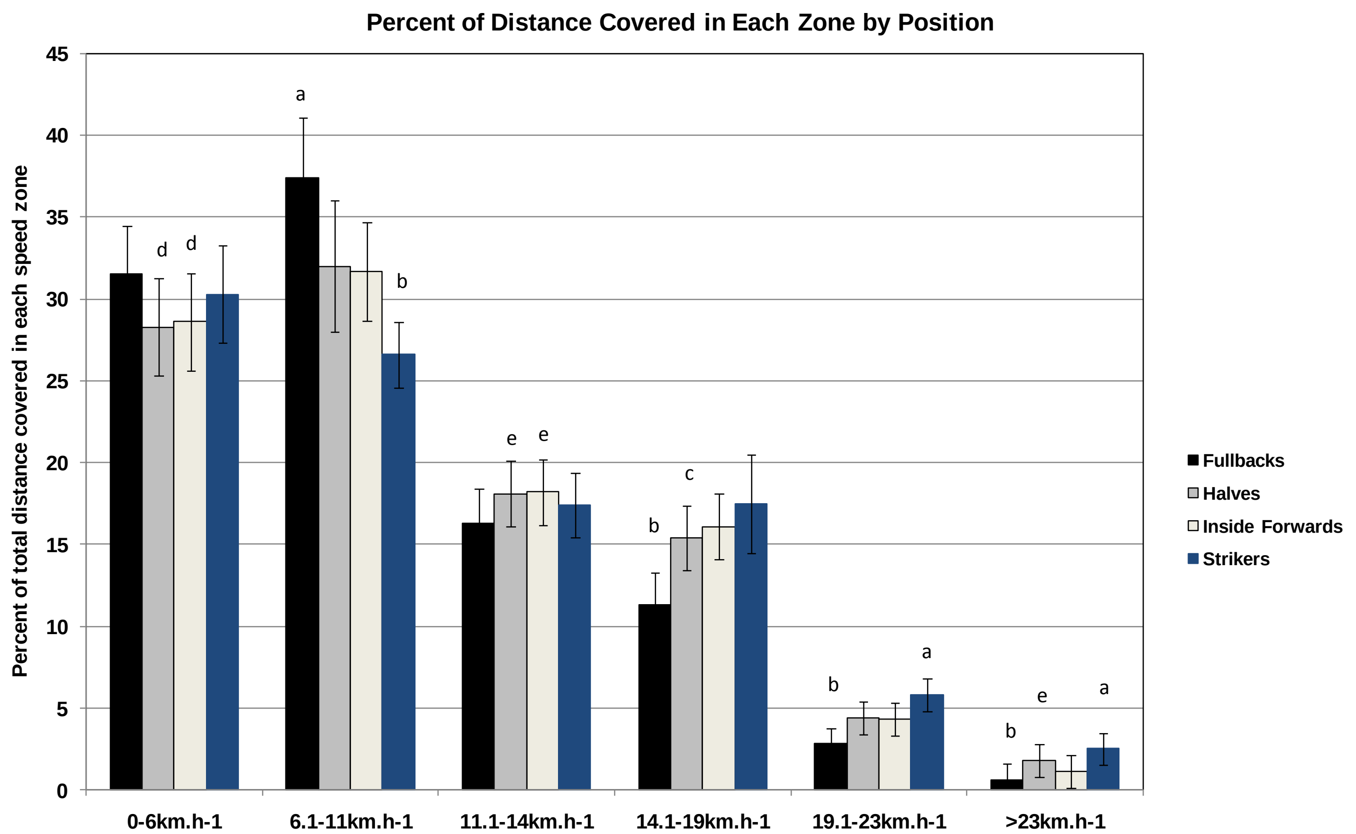
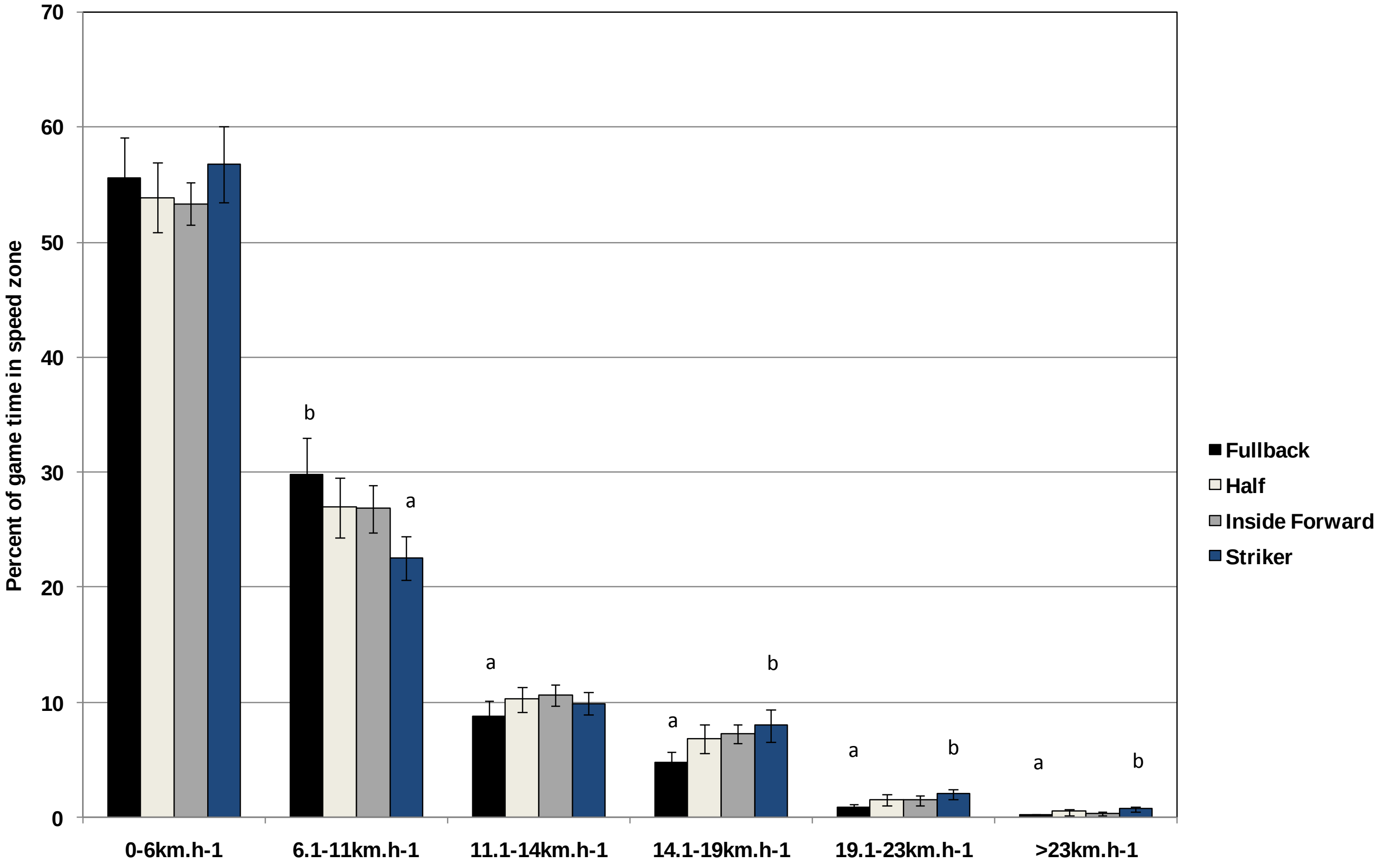


Figure 5: Distance covered during match-play for positional groups



a - denotes significant higher (P <0.05) percentage of distance than all other position groups
b - denotes significantly lower (P <0.05) percentage of distance than all other position groups
c - denotes significantly lower (P <0.05) percentage of distance than strikers
d - denotes significantly lower (P <0.05) percentage of distance than fullbacks
e - denotes significantly higher(P <0.05) percentage of distance than fullbacks

Figure 6: Percentage of total distance covered in speed zones for positional groups



a - denotes significant lower (P <0.05) proportion of time than all other position groups
b - denotes significantly higher (P <0.05) proportion of time than all other position groups

Figure 7: Percent of match time in each speed zone by position

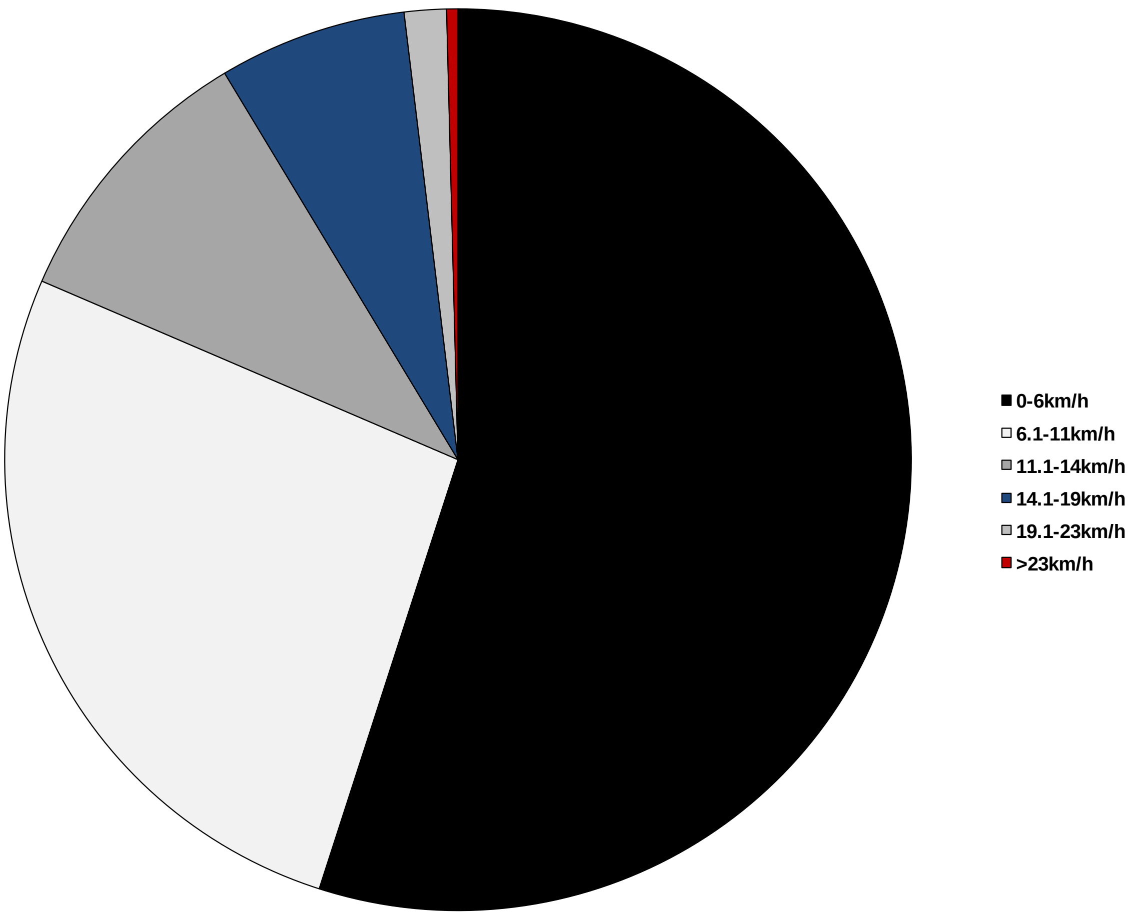


Figure 8: Average time spent in speed zones

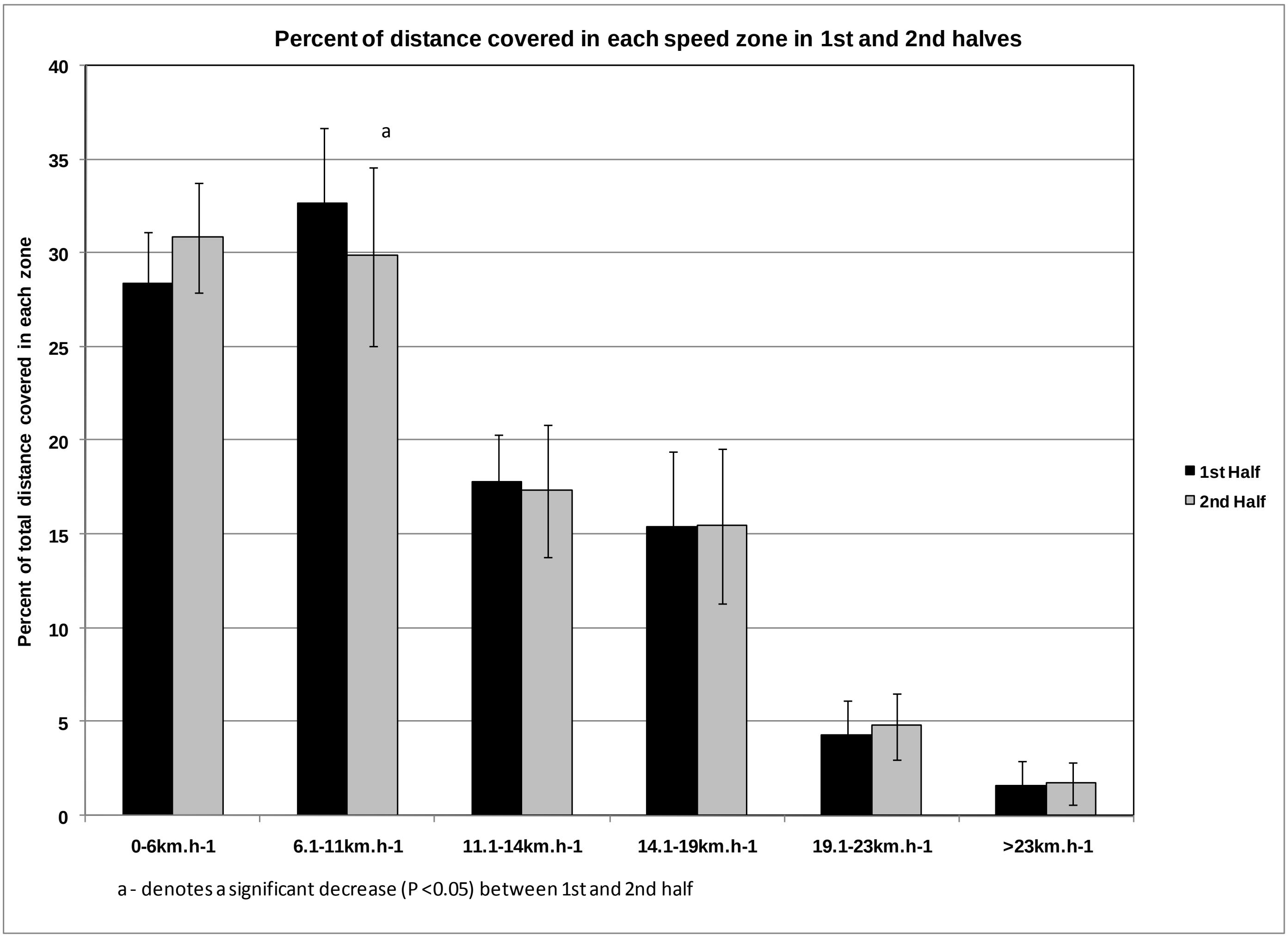


Figure 9: Percent of distance covered in each speed zone in 1st and 2nd half

Fullbacks also covered a significantly greater percentage of total distance at low intensities and a significantly smaller percentage of total distance at higher intensities (Figure 5). Halves covered significantly less zone 4, 5 and 6 distance than strikers and a significantly lower percentage of total distance in zones 4, 5 and 6 than strikers (Figure 6). Strikers covered a significantly smaller percentage of total distance in zone 2 and a significantly greater percentage of total distance in zones 5 and 6 as compared to all other positions.

