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Global Positioning System Analysis of Elite and Sub-Elite Scottish Field Hockey:

Understanding the Physical Demands of Competition and Training

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Abstract

The purpose of this doctoral thesis was to identify the physical activity of Scottish elite and sub-elite field hockey competition and training. Secondary aims included the identification of specific analysis procedures and training interventions for this group. Global Positioning System (GPS) analysis was used to quantify the physical activity demands at both levels. All observations were made using the Catapult MinimaxX 5 Hz GPS for male and female field hockey in both the elite and sub-elite environment. Initial study validated the use of Full Game (FG) analysis as a more specific measure of field hockey competition than Time on Pitch (TOP) analysis due to the inclusion of bench time important in field hockey. Competition and training analysis reported that elite Scottish players complete less activity than other elite players in the literature. Analysis of training showed that the drills used have the potential to stimulate the correct energy systems but are affected by duration and skill level. The comparison of elite and sub-elite field hockey revealed the utilisation of energy systems was different at each level of competition. Opposition ranking was shown to negatively affect competition activity when playing against high and low ranking teams. Additionally, poorer skill levels in the sub-elite environment reduces the intensity of competition and training thus diminishing the conditioning effect during the domestic season. Elite Scottish hockey players are detrimentally affected by the sub-elite environment – the reduced activity in sub-elite field hockey and inappropriate conditioning stimulus affect the resultant activity levels in elite competition. To further investigate this area it is necessary to study potential training interventions to improve speed training and potential logistical changes such as player drafts and rules regarding player numbers in a match day squad.

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Publications & Posters

Publications

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Abstracts

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Influence of Opposition on Game Play intensity During Women's National League Field Hockey.

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Contextual Effects on Activity Profiles of Domestic Field Hockey During Competition and Training. Journal of Human Movement Studies.

Definitions

Variable	Description
Elite	International standard (i.e. Scotland, Great Britain, etc.)
Sub-Elite	Domestic standard (sometimes referred to as national standard)
$Elite_{SE}$	International player playing in domestic environment
Competition	Any match-play with officials including friendlies
Training	All other un-officiated hockey sessions
Absolute *Variable*	Variable as raw data
Normalised/Drill (per 70 min)	Variable normalised to 70 minute competition period [(variable/drill duration) x 70]
Relative *Variable*	Variable relative to 1 minute (variable/duration)
'Efforts'	An effort is categorised as an action lasting longer than 1sec (i.e. running at 15 $km \cdot hr^{-1}$ for 1 sec would equal 1 effort > 15$km \cdot hr^{-1}$)
Exercise Time	Duration minus Rest Time
E:R Ratio	Exercise to Rest Time Ratio

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1. Introduction

1.1 Field Hockey

1.1.1 Basic history

Field hockey is suggested to originate from as far back as 1000 BC where it is said people in Ethiopia played a game which resembled the sport which is played today. However, the modern version of hockey is more similar to the game played in England in the mid - 18th century. Its evolution and development has spread the game to 5 continents and 127 member associations. It is a well-established Olympic sport, is played at the Commonwealth games, numerous international competitions along with numerous domestic leagues across the globe being played throughout the year.

1.1.2 Rules

Field hockey is played on an Astro-turf pitch which is rectangular in shape and has a regulation size of 91.4 m (~ 100 yards) x 55.0 m (~ 60 yards). The pitch has two goals at the ends of the pitch which are surrounded by a 14.6 m (~ 16 yards) semi-circular lined box (FIH Rulebook, 2013). Players play with a hooked stick which has a flat left side – only this side of the stick can be used to contact the ball at any time. Sticks are allowed a small vertical bend but restrictions apply as to how much they can diverge when lying flat on the ground. Goalkeeping sticks have an additional horizontal bend in the shaft unlike outfield players.

Games are played with eleven players, usually ten of which are outfield players and one goalkeeper. In some circumstances there can be eleven outfield players with one player given goalkeeping privileges. Substitutions are permitted at any time during the game except when a penalty corner or penalty stroke is awarded. Teams are allowed up to five substitutes and an unlimited number of interchanges. Further to this, teams can change as many substitutes in one go as they wish (i.e. remove five players and replace them with all five players on the bench) (FIH Rulebook, 2013).

A senior game of field hockey has a regulation time period of seventy minutes. This is broken into two thirty-five minute halves with a five minute interval (FIH Rulebook, 2013). The aim of the game is to score in the opposing goal and involves players, passing the ball along the ground or in an aerial fashion to members of their own team in an attempt to move up the pitch and score. Outfield players must not control or pass the ball with any part of their body. Only goalkeepers can kick the ball. Any infringement results in a 'free-hit', where the ball is stopped and the player can have a free pass to their teammates or themselves (known as a 'self-pass'). Infringements can lead to warnings, green cards (2 minute suspension from play), yellow cards (minimum of 5 minutes suspension from play) and red cards (removal from the game) (FIH Rulebook, 2013).

*All rules reproduced from International Hockey Federation (FIH) rule book, Lausanne, Switzerland which can be found on the FIH website, www.fih.ch/en/sport/rules.

1.1.3 Scottish Hockey

Scottish hockey has been around since the beginnings of the modern game