Strikers spent a significantly greater amount of time in speed zones 4, 5 and 6 ($p < 0.05$) and a significantly smaller amount of time in zone 2 ($p < 0.05$) as compared to other positions. Fullbacks spent a significantly greater amount of time in zone 2 ($p < 0.05$) and significantly smaller amount of time in zones 3, 4, 5 and 6 ($p < 0.05$) as compared to all other positions (Figure 7).

Total distance covered substantially decreased by 6.2% ($p=0.06$) from the first half (4179 ± 254m) to the second half (3981 ± 301m) with an average of 51.2% of total distance being covered in the first half. There were statistically significant decreases in distance covered between the 1st and 2nd halves in zone 2 for all positions, and for the team as a whole, but all other zones showed non-significant changes (please refer to figure 9 and Table 12).

Table 11: Frequency and duration of motions

	Speed Range	Frequency	Duration (s)
Zone 1	0-6km.h-1	310.6 ± 54.1	7.4 ± 1.0
Zone 2	6.1-11km.h-1	445.0 ± 65.2	2.5 ± 0.7
Zone 3	11.1-14km.h-1	220.9 ± 33.1	1.9 ± 0.4
Zone 4	14.1-19km.h-1	126.9 ± 28.6	2.2 ± 0.6
Zone 5	19.1-23km.h-1	36.3 ± 15.2	1.7 ± 0.4
Zone 6	>23km.h-1	8.3 ± 5.4	2.0 ± 0.4
Total		1148.0 ± 128.9	

An average of 1148 ± 128.9 motion changes were recorded during the matches (please refer to table 11). The highest number of entries into speed zones occurred for zones 1 and 2 and the duration of motions in these two categories were also the highest. Excluding zone 1, all other motion durations averaged to approximately two seconds.

Table 12: Distances covered by team and position in 1st and 2nd half (1st half/2nd half)

	Speed Range	Fullback	Half	Inside Forward	Striker
Zone 1	0-6km.h-1	1187/1209	1120/1193*	1177/1213	1255/1286
Zone 2	6.1-11km.h-1	1503/1345*	1425/1192*	1384/1261*	1200/1030*
Zone 3	11.1-14km.h-1	658/584	770/706	784/737	742/717
Zone 4	14.1-19km.h-1	445/415	635/625	683/657	755/713
Zone 5	19.1-23km.h-1	101/113	163/199	173/186	248/236
Zone 6	>23km.h-1	19/29	57/88	46/47	120/89
Total		3914/3695*	4170/4003	4246/4101	4320/4071

* statistical significance at p>0.05

The distance covered during each five-minute period of the match is shown in figure 10 with the first and second halves being shown as separate series'. There was a general negative sloping trend indicating that distance covered decreased as the half progressed. The second half showed a greater decrement with a negative slope of -2.2% (R^2 = 0.63) compared to -1.6% (R^2 = 0.54) for the first half. The slopes of the individual speed zones were all small and negative (-0.2 to -6.3% of average distance covered in that zone) other than zone 1 during the first half (2.3%)(table 13).

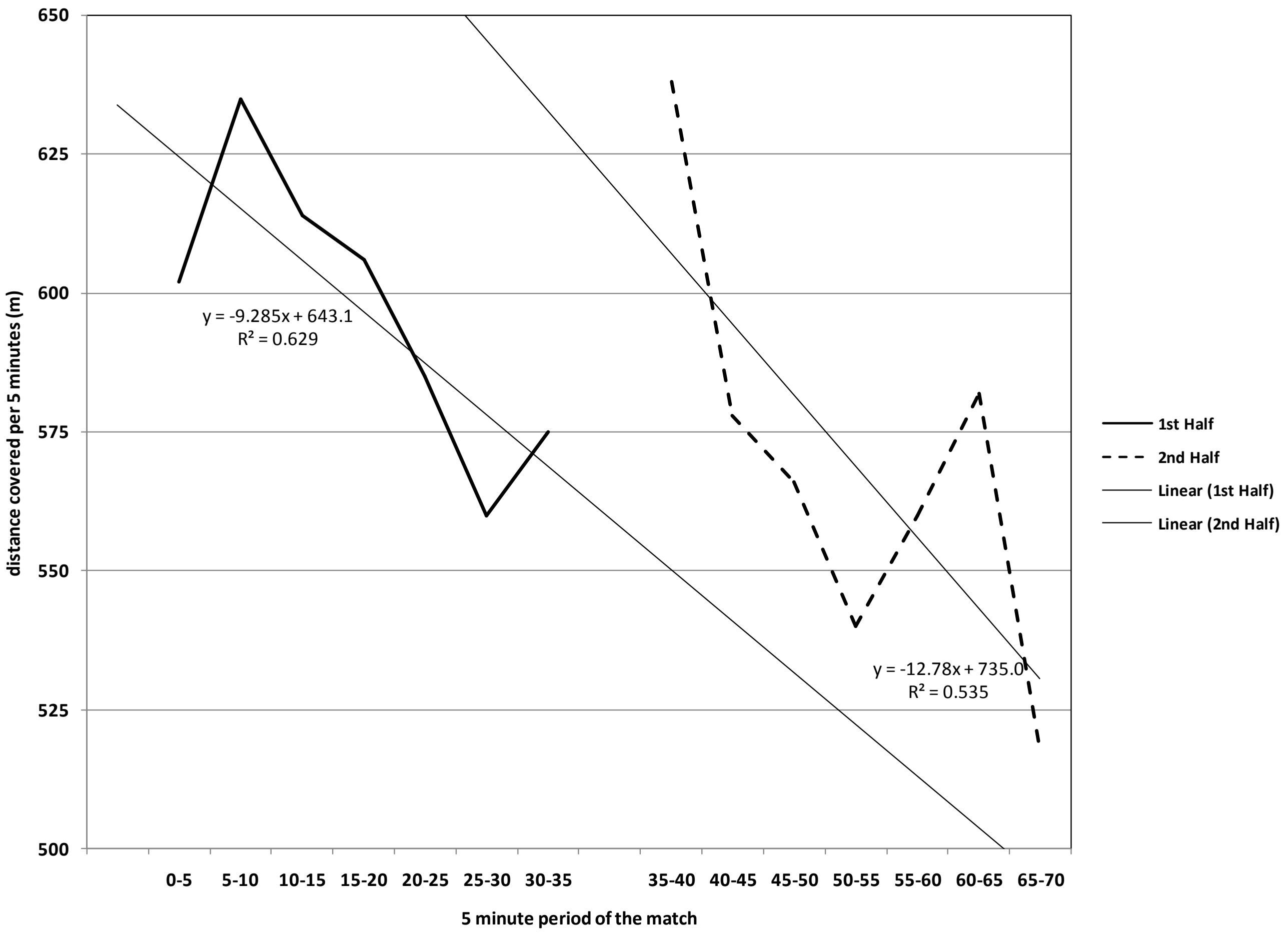


Figure 10: Trend of distance covered per 5 minutes of match time

Table 13: Trend lines for distance flow during each half

	Speed Range	1st Half Slope (R^2)	2nd Half Slope (R^2)
Zone 1	0-6km.h-1	2.3% (0.70)	-0.8% (0.04)
Zone 2	6.1-11km.h-1	-1.9% (0.35)	-6.3% (0.51)
Zone 3	11.1-14km.h-1	-3.9% (0.66)	-3.5% (0.51)
Zone 4	14.1-19km.h-1	-4.2% (0.85)	-1.7% (0.44)
Zone 5	19.1-23km.h-1	-0.9% (0.23)	-0.3% (0.02)
Zone 6	>23km.h-1	-0.5% (0.22)	-0.2% (0.05)
Total		-1.6% (0.13)	-2.2% (0.53)

Average speed during the match for all positions was 6.8km.h^{-1}. This represents 41% of peak aerobic speed and 21.5% of maximal running speed. Fullbacks had the lowest average speed (6.4km.h^{-1}) compared to other position groups. The other position groups were not significantly different to each other.

Players reached an average of 84.9% of their maximum speed during matches with strikers running both the fastest (mean 28.2km.h^{-1}, maximum 31.5km.h^{-1}) and the highest percentage of their maximum speed (89.2%). A sprint was recorded if a player exceeded 23km.h^{-1}. Using this criterion, the average sprint duration was 3.3 ± 1.9s and there were an average of 338 sprints performed per match. Strikers performed significantly more sprints (46.9, $p < 0.05$) than all other positions and fullbacks performed significantly less sprints (19.8, $p < 0.05$) than all other positions. Halves (33.0) and inside forwards (29.6) were not different to each other. Approximately 75% of sprints were of short (1-2s) or of medium (3-4s) duration (please refer to figure 11) with the longest single sprint being 11 seconds.

The average rest duration between high intensity efforts are shown in table 14 using two high intensity thresholds, 14 km.h^{-1} and 19km.h^{-1}.

Table 14: Frequency and rest duration of high intensity efforts

	Number of HI efforts per position 70 per match	Average rest duration betweens HI efforts
Threshold 14km.h^{-1}	114 ± 25	36 ± 10s
Threshold 19km.h^{-1}	37 ± 16	113 ± 51s

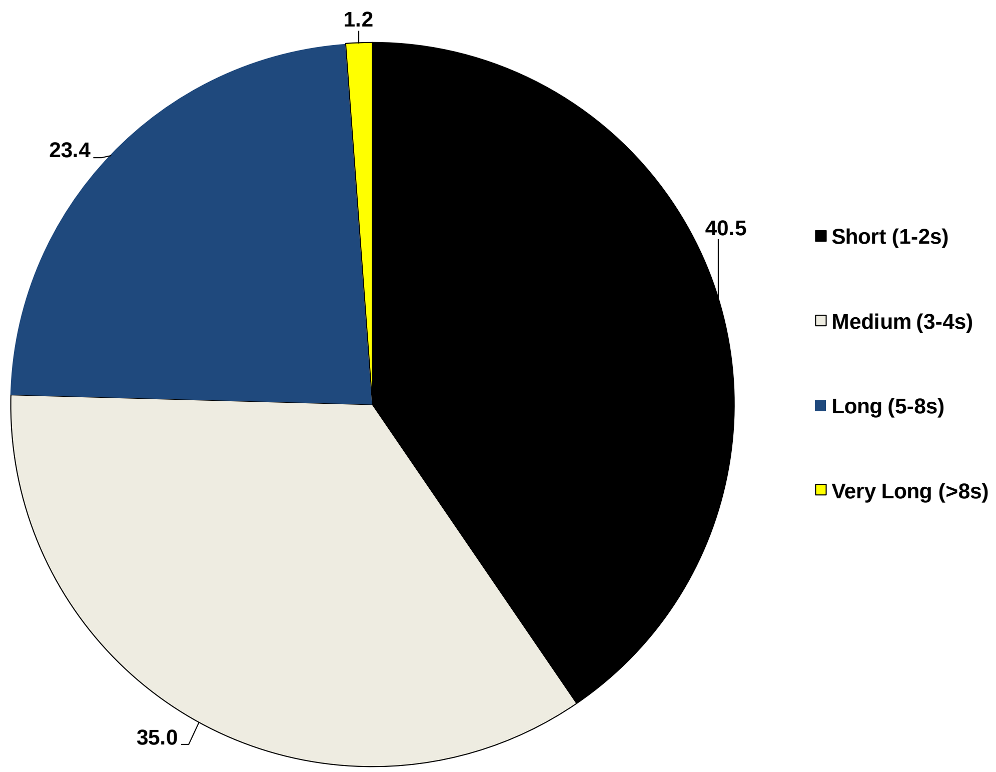


Figure 11: Distribution of sprint duration

Heart Rate

Mean HR during match play was 161b.min^{-1} which equated to 85.3 ± 2.9% HR_{max}. An example of an individual HR response to match play is shown in figure 12. Peak HR reached during the matches was 196 b.min^{-1} or 96.3 ± 2.7% HR_{max}. In only two instances did a players HR equal or exceed (in both cases by 1b.min^{-1}) that recorded during the MSFT. Mean HR decreased from 86.7% HR_{max} to 84.4% HR_{max} between the 1st and 2nd halves, a difference that almost reached statistical significance ($p=0.053$). Inside forwards had significantly lower mean HRs in the second half as compared to the 1st half but there were no other positional groups that showed any such significant differences. Players spent 90% of the match above 75% HR_{max}, 60% of the match above 85% HR_{max} and 4% of the match above 95% HR_{max} (Figure 13). Strikers had a significantly lower mean HR than inside forwards ($p<0.05$), spent a greater percentage of match time above 95% HR_{max} than fullbacks ($p<0.05$) and a greater percentage of match time below 75% of HR_{max} than inside forwards ($p<0.05$). Strikers also spent a greater amount of time above 95% HR_{max} as compared to halves, a difference that approached statistical significance ($p=0.06$).

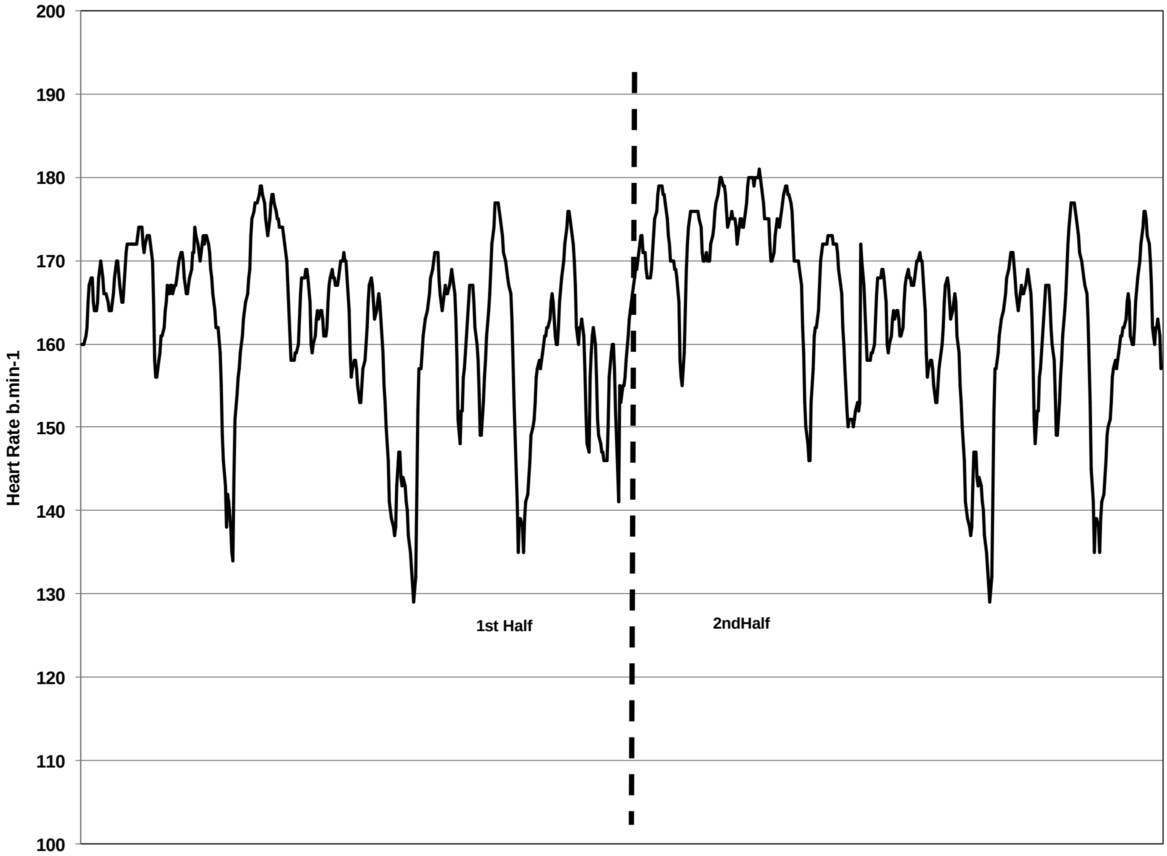


Figure 12: A typical players HR response to match-play

Table 15: Summary of HR variables during matchplay

	Average	Fullback	Half	Inside	Striker
Overall Mean HR (%HR_{max})	85.3 ± 2.9	84.4 ± 2.5	84.8 ± 2.8	86.5 ± 2.6	85.6 ± 3.7
Average Peak HR (%HR_{max})	95.9 ± 2.8	95.1 ± 2.2	95.3 ± 2.5	96.7 ± 2.9	96.8 ± 2.6
Percent of match at <75% HR_{max}	9.9 ± 5.7	10.6 ± 3.6	8.1 ± 5.8	8.0 ± 3.3	11.8 ± 7.3
Percent of match at 75-84% HR_{max}	29.3 ± 12.2	30.0 ± 9.5	28.7 ± 12.5	29.8 ± 9.7	27.3 ± 14.6
Percent of match at 85-95% HR_{max}	56.4 ± 13.0	58.3 ± 11.0	61.1 ± 15.2	57.2 ± 9.8	53.1 ± 13.9
Percent of match at >95% HR_{max}	4.3 ± 6.6	1.0 ± 1.8	2.1 ± 3.7	5.1 ± 5.9	7.8 ± 9.0

Note: HRmax was determined a-priori during a multistage fitness test (MSFT)

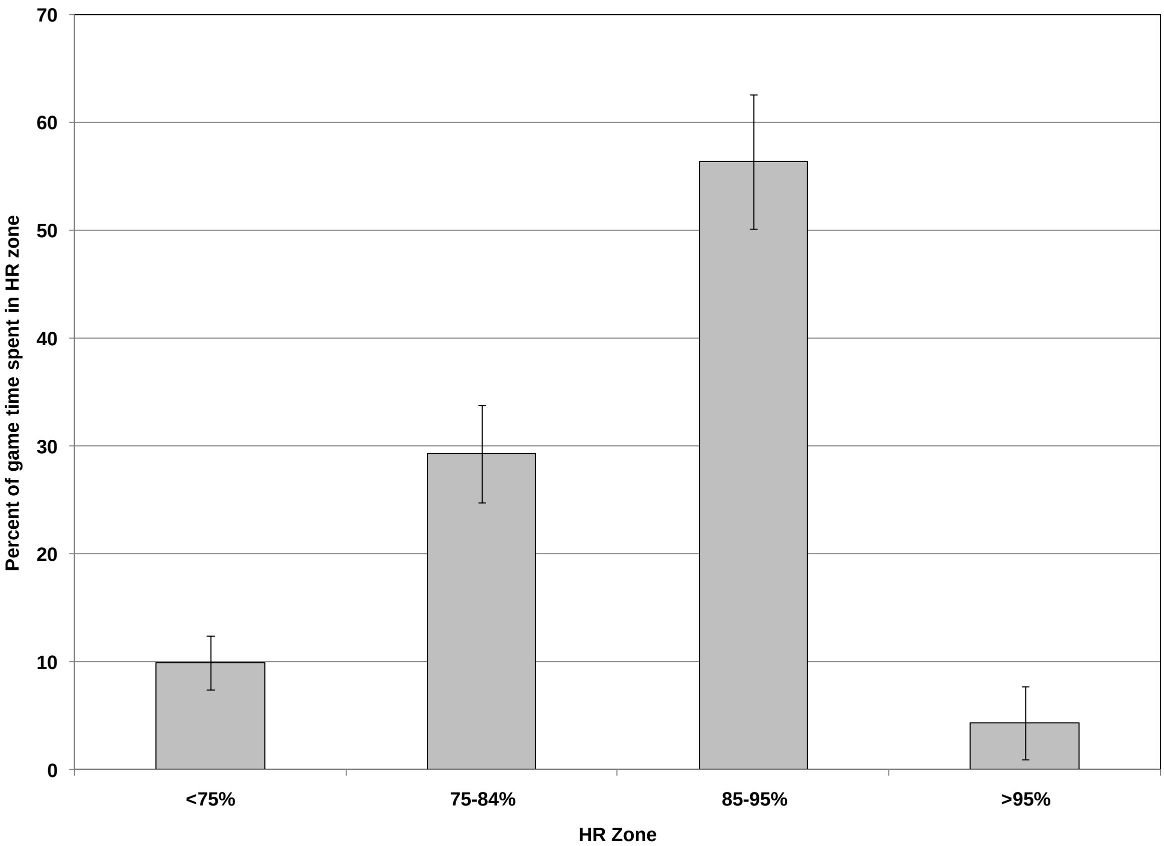


Figure 13: Percent of match time spent in HR zones

DISCUSSION

Limited time-motion information for elite men's hockey has been published since significant changes to the game were made. In the present study, five matches were played against the same opposition over eight days and a range of physical variables were monitored to describe the physical demands of match play.

Physical Characteristics

The athletes in this study were heavier, taller and leaner than hockey players reported in previous studies (Boyle et al., 1994; Ghosh et al., 1991; Johnston et al., 2004; Paun et al., 2008; Spencer et al., 2004). They also had higher aerobic capacity than those reported previously (64.9 $ml.kg.min^{-1}$ vs 57.9 $ml.kg.min^{-1}$ and 53.7 $ml.kg.min^{-1}$) (table 4) although this may be partly due to the methods used to estimate VO_2,max (in this study MSFT). Such differences in physical characteristics likely reflect an increase in athleticism that has occurred over the last 10-20 years in international hockey; a trend that has also been reported in soccer (Williams, Lee, & Reilly, 1999) rugby union (Quarrie & Hopkins, 2007), basketball (Abdelkrim et al., 2007) and Australian rules football (Buttifant, 1999; Dawson et al., 2004; K. I. Norton, Craig, & Olds, 1999).

Physical Outputs

In the present study, SpiElite GPS units were used to measure physical outputs of players during match-play. In pre-study assessments, these devices showed moderate to strong validity and reliability (Appendix 2). This agreed with previously reported data pertaining to similar GPS devices (Edgecomb & Norton, 2006; E. M. Hennig & Sterzing, 1999; Larsson, 2003; Larsson & Henriksson-Larsen, 2001; Terrier, Ladetto, Merminod, & Schutz, 2000).

Distances and Durations of Activity

In the present study the average distance covered per position70 was 8160 ± 428m and per player 6798 ± 2009m. This is higher than previous studies that reported total distances. Wein et al (1981) found an average match distance of 5610m during matches at the 1972 World Cup (Wein, 1981). These relatively low distances as compared to the present study are likely to reflect a combination of variables, primarily that the data was collected before the changes to the playing surface and rules came into effect. Also, given that the methodological details were not provided it is unclear whether the reported average distance included data from players who were on the field for less than 70 minutes. Maximum distance covered by a player was 8820m which is very similar to the highest position70 total reported in the present study (8958m). This suggests that the surface and rule changes were not completely responsible for differences in physical work rate of players between the former and modern era.

The only other hockey study to report distances covered was that of Paun et al (2008) who used GPS devices to measure movement characteristics of players from the Australian domestic competition. Average distance covered was 6419m during an average match time of 64 minutes per player. Some of the variation in distance to the present study may be explained by differences in methodology as they did not combine player data to make a position70 sum. When comparing by player only, the data from the present study (6798 in 51.9 minutes) is still significantly higher. However, despite this it would have been expected that given both this study and the present study used GPS and were performed using male elite players that the total distances reported would be more similar. Although no other published data is available for further comparison of total distance covered the present data does compare well to unpublished data collected from a range of domestic elite and international male New Zealand players between 2004 and 2006 (n=67, average total distance = 8250 ± 714m) (Lythe, 2006). This suggests that data from the present study is indeed reflective of international match play.

Rampanini et al (2007) reported that distances covered in professional soccer were greater at the end of a season as compared to the start of the season and that high match distances could be considered characteristic of a team in peak condition (Rampinini et al., 2007). Indeed, the subjects for the present study were in the final stages of preparation for a major tournament and as a consequence had be training consistently and playing regular matches for a number of months.

Distance covered consisted of 60.9% low speed running (zones 1 and 2; 0-11km.h^{-1}), 33% moderate speed running (zones 3 and 4; 11.1-19km.h^{-1}) and 6.1% high speed running (zones 5 and 6; >19km.h^{-1}). Although caution is necessary in comparing this data with reported results from literature (different technologies and categorizations were employed) Spencer et al (2004) (95%), Paun et al (2008) (89%) and Johnston et al (2004) (85%) reported a similarly high proportion of low intensity activity. This supports the notion that hockey, like many team sports is essentially a low intensity activity interspersed with bursts of high intensity (Edwards, McFadyen, & Clark, 2003). The average distance covered per minute was 116.6m which is similar to 117.3m in Futsal (Barbero-Alvarez & Castagna, 2006) and the 126.5m in professional soccer (Di Salvo et al., 2007). In the present study, average total and zonal distances compare well to those of professional soccer players (Di Salvo et al., 2007). If using raw data from Paun et al (2008) the distance covered per minute was 100.3m. Interestingly, if the soccer data was scaled to a 70 minute match duration soccer players cover greater total distance, but similar percentages of total distance in the speed zones. One noteworthy difference was that soccer players covered greater total distances in the fastest two speed zones (Table 16).

Table 16: Distance and zonal comparison between elite men's hockey and professional soccer

	Velocity Range	Hockey	Soccer*
Zones 1 and 2	0-11km.h-1	4995m (61.4%)	5469m (61.7%)
Zone 3	11.1-14km.h-1	1424m (17.5%)	1286m (14.5%)
Zone 4	14.1-19km.h-1	1232m (15.2%)	1368m (15.4%)
Zone 5	19.1-23km.h-1	355m (4.4%)	471m (5.3%)
Zone 6	>23km.h-1	124m (1.5%)	262m (3.0%)
Total		8130m	8861m

* Data converted to 70 minutes using information from Di Salvo (Di Salvo et al., 2007)

A possible reason that may contribute to the lower distances covered at high intensity during hockey as compared to soccer is the smaller pitch dimensions used in hockey (5000m^2 compared to ~7000m^2)[2]. Players have less opportunity to perform long bursts of high intensity running and consequently have less time to reach the fast speeds needed to record distance in the fastest two zones. Additionally, hockey players have a much more limited scope to play with the ball aerially as compared to soccer players. This restriction reduces the opportunity for long defensive clearances and rapid counter-attacks. When normalised to 70

[2] Note that soccer does not have fixed pitch dimensions. Length must be between 90m and 120m and width between 45m and 90m (www.thefa.com)

minutes, the comparison between soccer and hockey is moderately strong. Aside from the high intensity running (distances above 19km.h^{-1}) the comparison demonstrates that they are similar in the basic physical demands that they place upon players during competition and consequently their conditioning requirements.

In terms of high intensity running, players spent just 1.9% of total match time and 6.1% of total match distance at intensities greater than 19km.h^{-1}. However, there was an average of 37 high intensity efforts (where movement speed exceeded 19km.h^{-1}) performed with 125s between each effort. If recalculating these efforts using a slightly lower speed threshold of 14km.h^{-1}, the average number of efforts increased to 114 with just 36s rest between reps.[3] The frequency distribution of recovery time between sprints showed that 16% of the time, the recovery was less than 20s, 13% of the time the recovery was between 20 and 40s, 16% of the time recovery was between 40 and 60s and 55% of the time the recovery was greater than 60s. Only one other hockey study has used a fixed speed to identify high intensity efforts (Paun et al., 2008). Using 17km.h-1, Paun et al (2008) reported 40 efforts per match with a mean duration of 2.5s (Paun et al., 2008). Spencer et al (2004), who used an observational method to identify high intensity efforts during an international test match, reported 30 efforts per match with an average duration of 1.8s (Spencer et al., 2004). In further support of the current findings, Spencer et al (2004) found a remarkably similar distribution of recovery times with 24% less than

[3] To recalculate work and rest periods using a lower speed threshold of 14 km.h^{-1} simply provides an indication of the frequency and duration of efforts and illustrates how rapidly players must perform moderate or high intensity efforts. Given that some of these efforts may have involved changes of direction, player interaction and or technical actions such as a dribble or pass it is fair to investigate such efforts with a lower threshold to comment on the differences.

20s, 14% between 20 and 40s, 10% between 40 and 60s and 53% greater than 60s (Spencer et al., 2004). Such similarities probably reflect the comparability between subjects playing level. The slightly longer recovery between efforts reported by Paun et al (2008) is likely a consequence of the lower level of hockey where a lower level of athlete and a slower match pace is often observed.

Although very large proportions of the match time and distance were spent at low intensities it is clear that masked beneath this “low intensity” label are backward, sideways and diagonal movements, hitting, dribbling, tackling, shooting as well as rapid changes in speed and direction. Table 11 shows that the average number of times that a change in speed or tempo occurs for a position70. This translates to 1148 or an acceleration or deceleration every 3.65s (and does not include changes of direction). This number of tempo changes is higher than the 901 and 764 reported previously by Paun et al (2008) and Spencer (2004) respectively but some of this difference may be due to the fact that both studies used five speed zones as compared to the six used in the present study. [Six speed zones were chosen for this study in an effort to get a more accurate description of high intensity running]. A tempo change every 3.65s is similar to that reported by Reinzi et al (2000) and Strudwick et al (2002) in professional soccer (Rienzi et al., 2000; Strudwick, Reilly, & Doran, 2002). Such a high frequency of tempo changes suggests that caution needs to be exercised if simply using distances covered to assess the physical demands of elite hockey as considerable amounts of additional energy are utilized during accelerating and decelerating movements and when running backwards and laterally (Bloomfield et al., 2004; Williford et al., 1998).

In hockey an additional consideration when estimating the physical demands is posture. Players spend time in an ergonomically unsound, semi-crouched position while carrying or contesting for the ball, a position that likely increases the energy cost of match play. Reilly and Seaton (1990) reported that the additional effort required to dribble a hockey ball amounted to an increase in energy expenditure equivalent to approximately 15% of VO_2max and an elevated HR of 25 b.min^{-1} (Reilly & Seaton, 1990). However, the total amount of this activity may be too short to justify being treated separately as studies in soccer have shown that a player is in contact with the ball for less than 3 minutes and as a consequence the effect on overall physical output would be small (Ali & Farrally, 1991b; Di Salvo et al., 2007). There is no similar data for hockey to allow for estimation of time spent in possession of the ball and its associated increases in energy expenditure.

Effect of Multiple Matches

It is possible that the physical outputs of players during the later matches e.g. matches 3, 4 and 5 would have been affected by fatigue as a result of the busy schedule (five matches played in eight days). Rest periods between matches were 24, 76, 24 and 44 hours (with an average of 44 hours) and the match schedule was deliberately selected to simulate tournament play. Spencer et al (2002) provided time motion analysis data for three international matches played in five days by the Australian men's hockey team (Spencer et al., 2002). The percent of total match time spent standing significantly increased across all matches, the percent of time jogging significantly decreased (between matches 1 and 2 and between matches 1 and 3) and the number of repeated sprint bouts also decreased significantly across the three matches. The authors speculated that the decay in physical outputs may have been caused by residual fatigue. Odetoyinbo et al (2007) performed a similar analysis on professional soccer players using the combined results of 22 teams who had played three matches in five days during an English premiership season. They reported that players were able to maintain the total distance covered in each match but that average recovery times between high intensity efforts had increased by the third match (Odetoyinbo et al., 2007).

To determine if there was a fatigue effect a trend analysis was applied to the present data. Total distance (slope = 0.2%, R^2 = 0.08), zone 3 distance (1.4%, R^2 = 0.49), zone 4 distance (2.4%, R^2 = 0.63), zone 5 distance (0.2%, R^2 = 0.002) and zone 6 distance (1.9%, R^2 = 0.07) had small and positive slopes while zone 1 (-0.3%, R^2 = 0.04) and zone 2 distance (-1.3%, R^2 = 0.57), had small negative slopes. These trend lines suggest that unlike the findings of Spencer et al (2004) and Odetoyinbo et al (2007) there was minimal evidence of a residual fatigue effect. As these matches were an immediate precursor to a significant tournament there was heavy use of modalities to improve recovery which may have resulted in less fatigue than previous studies. Following each match a thorough on-pitch cool-down was performed by all players. In keeping with research informed practice, food and fluid were consumed in the dressing room immediately post-match and ice-water contrast baths were used (Barnett, 2006; Wilcock, Cronin, & Hing, 2006). The players were accommodated in a hotel during the matches meaning daily nutritional intakes were tightly controlled and active hydrotherapy recovery sessions were performed the morning after each game. It is possible that as a consequence of all these measures plus the peak physical condition of the players that the accumulated fatigue between the first and final match was reduced. Various methods to identify accumulated fatigue (daily subjective fatigue, soreness and mood ratings, daily bodyweight measurements) that were performed as part of the teams normal operations did not suggest that players were significantly fatigued (data not presented).

Positional Comparisons

Whilst average team statistics provide a general indication of the physical demands of hockey it is necessary to focus on positional demands if specific tactical and conditioning strategies are to be developed. In the present study, fullbacks were the most unique of the positional groups. They had the lowest average speed, covered the least total distance, a greater proportion of distance at low intensity and less distance at moderate and high intensities. However fullbacks played the highest amount of minutes per match (64.8 ± 16) which was significantly more than inside forwards (49.0 ± 14.4, p=0.01) and strikers (50.4 ± 15.4, p=0.02). The physical demands of all other positional groups were similar to each other.

The key role of the fullback is to organise, control and manage space in the defensive half of the field (Anders & Myers, 1999). This requires them to be well positioned at all times to limit the opportunities for opposing strikers to receive a pass, and to be ready to interject into the match when needed, for example to make a tackle or interception. If a team is on attack then it would be typical for its fullbacks to remain relatively deep to their own goal to provide security and simply occupy an appropriate space on the field. Consequently, the large amount of low intensity running (6.1-11km.h^{-1}) is a specific positional feature that supports their function and should not be viewed as a negative performance indicator. The physical outputs from different positions are supported by those of Spencer et al (2004) who found that fullbacks spent a high proportion of time in low intensity speed zones and performed a relatively low amount of high intensity sprints as compared to other the positions (Spencer et al., 2004). Unfortunately, other published studies involving hockey did not separate fullbacks from other defenders so it is not possible to compare data.

Inside forwards and halves produced similar outputs with the only significant difference being in Zone 6 where halves covered a significantly greater proportion of total distance than inside forwards (2.4% v 1.6%, $p<0.05$). Given that the team played a 2-3-2-3 (two fullbacks, three halves, two inside forwards, three strikers) formation during all of these five matches (as compared to a 4-4-2 formation favoured by some teams) it is not surprising that the physical outputs of halves and inside forwards are relatively similar as the roles they play are very similar. Strikers covered a significantly smaller proportion of total distance in zone 2 and a significantly greater proportion of total distance in zones 5 and 6 as compared to all other positions. A primary role of strikers is to create opportunities to score goals through "leading" (making oneself available for a pass from a team member). When done at speed this action also creates problems for opposition defenders. This leading explains the relatively large amount of high speed running demonstrated in both the present study and those reported previously (Johnston et al., 2004; Spencer et al., 2004).

The Effect of Intra-Match Fatigue

Although the absolute difference was relatively small, there was a statistically significant decrease in total distance covered between the first and second halves suggesting the presence of fatigue. Distance covered in Zone 2 also showed statistically significant decreases for all individual position groups and for the team as a whole. Such a reduction in distance between the first and second halves is a commonly reported finding in time and motion analysis studies especially those conducted in soccer (Bangsbo et al., 1991; Mohr et al., 2003; Reilly & Thomas, 1976; Weston, Castagna, Impellizzeri, Rampinini, & Abt, 2007) and Australian rules football (Dawson et al., 2004; K. Norton, Schwerdt, & Craig, 2001). Although the same decreasing trend has not been demonstrated in other studies involving elite men's hockey Spencer et al (2004) did report that average team motion decreased in intensity after the first 5 min of each half of the match. Additionally, they reported that percent time spent jogging for most 5 min periods in the first half and all periods of the second half was significantly less when compared with the first 5 min period in the first and second half, respectively suggesting a slowing of the pace of the match as each half progressed.

In the present study an average of 51.2% of total match distance was covered in the 1^{st} half which suggests a slight decrease in intensity in the 2^{nd} half. However the values for distance covered in the 1^{st} half of each individual game were 50.9%, 49.9%, 53.7%, 49.7%, and 51.9% which may suggest that the distance covered in the 1^{st} half will always be within a small enough variation from 50% to consider the difference between halves negligible. When applying a trend analysis to the distance covered in each 5-minute period of the game (each half was assessed independently) there was a downward sloping trend for total distance covered in both the 1st (slope = -1.6%, R^2 = 0.63) and the 2^{nd} halves (slope = -2.2%, R^2 = 0.54)(figure 10). This slightly downward trend was also found if each speed zone was considered separately. Other than for zone 1 in the 1^{st} half (which showed a 4% positive slope), all speed zones showed small downward sloping trends as the half progressed (slopes between -0.8 and -6.3%, mean slope -1.8%). Of primary significance is that distances covered at high intensity did not decrease as the halves progressed. This finding agrees with the findings of Spencer et al (2004) who found no significant decrease in the amount of striding and sprinting that occurred in each 5-minute period of the 1^{st} and 2^{nd} halves. This is an important issue as many authors suggest that it is high intensity running that is much more important as an indicator of physical outputs during a match than total distance (Rampanini et al., 2008, Dawson et al., 2004, Bangsbo et al., 1992) and it is during high intensity activity that many of the significant events of the match occur.

In elite soccer, player fatigue is considered the most likely reason for the observed 5-10% reductions in physical work rate towards the end of a match (Bangsbo 1992, Mohr 2003). In hockey however, with smaller pitch dimensions, a shorter match duration and unlimited substitutions, the reasons for any reductions in work rate may not be fatigue related. Temporary fatigue is undoubtedly present in hockey and occurs as a consequence of brief periods of high intensity activity with incomplete recovery periods but such fatigue has not been shown to result in a trend of decreasing work rate as a match progresses as the high intensity efforts tend to be randomly dispersed throughout the match.

Although the effect of a decrease in body temperature on performance at the start of the second half has been studied in soccer, the effect of temperature fatigue on hockey has not been investigated. In the present study, the 5-minute period at the start of the second half had the highest total distance output of any 5-minute period and the second highest 5-minute output for distance covered at speeds greater than $19km.h^{-1}$. This suggests that this type of fatigue may not be present for elite men's hockey which could be due to the shorter break between halves (10 minutes) and/or the warm conditions.

Depletion fatigue is caused by low glycogen concentrations and/or dehydration. For these matches players warmed up for 45 minutes (covering approximately 2.5km) and then played an average of 52 minutes of match time. During substitution periods and at half-time, players were able to rehydrate and refuel *ad-libitum* with a carbohydrate solution and other carbohydrate rich food. As described earlier in this document, the participants for this study were highly trained athletes and experienced with the rigours of elite level competition. They were well educated with regard to appropriate nutrition and hydration practices and were provided with food and fluid throughout the duration of the matches. As a result of this it would be expected that the demands of each match would be within their capabilities and as a consequence there would be minimal depletion fatigue. It is therefore considered most likely that the small decrease in overall distance covered between the 1^{st} half and the 2^{nd} half and the downward trend in total distance covered and zone 2, 3 and 4 distance covered were related to factors other than fatigue. For example, the perceived importance of the match and the current match score have been discussed by a number of authors to be responsible for much of the decrease in outputs towards the end of matches (Bloomfield, Polman, & O'Donoghue, 2005; Lago & Martin, 2007). For example, Lago et al (2007) and Bloomfield et al (2005) demonstrated that when a team is losing it tends to have a greater amount of possession (as it seeks to score and get back into the match). Similarly, Mohr suggested that games where the outcome had already been decided would have reduced outputs from both teams as compared to games where the teams were separated by just one goal (Mohr et al., 2003).

Heart Rate

Despite the intermittent nature of team sports, the HR response during match play provides a valid and useful global measure of physiological strain (Esposito et al., 2004). Mean and peak HR's during the present study suggest a very high level of physical exertion during field hockey. The overall mean HR of 161.2 ± 15.7b.min^{-1}

(85.3 ± 2.9% HR_{max}) is similar to the 156 ± 8 $b.min^{-1}$ (Boyle et al., 1994), 155 ± 12 $b.min^{-1}$ (Johnston et al., 2004) and 176 ± 13 $b.min^{-1}$ (Paun et al., 2008) reported by others for elite men's hockey. Unfortunately $\%HR_{max}$ was not reported in any of these studies so a comparison of relative exertion cannot be made. The observed HR values are similar to those reported by Krustup (87%HR_{max}, soccer), Florida-James (81%HR_{max}, Gaelic Football), McInnes (89%HR_{max}, basketball), Abdelkrim (91%HR_{max}, basketball) and Barbero-Alvarez (90%HR_{max}, futsal) during other intermittent team sports.

The mean peak HR during matches was 96.3 ± 2.7% HR_{max} (182.7 ± 7.3 bpm). These absolute numbers are lower than that reported by Paun et al (2008) who reported peak HR's of 193-206 $b.min^{-1}$ (Paun et al., 2008). The reason for such a difference is unclear although individual variation in genetic maximum HRs are likely to account for much of the difference as other measures of HR load were very similar between the studies. For example both found that approximately 60% of match time was spent above 85% of HR_{max}.

Maximum HR during match play was generally not observed to be higher than that recorded during the maximal fitness test conducted immediately prior to the series of games. This is in disagreement with both Deutsch et al (1998) and Paun et al (2008). Deutsch et al (1998) reported that the highest HR achieved during elite under-19 rugby match-play was 1 ± 2% above maximal treadmill determined HRs for all subjects (Deutsch et al., 1998). Similarly, Paun et al (2008) found that peak HR during laboratory based testing was significantly lower than peak match HR during hockey (Paun et al., 2008). The treadmill protocols used by these authors and the familiarity of the athletes to the testing procedures may have contributed to the low peak HR measurements in comparison to those of the present study. In the present study the peak HR's gained during the MSFT were very stable values. All of the athletes involved had been in the national (or national development teams) for a number of years and as a consequence had become extremely familiar with maximal testing and had performed numerous tests (repeated maximal values have shown to have greater stability) (Bagger, Petersen, & Pedersen, 2003).

Despite spending 61% of the match in low intensity movement categories (less than 11km.h^{-1}) players had a high average HR (85.3 ± 2.9% HR_{max}) and spent a very high proportion of the match in high HR zones. Players were above 75% HR_{max} for 90% of the match, above 85% HR_{max} for 60% of the match and above 95% HR_{max} for 4% of the match. The disparity between intensities as measured by HR and motion analysis has been commented on by other authors and is suggested to be caused by factors such as the effects of psychological arousal and anxiety on match HR and the physiological costs of sport specific movements (Krustrup et al., 2005; Paun et al., 2008).

It is suggested that dehydration affects HR (Bachle et al., 2001; Barr, 1999; Coyle, 2004). Coyle stated that dehydration appears to have a robust effect on cardiovascular strain as evidenced by the observation that for every 1% of body weight loss due to dehydration, HR increases by 5–8 b.min^{-1} and cardiac output declines significantly (Coyle, 2004). Sweat evaporation provides the primary avenue of heat loss during vigorous exercise in warm and hot weather; therefore sweat losses can be substantial. In the present study the subjects exercised under relatively mild conditions with match average temperatures between 18 and 22^{o}C and humidity between 70 and 79%. The substitution rules in hockey make it possible for players to take on fluid during the match in addition to half time which reduces the heat stress unlike other sports where this is more difficult. As a result of this opportunity for fluid intake (in addition to the moderate bodyweights, low levels of bodyfat and relatively high levels of aerobic fitness) the levels of dehydration during match-play in non-extreme environments are usually small to moderate. Pre- and post-match measurements of body mass were taken in the dressing room before the commencement of the warm-up and immediately following the conclusion of the match as a means to assess dehydration. During the five matches in this study the average bodyweight decrease was 0.8% with a range of +0.2% to 1.5% which would indicate low to moderate levels of dehydration.[4] This suggests the negative impact on physical and cognitive performance as a result of dehydration would have been minimal (Maughan, Merson, Broad, & Shirreffs, 2004).

Emotion

Emotion may also have had an effect on HR during the matches. Although the matches were being used to select the team to represent New Zealand at the 2006 Commonwealth Games players had an average of 60 international appearances and were extremely familiar with elite level competition so it is not anticipated that anxiety levels would have been influential on HR. Additionally, mean match HRs were 85.3% of maximum and it has been suggested by Astrand and Saltin (1961) that the influence that emotion has on HR is neutralized at such high workloads (Astrand & Saltin, 1961).

The most significant reasons for a difference between the relative intensities measured using time motion analysis and HR methods are related to the additional

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[4] It is common practice to use changes in body mass as an index of body water content changes and thus of hydration status with a decrease of less than 2% of the pre-exercise body mass being considered desirable. (Harvey, Meir, Brooks, & Holloway, in press; Shirreffs, Sawka, & Stone, 2006)

physiological strain of movement tempo changes, match specific movements and body positions.

A decrease in HR between the 1st and 2nd halves is a common finding in time-motion studies of team sports and is suggested to be mostly related to decreasing physical outputs either through tactics or fatigue. In the present study there was a decrease in mean HR between the 1st (86.7%) and 2nd halves (84.4%), a value which approached statistical significance (p=0.053). This suggests that hockey follows the trend of other sports of a slightly lower physiological strain in the 2nd half. No positional group provided HR's that were especially distinctive to the other groups although small differences did exist (table 15). The HR responses of individuals are very much unique and such differences are said to eliminate or reduce any positional variations (Reilly & Doran, 2001; Rodriguez-Alonso et al., 2003).

Conclusion

This analysis of elite men's hockey suggests that players require a high level of conditioning due to large distances covered, repeated bursts of high intensity running and a variety of additional physical demands associated with repeated changes in tempo, a semi-crouched body position and the body contact and technical requirements of hockey matches. Aside from fullbacks, the positional groups in hockey were very similar in their physical requirements. Fullbacks had the lowest average speed, covered the least total distance, a greater proportion of distance at low intensity and less distance at moderate and high intensities. There were small but significant decreases in physical outputs between the first and second halves and there was a general downward trend of distance covered in each

5 minute period during both halves. There was no indication of residual fatigue across the five matches with total physical outputs remaining stable.

Elite men's hockey requires a very high level of physical condition and the scheduling of multiple matches in close proximity means the use of thorough nutritional and recovery strategies is also extremely important. Changes to the rules of the game appear to have resulted in an increase in the physical demands of the game and in turn increases in the physical characteristics of players.

CHAPTER 4: THE IMPACT OF SUBSTITUTIONS ON THE PHYSICAL AND TECHNICAL OUTPUTS OF STRIKERS DURING HOCKEY

INTRODUCTION

A variety of previous research supports the notion that increasing physical and technical outputs of teams improves the likelihood of success (Hunter & O'Donoghue, 2001; Luhtanen, 1990; Mohr et al., 2003; Reilly & Gilbourne, 1997; Wisloff, Helgerud, & Hoff, 1998). In soccer it has been shown that high physical outputs are positively related to match success (Reilly & Gilbourne, 1997; Wisloff et al., 1998) and that the physical outputs of substitute players are considerably higher than that of players who have played the entire match (Mohr et al., 2003). It has also been shown that in soccer, losing teams were less successful than winning teams in the performance of basic skills such as passing, receiving, dribbling and shooting (Luhtanen, 1990; Rampinini et al., 2008) and that successful teams in rugby have more entries into opposition space than unsuccessful teams (Hunter & O'Donoghue, 2001). Hockey allows for the unlimited use of five substitute players during matches. A coach may substitute as frequently as desired in an effort to maximise the physical and technical outputs of the team and consequently increase the chances of winning the match.

In soccer, fatigue during matches is manifested through decreases in physical outputs and contributions to the game (Burgess et al., 2006; Mohr et al., 2003; Rampinini et al., 2008). However, a soccer match has a duration of 90 minutes and is played upon a large pitch area. It is unclear whether hockey, with a match duration of 70 minutes and a smaller playing area is subject to the same fatigue-induced decreases as this is the first study to address the issue. The only study to provide and relevant information was that of Spencer et al (2004) who measured the physical outputs of an international test match and reported that as each half progressed players jogged less and walked and stood more, a trend that was increased in the 2nd half (Spencer et al., 2004).

Measuring the technical outputs or contributions of players during matches is a common component in performance analysis in many team sports, especially those involved in international and profession competitions (Bloomfield et al., 2004; Duthie et al., 2005). In elite hockey however, no published information exists on such a practice although Boddington et al (2003) measured and discussed overall performance statistics such as attacking 25 entries and shots taken during elite competition. As it has in soccer, developing a system of technical evaluation will allow for player selection to be improved through the ability to compare performances of one versus another and also allow for the effect of various performance enhancing interventions to be evaluated.

A hockey coach can select sixteen players for a match and determining the distribution of these players across the five positional groups (goalkeeper, fullbacks, halves, inside forwards, strikers) is an important and significant decision.

PURPOSE

Given the gaps in previous literature and the desire of the current NZ coach to develop a performance enhancing substitution strategy the purpose of this study is to quantify the technical outputs of strikers during elite hockey match play and to investigate the effects of differing substitution strategies on the physical and technical outputs of strikers.

METHODS

Experimental Design

Five hockey matches were used for data collection. The matches were between the New Zealand Men's National Squad and the Tasmanian State Representative Team (Australia). Three different substitution conditions were assessed during these five matches; five strikers with a high frequency of substitutions (condition S5 – matches 1 and 4), four strikers with a moderate frequency of substitutions (condition S4 – matches 2 and 5) and three strikers (condition S3 – match 3) with no substitutions. Substitutions were made using a predetermined schedule. Fifteen substitutions were made per match in the S5 condition and 8 per match in the S4 condition.

Participants

Eighteen members of the New Zealand Men's National hockey squad were involved with subject characteristics presented in table 6. Ethics approval was gained prior to commencement of the study and written informed consent was obtained from each participant prior to commencing data collection.

Match Data Collection

An assistant was on the sideline of each match noting and detailing exact timings for the match including start and end of each half, timing and details of substitutions, position changes of players and stoppages. These timings were then used to edit the GPS, HR and technical statistics so that data was presented for 10 positions (goalkeeper excluded) rather than for each player. Positional data was made up of the 70 minute sum of all players who were in that position during the match.

Physical Outputs

A GPS recording device (SPI elite, GPSports Systems Ltd, Australia) was used to recorded the position coordinates of the player at a frequency of 60Hz (1 sample per second) and derived speed and distance information from the changes in position coordinates. A single unit was worn by each out-field player during all matches. Following the conclusion of the match the data was downloaded using the manufacturer-supplied software (GPSports Team AMS v1.2.1.0). Raw data was then exported into Microsoft Excel for analysis.

In all matches players wore a HR monitor chest strap (Team Polar, Polar Electro Oy, Kempele, Finland) which recorded HR every 5 seconds. Following the conclusion of the match the data was downloaded using manufacturer-supplied software (Polar Precision Performance v4.03.043) and processed. Using substitution timings the HR data was edited so that the analysis did not include half time data, injury breaks or time spent off the field of play. By referencing to HR_{max}, the match HR data was divided into four zones as described by Deutsch et al (1998) and Johnston et al (2004) (table 8). Mean and peak HR's were also calculated.

Data Analysis

GPS data was edited to only include time spent on the field of play and then separated into six speed zones as presented in table 7. Similarly, HR data was edited so that the analysis did not include half time data, injury breaks or time spent off the field of play. Match HR data was divided into four zones (Table 8,). Mean and peak HR's were also calculated.

Video Analysis – Technical Outputs

Video footage was taken using three video cameras (Panasonic NV-GS300, Panasonic NV GS400 x 2) on mini-DV tape. Two cameras held a fixed field of view (one was fixed on the attacking half, one on the defensive half) and one camera, operated by an experienced sports videographer, followed the match by panning and zooming. (please refer to figure14). All cameras were positioned on a balcony on the half way line approximately 10m above the level of the pitch(figure 15). Footage was captured to an Apple G5 computer using SportsCode Elite version 6.5.49 for later analysis. The video footage was used to measure the technical outputs of the strikers and the performance statistics of the two teams.

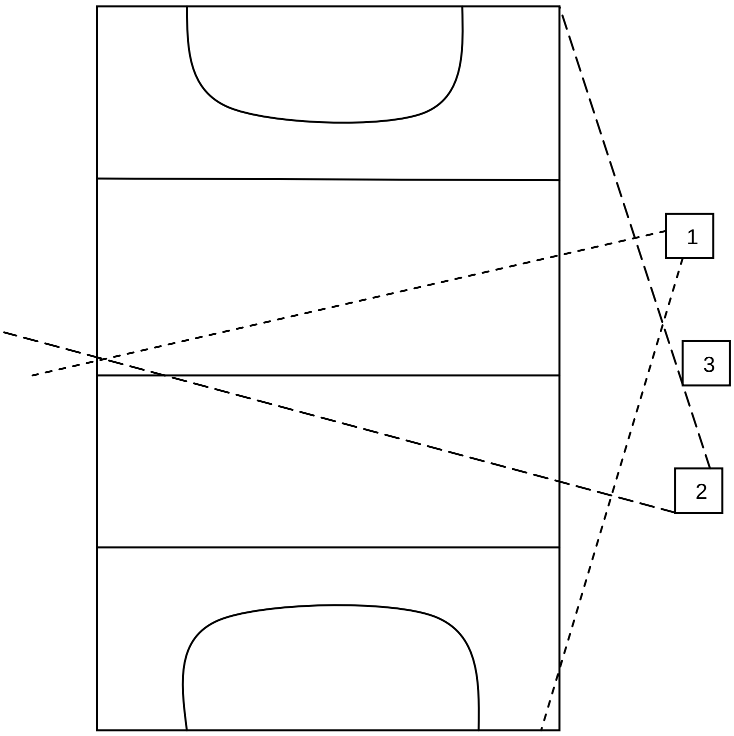

Figure 14: Camera positions for match video recording

Striker Technical Output Criteria

A set of operational definitions were developed by the national coach to evaluate the activities of strikers. Strikers were awarded 0 (ineffective), 1 (slightly effective), 2 (effective) or 3 points (extremely effective) each time they contributed to the match. Points were awarded based upon their movement and positioning, their activity when in possession of the ball and their defensive work (table 17). Video tapes from all three cameras were synchronised and watched in unison in slow motion while the activity of the strikers was assessed against the criteria. To improve the validity of the application of technical criteria the head coach observed the coding of all matches to ensure that the correct interpretation of the technical criteria was being made by the researcher. In addition, one match was chosen at random and analysed twice to assess the reliability. The researcher was also an experienced video analyst who had performed match analysis on more than 80 international hockey matches in the previous 12 months.

Figure 15: Playing venue for matches

Table 17: Striker technical output criteria during matchplay

Task Evaluation	Points	Activity
Category 1: Creating Space and Leading		
Ineffective	0	Running and moving but never creating opportunity to receive
Slightly Effective	1	player leads for the ball and links with another but with no forward momentum
Slightly Effective	1	Getting into good position for a pass but not being given the ball
Effective	2	Player leads and takes opponent away from area leaving space for another
Effective	2	Player leads, receives ball with second pass immediately available
Effective	2	Leads back to receive and hold and relieve pressure on defence
Effective	2	Running hard to provide support in counter-attack
Effective	2	Offering significant forward momentum
Extremely Effective	3	Lead results in creation of significant attacking space/opportunity
Extremely Effective	3	Receive in space in A25 with immediate pass available
Extremely Effective	3	Significant forward momentum is initiated or maintained
Extremely Effective	3	Available for a pass inside the circle with opportunity to achieve attacking output
Category 2: Activity When In Possession		
Ineffective	0	Dispossessed
Slightly Effective	1	Makes a pass back or across field
Effective	2	Eliminates defender with forward momentum
Effective	2	Makes a forward going pass
Effective	2	Maintaining momentum above the opposition with positive carry
Extremely Effective	3	Eliminate defender with significant forward momentum in attacking half
Extremely	3	Priority pass achieved to player in attacking space

Effective		
Extremely Effective	3	Circle penetration made, shot taken or PC won
Category 3: Defensive Play		
Ineffective	0	Defensive running but opposition able to easily switch play
Slightly Effective	1	Defensive running causing opposition to be channelled or passing option eliminated
Effective	2	Opposition channelled into difficulty or dispossessed
Extremely Effective	3	Opposition pressed and dispossessed in own 25
Extremely Effective	3	Dispossession results in counter attack

Performance Statistics

In addition to technical outputs, a number of performance statistics were also collected. Among the variety of performance statistics used by elite hockey coaches worldwide there are three universal measures of performance; entries into the attacking 25', entries into the attacking circle, and attacking outputs (shots taken or penalty corners awarded)(table 18). An indication of how common these statistics are is that all twelve nations who competed in the 2006 World Cup used these criteria (personal communication).

Table 18: Team performance statistics

Performance Statistic	Notation	Description
Attacking 25	A25	Being in possession of the ball while in the attacking 25
Attacking Circle Penetration	ACP	Being in possession of the ball while in the attacking circle
Attacking Outputs	AO	Taking a shot or being awarded a penalty corner
Defensive 25	D25	Your opponents being in possession of the ball while in your defensive 25
Defensive Circle Penetration	DCP	Your opponents being in possession of the ball while in the your defensive circle
Defensive Output	DO	Your opponents taking a shot or being awarded an penalty corner
A25 Conversion Rate	A25%	How many attacking 25's were converted into attacking circle penetrations
ACP Conversion Rate	ACP%	How many attacking circle penetrations were converted into attacking outputs
D25 Conversion Rate	D25%	How many defensive 25's were converted into defensive circle penetrations
DCP Conversion Rate	DCP%	How many defensive circle penetrations were converted into defensive outputs

Statistics

Conditions were compared using multiple paired T-Tests with unequal variances. Statistical significance was set at $p < 0.05$. The reliability of the technical evaluation was assessed using pearson correlations and the typical error of measurement spreadsheets of Hopkins (www.sportsci.org). Trends were assessed using linear regression techniques.

RESULTS

A high level of observer reliability was found when applying the technical criteria twice to the same match. A pearson correlation of r=0.96 and a TEM of 1.2% were found.

Striker Contribution Points

Strikers made an average of 119 ± 27 contributions to the match. Of this, 48 (40.3%) were rated as being “slightly effective”, 43 (36.4%) were rated as “effective” and 28 (23.2%) were rated as being “extremely effective”. These contribution events summed to 214 ± 38.6 contribution points per match.

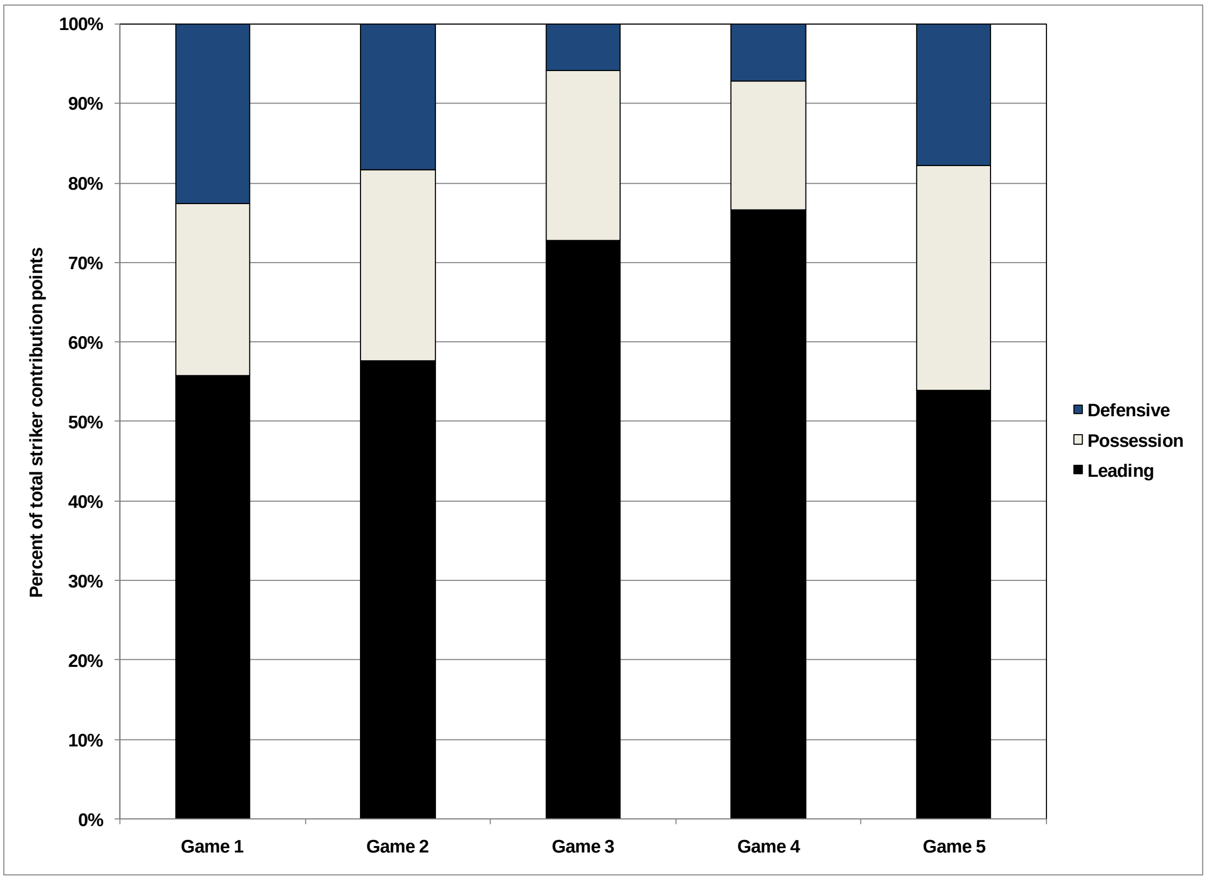

Figure 16: Distribution of striker contribution points over the 5 matches

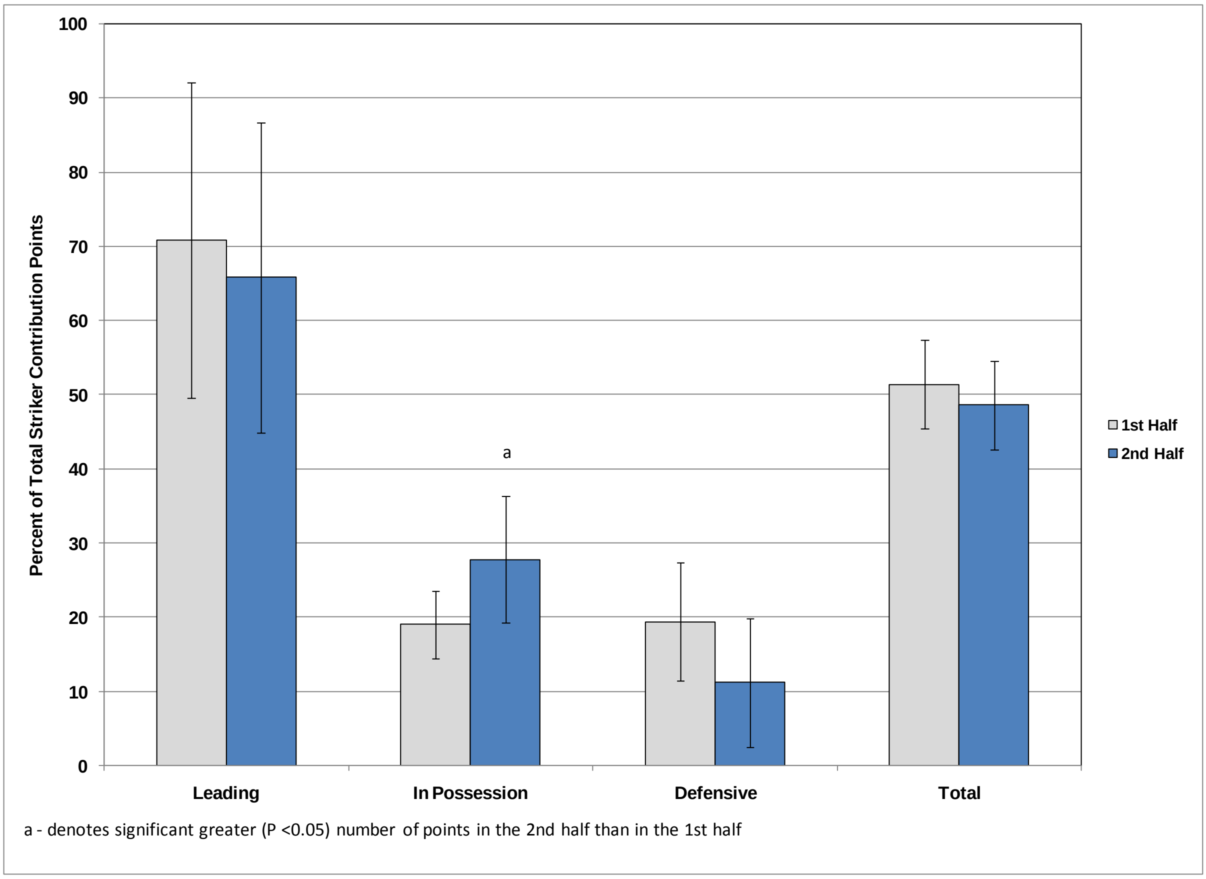

Figure 17: Distribution of striker contribution points for each half

The greatest proportion of these points, 137 (64%) were earned in the category of "creating space and leading" with 47 (22%) and 30 (14%) being earned in the categories of "activity when in possession" and "defensive play" respectively. The distribution of points in these categories over the five matches are illustrated in Figure 16.

The total amount of points decreased slightly from 1st half to 2nd half but the change was not significant. Changes in points earned in the three categories from the first half to the second half (figure 17) did not reach statistical significance at $p<0.05$ but the increase in possession points ($p=0.09$) and decrease in defensive points ($p=0.16$) both approached this value. There was a very slight downward sloping trend when points were mapped against 5-minute periods of the match (slope = -1.6%, R^2 = 0.11).

There was a relationship between striker contribution points and performance statistics. Total striker contribution points per match were moderately correlated with Attacking 25 Entries (r=0.77) and Attacking Scoring Outputs (r=0.73). Total leading contribution points were moderate-strongly correlated with Attacking 25 Entries (r=0.80) and strongly correlated with Attacking Scoring Outputs (r=0.90).

The number of striker contribution points increased as the number of strikers increased with S5 > S4 > S3.(table 19) There was a large decrement in contributions points between the 1st half and the 2nd half in the S3 condition, no decrement in the S5 condition and an increase in the S4 condition.

Table 19: Striker contribution points under the different substitution conditions

	5 Strikers	4 Strikers	3 Strikers
1st Half	123 ± 18	96.5 ± 16	106
2nd Half	118 ± 17	110.5 ± 22	67
Total	241 ± 35	207 ± 38	173

Team Performance Statistics

An average of 34 entries were made per match into the attacking 25 of the opponent with 18 of these resulting in an attacking circle entry. This represents a conversion rate of 53%. Once inside the attacking circle an average of 10 attacking outputs were achieved per match representing a conversion rate of 56%. The opponents made an average of 22 entries into the New Zealand defensive 25 with 15 of those resulting in defensive circle entries, a conversion rate of 68%. Of these, 9 resulted in a defensive output, a conversion rate of 60%.

Table 20: Team performance statistics under the different substitution conditions

	5 Strikers	4 Strikers	3 Strikers	Average
Attacking 25 Entries	40	30	34	34 ± 7.5
Attacking Circle Entries	19	18	19	18 ± 2.6
Attacking Outputs	13	9	10	10 ± 2.3
Defensive 25 Entries	18	28	21	22 ± 9.9
Defensive Circle Entries	10	21	13	15 ± 8.2
Defensive Outputs	4	14	10	9 ± 6.3
Aggregate Score	6-2	5-2	1-2	

When five strikers played and a large number of substitutions were made the team performance statistics were the highest with the most attacking statistics and the least defensive statistics. The score results were also the most favourable in the S5 condition.

Physical Outputs

There were no significant differences between the conditions with regard to total distance covered or distance covered in any of the zones (Table 21). However, the decrements in total distance and zone 6 distance between the 1st and 2nd halves were significantly greater in the 3 striker condition than in both the 4 striker and 5 striker conditions (Table 22). The decrement in zone2 and zone4 distance between the 1st and 2nd halves was significantly greater (p=0.03) in the 3 striker condition than in the 4 striker condition and also the decrement in zone4 distance between the 1st and 2nd halves was significantly greater (p=0.04) in the 5 striker condition than in the 4 striker condition.

Table 21: Total and zonal distance in striker conditions

	5 strikers	4 strikers	3 strikers
Zone 1: 0-6km.h^{-1}	2538	2590.	2451
Zone 2: 6.1-11km.h^{-1}	2258	2211	2210
Zone 3: 11.1-14km.h^{-1}	1406	1515	1450
Zone 4: 14.1-19km.h^{-1}	1531	1422	1438
Zone 5: 19.1-23km.h^{-1}	498	464	495
Zone 6: >23km.h^{-1}	203	221	228
Total Distance	8414	8422	8282

Table 22: Percent decrement between 1st and 2nd halves in striker conditions

	5 strikers	4 strikers	3 strikers	Significance
Zone 1: 0-6km.h-1	-7.1%	0.1%	0.7%	S5>S4, p=0.29 S5<S3, p=0.25 S4<S3, p=0.91
Zone 2: 6.1-11km.h-1	11.9%	11.4%	21.6%	S5>S4, p=0.95 S5<S3, p=0.25 S4>S3, p=0.01
Zone 3: 11.1-14km.h-1	2.1%	1.2%	25.1%	S5>S4, p=0.93 S5<S3, p=0.16 S4<S3, p=0.15
Zone 4: 14.1-19km.h-1	9.4%	-13.1%	22.2%	S5>S4, p=0.04 S5<S3, p=0.43 S4<S3, p=0.05
Zone 5: 19.1-23km.h-1	2.0%	-25.5%	12.3%	S5>S4, p=0.44 S5<S3, p= 0.73 S4<S3, p=0.38
Zone 6: >23km.h-1	-15.6%	-27.5%	63.5%	S5>S4, p=0.83 S5<S3, p=0.04 S4<S3, p=0.03
Total Distance	4.4%	0.0%	18.0%	S5<S4, p=0.43 S5<S3, p=0.03 S4<S3, p=0.03

[Negative value denotes an increase in distance between 1st and 2nd halves]

The average number of high intensity efforts performed per striker position70 was lower in the S3 and S5 conditions (S5 and S3 = 46 per match, S4 = 48 per match) as compared to the S4 condition but the difference was not statistically significant (p=0.35).

Heart Rate

There was no difference in average HR or percentage of match time spent in any of the HR zones between the substitution conditions (table 23).

Table 23: HR of team and strikers under substitution conditions (team/strikers)

	5 strikers	4 strikers	3 strikers
Average HR	85.1 / 85.7	85.4 / 84.8	85.3 / 85.5
Percent of match time spent below 75% HR_{max}	9.9 / 11	10.4 / 13.8	9.5 / 10.6
Percent of match time spent between 75-84% HR_{max}	30.6 / 26.5	26.7 / 27.8	30.8 / 27.6
Percent of match time spent between 85-95% HR_{max}	56.3 / 56.4	57.8 / 57.1	55.1 / 55.8
Percent of match time spent above >95% HR_{max}	3.2 / 6.1	5.1 / 11.3	4.6 / 6.0

DISCUSSION

With unlimited use of five substitutes during a match, it is important for a coach to carefully select these players to best support the tactical plan. An increasingly common trend in international hockey matches is for coaches to forego a goalkeeper substitute, a strategy that carries great risk, so as to allow an extra substitute player to cover the four outfield position groups. Knowing how many substitutes to allocate to the strikers allows decisions to be made about the positional orientation of the remaining three substitutes and whether the risk of playing without a substitute goalkeeper needs to be taken (if the goalkeeper became injured an outfield player would have to take his place). Consideration of this issue by NZ coaches highlighted the need to explore the effects of different substitution strategies on the physical and technical outputs of strikers during match play.

There has been a recent increase in the amount of published literature describing and piloting methods to evaluate the technical-tactical performance of team sport players, particularly soccer, during match-play (Balyan et al., 2006; Hughes & Maloney, 2006; Merce et al., 2006; Rowlinson & O'Donoghue, 2006). Although all these authors sought to develop a unique performance analysis system a similar and critical theme from all of the studies was the need to develop of a sport-specific set of performance criteria so that reliable and valid information could be generated and consequently used within the team training and competition environment.

Striker Technical Outputs

The criteria used to evaluate the technical performance of the players in the present study were developed specifically for this project by the key users of the output information; the head coach and assistant coach of the team. Tight and concise definitions were agreed upon a priori and the process of data analysis was conducted in such a way as to ensure that correct and consistent interpretation of the criteria were made (the head coach was present as all video footage was processed and technical points allocated). Key features of the systems were an incremental scale of effectiveness (from 0 to 3 points) and categories of activity to represent the different tasks that a striker is required to complete in a match.

The contribution events summed to an average of 214 ± 38.6 contribution points per match with the highest proportion of these points being earned in the category of “creating space and leading”. This contribution category had unsurprisingly high correlations with attacking 25 entries (r=0.77) and attacking outputs (r=0.73) and illustrates that when strikers are regularly involved with the match the likelihood of creating scoring opportunities is greater. A lesser proportion of striker contribution points were earned in the categories of “activity when in possession” (22%) and “defensive play” (14%). This illustrates that an overwhelming majority of activity occurs without individual possession of the ball (making off the ball movement and support play very important). It also highlights that despite having very small amounts of possession with the ball, reported to be approximately 3% of game time (Reilly & Seaton, 1990), that 22% of overall contribution to the game is made during these brief moments. From a coaching and conditioning perspective this is a very important issue. To be effective, strikers need to be able to make very calculated decisions when in possession of the ball so that they can maximally impact on the performance of the team. Consequently, mental freshness and a clear game plan are significant benefits for strikers (which supports the use of regular substitutions to allow physical recovery and tactical discussion with the coaches).

Strikers made an average of 119 ± 27 contributions to each match. The centre striker, as the name suggests, is predominantly positioned in the middle of the pitch and is more consistently involved in the play of the match than either the left or right striker. This resulted in approximately 40% of the contributions being performed by the player in this position which suggests that an effective substitution system to ensure that this position is performing efficiently is very important.

Although the highest proportion of contributions (40.3%) were rated as being only "slightly effective" this is more a reflection of the face value of the task than its value to the performance of the team. For example, in the defensive play category is a performance indicator called "Defensive running causing the opposition to be channelled or a passing option eliminated" which is labelled slightly effective and allocated one contribution point. A large number of these actions are performed by strikers throughout the match as a way to build pressure, frustrate the opposition and force a mistake. An individual action such as this may only contribute one point but it may also cascade and lead to another action of the same kind or one of greater value (effective) such as "channelling the opposition into difficulty and forcing a turnover of possession".

As a match progresses and the result (sometimes) becomes more certain the effort expended by strikers on various tasks may become less justifiable. For example, when comfortably winning a match the desire to vigorously perform all defensive duties may not be as strong as when the scores are close. In this regard, the results show that although the total amount of striker contribution points decreased slightly from 1st half to 2nd half, the change was not statistically significant. Significance was also not reached in any of the individual points categories although both the decrease in defensive points and the increase in possession points were close. The trend of striker contributions points earned per 5-minutes had a slight downward slope (-1.2%). In all but one match, the highest 5-minute period was inside the first 15 minutes of the match. This finding is similar to that of Burgess et al (2006) who reported that Australian soccer players had a greater engagement with the match in the first half as compared to the second half as indicated by a decrease in the amount of player events per minute (Burgess et al., 2006). This may have been associated with fatigue as, Helgerud (2001) showed that improving aerobic endurance in soccer players increased the number of involvements with the ball during a match by 24% (Helgerud et al., 2001).

The increase in possession points between the 1st and 2nd halves is both supported by and contradicted by the findings of Lago and Martin (2007) who investigated the determinants of possession in Spanish professional soccer. They identified some key variables of importance including the evolving match status (i.e. whether the team is winning, losing or drawing) and the venue (with the associated home advantage). They stated that the team playing at home increased possession by 6% compared with the team playing away and that when a team is losing it requires greater possession of the ball so as to create more goal-scoring opportunities to draw or win the match (Lago & Martin, 2007). In the present study the results of the matches were (NZ score first) 3-1, 2-0, 1-2, 3-1 and 3-2 with the series result being 4 games to 1. The subject team (NZ) was the home team and enjoyed the advantage of crowd support and the familiarity of conditions. They spent 57.5% of match time in a winning position, 16.9% drawing and 25.6% losing. In the second half the time spent winning increased to 67.6%, mostly at the expense of time drawing which decreased to just 2.1%. The relatively low proportion of time spent losing a match in the 2nd half suggests that either the assertion of losing teams gaining possession does not apply to hockey or that the possession points allocated to strikers using the performance indicator criteria are not a reflection of time spent in possession of the ball.

The number of striker contribution points increased as the number of strikers increased with S5 > S4 > S3 but statistical significance was not achieved. In addition to this there was large decrement in contributions points between the 1st half and the 2nd half in the S3 condition which was not seen in either the S4 or S5 conditions. It therefore appears that player fatigue was not manifested in decreases in distances covered but it was manifested in decreases in contributions to the match. When a player is substituted, they are able to physically rest and rehydrate but perhaps more importantly they are able to receive feedback from the coach and be given specific instructions for when they rejoin the match. At the international level of competition it is increasingly common for a substituted player to receive information from a performance analyst and view specific video footage of the match from a computer on the sideline. Such information can highlight areas of weakness and opportunity in the opponent and allow for the development of specific tactical strategies. When substitutions are not possible the opportunity to pass on such information is restricted to the half time break at which time the coach is typically focused on general feedback to the entire team as opposed to specific feedback for an individual.

The usefulness and longevity of performance analysis systems is often determined by practicalities. The Bloomfield classification system is a performance analysis system that is used to describe the movements and match activities in soccer in great detail (Bloomfield et al., 2004). Unfortunately the level of detail required to accurately code using this system requires both specific video footage (close up) and a large amount of time (a single 15 minute sequence of match-play takes a trained observer 4-6 hours to analyse). Drawbacks of such a time-heavy system are that the analysis can only be performed by professional teams with large budgets and lots of staff. Otherwise the information will be reported too slowly to be of use to the team. The classification system used in the present study required four hours per match (24 hours in total as 4 matches were analysed once and 2 matches analysed twice). Although multi-camera video footage was collected the majority of decisions were able to be made from the main match camera which panned and zoomed with the play of the match. This suggests it could be adequately performed using footage from a single video camera (with a trained operator). The major drawback of the system as performed during this study is that it required the coach to be present during video playback to ensure correct allocation of striker contribution points. If the analysis was being performed again then a person with a high level of hockey knowledge and a clear understanding of the technical criteria points system would be required.

Performance Statistics

The primary author of this report has operated as performance analyst for the subject team for four years and has attended major international tournaments such as the Olympic Games, Commonwealth Games and Hockey World Cup. Through this work there has been considerable professional engagement with those similarly employed by other teams. As a consequence it is possible to confirm that there are an almost universal set of performance statistics that are used in international hockey (please refer to table 18) and that these were adopted as a tool to quantify performance outputs. In the present study, more attacking 25 entries, more attacking circle entries and more attacking outputs were performed than the opponents but poorer conversion rates (A25:AC and AC:AO) were evident compared to the opposing team. Despite this, the overall match performance outputs would appear to be representative of a typical performance for the team. Stability of performance statistics are encouraged when multiple matches (5+) are played against the same opponent (McGarry & Franks, 1996; Miyagi, Ohashi, & Kitagawa,

1999) and Hughes and Bartlett (2002) suggested that a reasonable number of matches for performance to be considered representative of typical performance was six (Hughes & Bartlett, 2002). The closeness of the current number of matches to the recommended number it was close enough to suggest that performance was sufficiently stable.

With just two, two and one match per condition it is difficult to establish whether performance statistics were significantly affected by the striker substitutions. A comparison of performance across the five games showed no clear pattern. It is apparent that the S5 condition produced the most attacking 25 entries and the most attacking outputs but attacking circle entries were almost the same under all the striker conditions. The high correlation between total striker points, leading contribution points and performance statistics suggest that given a larger sample size, a positive effect would have been found i.e. more A25's and AO's in the S4 and S5 conditions.

Physical Outputs

It was found that manipulating the number of striker substitutions made no significant difference to the total distance or the distances covered in any of the individual speed zones during the match. However, there were some differences when comparing the 1st and 2nd halves under the different striker conditions. There was greater fatigue in the S3 condition as represented by significantly greater decrements in 1st to 2nd half distance. The S3 condition had greater decreases in zone 2 (p=0.01), zone 4 (p=0.05), zone 6 (p=0.03) and total distance (p=0.03) as compared to the S4 condition. The S3 condition had greater decreases in zone 6 (p=0.04) and total distance (p=0.03) as compared to the S5 condition. Also, the S4 condition had greater decreases in zone 4 (p=0.04) distance as compared to the S5 condition. This suggests that the fatigue of strikers during the S3, no substitution condition was greater than that during the S4 or S5 conditions were substitutes were used (although the total match distance was not significantly different between conditions).

Given that previous literature has reported significantly enhanced outputs of substitute players (Mohr et al., 2003) it is unclear why no significant differences between striker conditions were found in this study. A possible explanation may lie in the balance between physical stress and physical conditioning for these players. The strikers in this study were extremely well conditioned with an average VO_2max of 65ml.kg.min^{-1} as measured by MSFT. Given this high level of fitness and the relatively short duration of hockey matches it is possible that, compared to soccer, the matches were not stressful enough to induce sufficient fatigue to create a significant decrease in physical outputs between conditions, even in the S3 condition when each striker played the full match (70 minutes). Mohr et al (2003) reported that when substitute players were introduced to game during the second half of a match, they covered 25% more high intensity distance during the final 15 min of professional soccer matches than players who had been involved in the entire match (Mohr et al., 2003). It could be expected that the professional soccer players used in that study had similarly high levels of fitness to the hockey players in the present study and the workload per minute is relatively comparable between the two sports (126.5 m.min^{-1} v 116.6m.min^{-1}) (Di Salvo et al., 2007). Therefore it is possible that if the hockey matches were 20 minutes longer (and therefore comparable to soccer) then greater differences would have been found between S3, S4 and S5 conditions. Although overall match outputs were not affected there was evidence of greater fatigue in the S3 condition as represented by greater decrements in 2nd half distance covered as compared to the other conditions. The striker condition also had no impact on the distances covered by other players in the team. It may be expected that if some players within the team are more fatigued then other players may absorb this deficit by increasing their work outputs. This was not found however as the non-strikers did not show any significant differences between conditions to suggest that they were compensating for less activity by the strikers.

Wisloff et al (1998) reported that better performing teams were fitter and covered greater distances during match play compared to poor performing teams (Wisloff et al., 1998). As yet, this question has not been investigated in hockey. An issue that needs to be considered in hockey (and other team sports) is that it is not a competition to see which team can run the most. Although the findings of Wisloff et al (1998) demonstrate that there is a positive relationship between success and physical outputs, it is unclear as to how much is enough and when does more physical output result in no further improvement in chances of success. Conversely to others, Yamanaka et al (1988) reported that distances covered in soccer actually decreased as the grade increased from club to collegiate to professional (Yamanaka et al., 1988). Burgess et al (2006) also reported that the distances covered by Australian national league players were significantly higher than those of English professional counterparts and suggested that distance is not a good indicator of performance level (Burgess et al., 2006). Rienzi et al (2000) compared the distances covered by Brazilian International soccer players to those of English Professional players. They reported that the Brazilian players covered significantly less distance than the English players (8638 ± 1158m vs 10104 ± 703m) (Rienzi et al., 2000). [If an objective of match play accumulate distance then perhaps the impact of increased substitutions in the present study would have been more significant on the overall physical outputs of the strikers and the team]. Collectively these findings somewhat oppose the notion of distance covered being important and that technical and performance outputs, independent of distance are more important.

Conclusion

In conclusion, this study found that manipulating the number of striker substitutions made no significant difference to the total distance or the distances covered in any of the individual speed zones. However, there were some differences when comparing the 1st and 2nd halves under the different striker conditions. It was found that the decrements in total distance and in zone 6 distance were significantly greater in the S3 condition as compared to both the S4 and S5 conditions.

In summary, when more strikers and a higher frequency of substitutions were used there was a higher total technical output and an increase in performance statistics. There was however no increase in physical outputs as compared to the S4 and S3 conditions.

CHAPTER 5: SUMMARY AND CONCLUSIONS, PRACTICAL APPLICATIONS AND LIMITATIONS

OVERALL SUMMARY AND CONCLUSION

A relatively small amount of published literature exists for elite men's hockey and recent rule changes have increased the need for an accurate and current description of the game. This project sought to provide a detailed analysis of the physical demands of elite men's hockey and to also answer a specific question relating to the substitution of strikers. The objectives of this thesis were to use methods of performance analysis to measure the physical and technical outputs of all outfield players during elite hockey and to specifically measure the impact of differing substitution strategies on the physical and technical outputs of strikers during match play.

Chapter three confirmed findings of previous studies that suggest that international level hockey players require a high level of conditioning due to large distances covered, repeated bursts of high intensity running and a variety of additional physical demands associated with repeated changes in tempo and the body contact and technical requirements of hockey matches. Average total distance covered during 70 minutes by a position was 8160 ± 428m of which 479 ± 108m (6.1%) was performed at speeds greater than $19 km.h^{-1}$. Within this high intensity distance were 34 ± 12 sprints per player with an average duration of 3.3s. Average match HR was 85.3 ± 2.9% HR_{max} and average peak HR was 96.3 ± 2.7% $HR_{max.}$ Distance covered decreased by 6.2% between the 1st and 2nd halves and there was a trend of decreasing distance in both halves when total distance was broken into five-minute time periods.

Aside from fullbacks, the positional groups in hockey were very similar in their physical requirements. Fullbacks had the lowest average speed, covered the least total distance, a greater proportion of distance at low intensity and less distance at moderate and high intensities. The project also presented opportunity to extend the analysis of hockey with specific manipulation of player substitutions.

Chapter four investigated the potential for substitutions to enhance physical and technical performance. In hockey, the coach can substitute any of the eleven working players with any of the five bench players. The coach can do this as frequently as desired during a match which allows for substitutions strategies to be developed that can maximise the performance of a team. Pilot data had indicated that the striker positional group had very high physical outputs and were typically substituted more regularly than other positional groups. On the basis of this, the strikers were selected as a focus for investigation.

Three striker conditions were assessed; three strikers with no substitutions, four strikers with a moderate amount of substitutions; and, five strikers with a large amount of substitutions. Five matches between the New Zealand men's hockey team and Tasmania state representative team were played over eight days. Physical outputs of players were measured using portable GPS units and heart rate monitors and technical aspects of match play were measured using team performance statistics and a set of technical criteria which awarded points to strikers for each contribution they made to the game based upon a scale of effectiveness.

When assessing the impact of substitutions on the performance of strikers it was found that there were no significant differences in physical outputs between conditions with total distance (S5 = 8414m, S4 = 8422m; S3 = 8282m) and distance covered at speeds greater than 19km.h^{-1}(S5 = 701m, S4 = 685m, S3 = 723m) being similar. Large differences were found in technical outputs between the substitution conditions with more strikers and greater substitutions offering a better total output than less strikers and fewer substitutions (S5 = 241, S4 = 207, S3 = 173) but statistical significance between conditions was not present. There was a trend towards a better overall team performance with more substitutions but more matches would need to be analysed before any such pattern could be confirmed. The results suggest that although substitutions are not a means to increase the physical work of strikers they do appear to be a way to enhance the technical contributions that strikers are making to the game.

PRACTICAL APPLICATIONS

The study confirms the findings of previous studies that elite hockey places very high physical demands on players and that there is significant justification for requiring both that elite players are kept in high physical condition and that rigorous recovery practices are implemented when a series of matches are played within a short time period. The ability to produce high physical outputs during matches and to sustain these outputs when a series of matches are played in close proximity to each other is significant to performance given that the majority of international hockey is played in tournament situations with the most important matches at the end (i.e. the classification games and final).

Developing a substitutions system, appropriately matched to the ability of the available players, to enhance the outputs of strikers (and all positions) will increase performance statistics and consequently the likelihood of success. It appears that given a selection of players with similar ability, a substitution system that has players on the pitch for 8-10 minutes followed by 2-4 minutes rest will encourage a high level of technical performance.

LIMITATIONS

Using an elite athlete subject group during competition provides both positive and negative consequences. On the positive side, the data obtained is real and reflects current, high level performance. Findings are therefore directly applicable to athletes at the same and similar levels. Negatively, the ability to control variables and create a stable research environment is reduced. Injuries to players during matches, results going against the run of play, influence of umpires etc are all intrinsic qualities of sporting competition that can confound the results. The most comparable of previous studies was conducted on international competition and investigated three matches (Spencer et al., 2004). Paun et al (2008) studied four matches but only 6 players per game and at a domestic level. Genuine comparison is difficult as a consequence. There are inherent difficulties in investigating both physical and technical outputs during a team sport and it is acknowledged that the present study was conducted using just five matches against the same opposition. This number of matches limits the statistical power of the findings and recommendations but does provide insight into the potential effects of different substitution strategies. When similar investigations into physical fatigue and technical performance have been performed in soccer they have typically used a large number of matches over an entire professional season to make their observations. Typically, most elite level hockey is played in tour or tournament situations with clusters of 4-8 matches over a short time period. A strong professional competition, of similar quality to international hockey, is played in the

Netherlands and future studies there may provide opportunity to identify performance analysis relationships and trends. Despite the limited number of games, the constant opposition provided some stability to the research design.

A limitation to the comparison of striker conditions is the assumption that all strikers are equal and that the timing of a substitution can be based purely on fatigue rather than differences in ability. In all teams there is likely to be a difference in ability between players which makes the substitution decision multi-factorial. Balancing the fatigue of a player currently on the field against the reduced technical ability of the substitute is a difficult task for the coach. The data presented in this study suggest that the most highly skilled strikers should be used for long periods with only short rests for rehydration and tactical discussion with the coaches. A final limitation is the interaction of the opposition team on physical and technical performance. No team plays in an identical fashion for each match. The variation in performance of the opposition for the present study was not measured (aside from team performance statistics). The physical and technical outputs of these players will have had an impact on the outputs of the subject team and variations would have reduced the ability of the project to measure the effect of the striker conditions.

FUTURE RESEARCH

As there has been only a relatively small amount of published literature on elite hockey it is likely that there is still much to learn and significant benefit to be gained from performance analysis research. It is important that basic notational analysis of hockey continues so as to thoroughly document the physical demands of the game at all levels including men, women and youth. Future research needs to be less concerned about total distances covered and instead focus on moderate and high intensity running categories as this activity influences the game to a greater extent. Also, the detailed technical analyses of authors such Bloomfield et al (Bloomfield et al., 2004; Bloomfield, Polman, & O'Donoghue, 2006, 2007a; Bloomfield et al., 2007b; Bloomfield, Polman, & O'Donoghue, 2005) would also be useful to fully identify the qualities of different positions and the characteristics of different playing styles.

Investigating whether there are ideal durations for work and rest periods is also a relevant question i.e. should a player be on the field for 5, 10, 15, 20 minutes before being substituted and should they be given 2, 5, 10 minutes of rest before returning to the game?

Replicating the present study using a larger sample of matches would be beneficial. It is possible that the impact of substitutions on the women's game would be greater given the lower fitness levels of players so performing this analysis in this subject population may provide different outcome to the present study. A larger and inevitably more complex (but undoubtedly more relevant) issue is the overall substitution system used by a team. This would require investigation into the optimal timing and frequency of substitutions for all players so as to allow physical, technical and performance outputs to be maximised. Tracking of a professional team over an entire season or a national team over a series of international tournaments or tours may provide enough information to identify trends and suggest recommendations to help coaches with this difficult question.

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APPENDIX 1: FITNESS ASSESSMENT PROCEDURES

Experimental Procedures and Protocols

A series of anthropometric, physical and game assessments were performed at the start of the study to determine baseline measures prior to intervention. Players were well accustomed to the procedures in this study as they had performed the tests on several occasions previously.

Anthropometrics

Body mass was measured to the nearest 0.1kg using Seca Alpha 770 digital scales (Hamburg, Germany). Players were weighed in a hydrated state, wearing minimal clothing before a morning (8am) training session on five consecutive days. The average of these measurements was recorded as a player's mass. Height was measured in the mid-morning to the nearest 0.5cm using a wall-mounted stadiometer. Body fat was measured using a sum of 8 skinfolds as directed by the ISAK level 1 protocol. Skinfolds measurements were taken in duplicate using slimguide calipers at biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, thigh and calf sites. The sum of these eight measurements was calculated and used as a measure of leanness.

Table 24: Physical characteristics of participants

Measure	Mean (SD)	Range
Age (years)	24 (4.58)	17.1 - 33.2
Height (cm)	180.1 (4.9)	172 - 191
Body Mass (kg)	78.4 (6.5)	68.8 – 94.6
International Caps	59.2 (69.3)	0 - 198

Aerobic Fitness

The 20m Multistage Fitness Test, performed outdoors on a hockey turf, was the primary measure of aerobic fitness and was performed five days before the first data collection match. Conditions were cool (20^{o}C, 56% rH), fine and still. The pace of the test was controlled by a music CD recording (Australian Sports Commission, 2000) which was played on a portable stereo system operating on mains power. The test started at level 1.1 and progressed until each subject either reached volitional exhaustion or was withdrawn from the test for failing to achieve two consecutive shuttles. The last successfully completed length was recorded and expressed in three ways; 1) as a test score e.g. 15.02; 2) by the number of lengths completed e.g. 146; and 3) the estimated VO_2Max e.g. 64.2 ml.kg^{-1}min^{-1} using the conversion table reported by Ramsbottom et al 1988. In preparation for the test the subjects performed a structured and standardised warm-up that consisted of jogging, static and dynamic stretches and moderate intensity agility exercises. All players wore a downloadable HR (HR) monitor (Team Polar, Polar Electro Oy, Kempele, Finland) which recorded HR at 5 second intervals during the test. The highest HR during the test for each individual was then checked against their known HR_{max} to ensure that their effort in the test was maximal (within 5 b.min^{-1}). All participants were very experienced at performing the beep test and achieved the HR criteria.

Speed Testing

Speed and quickness were measured using a single test which was performed on turf using dual beam electronic timing lights (SWIFT Performance Equipment, Lismore, Australia). The testing session was performed in still conditions. After a thorough, structured warm up, athletes sprinted in a straight line through timing gates placed at 0m, 10m, 20m, 30m, 40m, and 50m marks. A line was drawn on the turf 30cm back from the first (0m) gate. Before starting each trial the subjects' front foot/toe was required to be on this line. Each trial was started with a verbal countdown (3-2-1-Go!) and direct instruction was given not to rock backwards before starting. The time started as the subject broke the beam of the gate at 0m. Three trials were performed by each athlete with a rest period of at least 3 minutes between trials. Two variables were taken from the data; quickness and maximum speed. Quickness was measured as the time taken between the 0m and 10m gates using the average of the two fastest trials. Top speed was defined as the fastest 10m segment in each trial. The average of two fastest trials was then converted to $km.h^{-1}$.

Bench Press

Upper body strength was measured ten days prior to the first data collection match using 3RM (repetition maximum) barbell bench press. After two submaximal warm up sets the athletes were required to perform three consecutive and unassisted repetitions using the heaviest weight possible. Athletes were allowed a maximum of 3 incremental attempts to record their 3RM. If a repetition was to qualify as complete the bar was required to touch the chest at the bottom of the movement and the elbows needed to be straight at the top of the movement. The bar was not allowed to bounce off the chest and the hips, shoulders and head were required to be in contact with the bench at all times. Assistance was only given to the athlete if the bar was unable to be lifted or was stationary for 3 seconds during the movement. Assistance resulted in an unsuccessful attempt. The load was recorded as the weight of the bar (20kg) plus added weight (in 2.5kg increments).

APPENDIX 2: GPS SPIELITE RELIABILITY AND VALIDITY

As there are no published studies using the SPI Elite GPS units during team sports there are no independent measures of validity or reliability. Consequently a series of simple studies were carried out to assess some key points.

1. Vailidity/Accuracy of distance measurements across a range of speeds
2. Vailidity/Accuracy of speed measurements across a range of speeds
3. Inter-reliability of the units (distances in zones, speed)

Validity of Distance Measurements

The objective was to compare the distance recorded by multiple GPS units over a set course to the actual distance as measured by a calibrated meter wheel. Two courses were set-up on a hockey turf using marker cones. One consisted of relatively long distances with few turns while the other consisted of short distances with frequent changes of direction. Each course was completed a total of eight times; twice each at four incremental speeds by a single subject. The data was analysed to compare total distance travelled to the actual distance.

Course 1: (Actual distance: 198.6m)

Course details: A zig-zag pattern requiring 18 changes of direction of between 90 and 180 degrees. The average distance between a change of direction was 10.5m (refer to figure 18)

Table 25: GPS validity and reliability data - Course 1

	Average Speed (km.h-1)	Average Distance Recorded	TEM %
Speed 1 – Walking	5.6	203.5	2.47
Speed 2 – Jogging	9.9	208.9	4.98
Speed 3 – Running	13.2	212.0	6.75
Speed 4 – Fast Running	16.3	216.5	9.01

Course 2: (Actual distance: 226.0m)

Course details: A square/loop pattern with seven changes of direction of between 45 and 90 degrees. The average distance between changes of direction was 28.3m (please refer to figure 18)

Table 26: GPS validity and reliability data - Course 2

	Average Speed (km.h-1)	Average Distance Recorded	TEM %
Speed 1 – Walking	6.6	230.0	1.77
Speed 2 – Jogging	11.9	237.0	4.87
Speed 3 – Running	17.3	239.5	5.97
Speed 4 – Fast Running	21.3	245.5	8.63

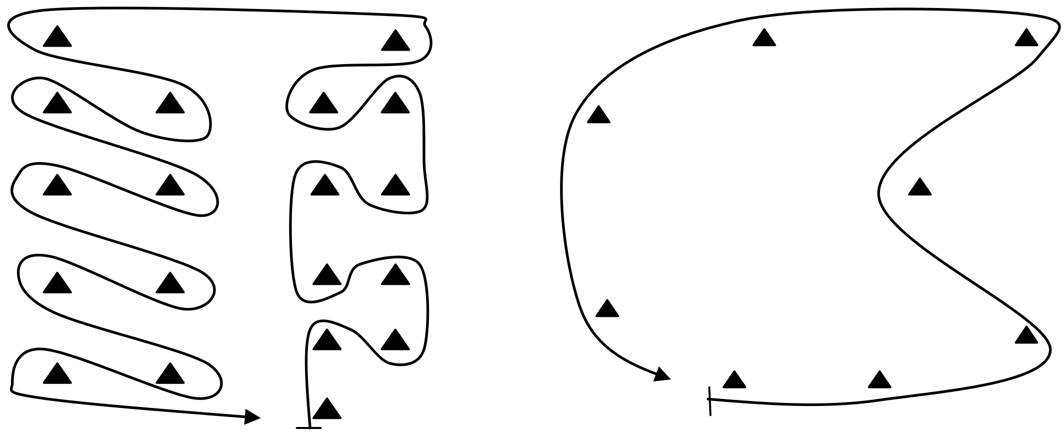

Figure 18: Reliability course 1 (left) and course 2 (right)

Validity of Speed Measurements

The objective was to identify the comparability between speeds reported by the GPS units and those recorded by speed timing lights. One participant wore two GPS units while performing six sprints of incremental speed on an athletics running track. The session was recorded with a video camera from a side-on position at a height of approximately 20 metres and distance of 40m. Marker cones were placed every 1 metre on the running track to provide a calibration scale for speed and distance measurement. A sprint was performed approximately every two minutes and each sprint was preceded by a 60 second stationary period (to allow for exact determination of the start of the sprint within the GPS data). The video footage of each sprint was captured to a PC computer and maximum speed was calculated using Silicon Coach.

Table 27: GPS validity of speed measurements

Trial	Speed Video (km.h-1)	Speed GPS (km.h-1)
1	17.28	17.2
2	24	23.7
3	24	24.05
4	24	24.2
5	27.6	27.3
6	27.05	27.1

Finding: the data suggest that the speed information provided by the GPS units is similarly accurate to cinematographic methods.

Inter-unit Reliability of Measurements

Part 1: Reliability of distance measurement

The objective was to identify the comparability between the outputs of two units when worn by the same player during a hockey match. One player wore two units during a club hockey match. The two units were worn in separate harnesses but were taped together side by side to ensure that one did not block the others communication with the satellites in any way.

Table 28: Reliability of GPS units during matchplay

Zone	Speed Range (km.h-1)	Unit 1	Unit 2	Stdev as % of Average
Very Low Intensity	0-6	2315	2334	0.58
Low Intensity	6.1-11	2408	2441	0.96
Moderate Intensity	11.1-14	1080	1103	1.49
High Intensity	14.1-19	1176	1190	0.84
Very High Intensity	19.1-23	492	518	3.64
Maximal Intensity Sprint	23+	284	301	4.11

Finding: the units provided similar measurements in all zones with the two fastest speed zones have the lowest inter-unit reliability.

Part 2: Reliability of speed measurement

The objective was to identify the comparability between two units when worn by the same player during speed training session. One participant from the study wore two units during a fitness session. The two units were worn in separate harnesses but were taped together side by side to ensure that one did not block the others communication with the satellites in any way. The player performed 14 repetitions of a 50m near-maximal sprint with 90 seconds between repetitions.

Table 29: Reliability of speed outputs from GPS units

	Unit 1	Unit 2
Average distance per repetition (m)	54.91	54.90
Average duration of each repetition (s)	7.36	7.21
Average top speed of each repetition (km.h-1)	29.09	28.98

Finding: there was a high level of inter-unit reliability when recording speed during sprints

APPENDIX 3: MATCH VALIDITY

Table 30: Comparison of striker GPS outputs to international test match data

	International	Study Data Set
3 Striker Distance (m)	25171	25119
3 Striker High Intensity Distance (m)	2186	2099

Table 31: Comparison of performance statistics and striker contribution points to international test match data

	Average	Study Data Set
Performance Stats - A25	28	34.4
Performance Stats - ACP	19	18.4
Performance Stats - AO	9	10.4
Performance Stats - D25	26	22.2
Performance Stats - DCP	18	14.8
Performance Stats - DO	10	9
Total Technical Outputs	210	214

APPENDIX 4: PARTICIPANT INFORMATION SHEET AND CONSENT FORM

Project Title:	**The effect of differing substitution methods on the physical and technical outputs of strikers during match play in elite men's field hockey.**
Project Supervisor:	**Dr. Andrew Kilding**
Researcher:	**John Lythe**

You are invited to participate in a study investigating the effects of differing striker substitutions systems in elite men's hockey. This study is being undertaken as part of a Masters of Health Science qualification. Participation is completely voluntary and you may withdraw at any stage without giving a reason or being disadvantaged.

What is the purpose of the study?

The purpose of the study is to determine the most effective method of rotating strikers during international hockey matches. The typical 5 striker rotation will be compared to a 4 striker rotation and different substitute timings will also be investigated to see which system provides the greatest technical and physical contribution to the game.

Can I join the study?

The study is restricted to members of the NZ Men's Hockey Team. You are able to join the study if selected by the National Coach to be a member of this team.

Costs of participating?

You will not incur any monetary costs participating in this study as data collection will occur during trial matches and during preparation for Commonwealth Games.

What happens in the study?

Five games will be analysed to provide the data for this project. During these five games you will wear GPS units during the game to provide information as to the physical outputs. The game will also be subject to a detailed level of SportsCode analysis and your technical outputs will also be rated i.e. passes, carry's, shots, tackles etc.

What are the benefits?

These results will improve our understanding of the effects of different striker rotations. This improved knowledge will allow the selection of a more optimal team for each match and ultimately improve the performance of the team.

What are the discomforts and risks?

The risks involved in this study are minimal. Your only requirement is to wear a small GPS device in each of the matches. This device will not place you at any increased risk of injury or cause you any discomfort. Otherwise you will simply play the match as per normal.

What compensation is available for injury or negligence?

The researcher, AUT or the principal supervisor will not be responsible for any monetary loss incurred in the unlikely event of injury. The ACC system, with its limitations, will provide standard cover if participants are injured.

How is my privacy protected?

All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study.

Results

The results of this project will not be passed on to any others (including the national coach) without your specific approval. You will not be personally identified in any of the data reporting or project discussion. The results will be used for the purposes of a thesis and also academic publication. All data will be safely stored at AUT following conclusion of the project and then destroyed after a period of 6 years.

Time To Consider Invitation

You will be given time (14 days) to consider this invitation.

Participant Concerns

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Project Supervisor
Dr. Andrew Kilding
Senior Lecturer, Exercise Science
Division of Sport and Recreation
Auckland University of Technology
Phone 921 9999 ext 7056

Principal Investigator
Mr John Lythe
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Auckland University of Technology
Phone +6421 745-551
Email: fitter@slingshot.co.nz

Approved by the Auckland University of Technology Ethics Committee:
AUTEC Reference number:

Consent to Participation in Research

Title of Project: **The effect of differing substitution methods on the physical and technical outputs of strikers during match play in elite men's field hockey.**

Project Supervisor: **Dr. Andrew Kilding**

Researcher: **John Lythe**

- I have read and understood the information provided about this research project.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all my data may still be used in the final report but my identity will remain confidential.
- I agree to take part in this research.
- I wish to receive a copy of the report from the research.
- I do not have any current injuries or medical conditions that would exclude me from participation.

Participant signature: ....……………………..

Participant name: ……………………………………………………………

Participant Contact Details (if appropriate):

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………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on:

AUTEC Reference number:

Note: The Participant should retain a copy of this form.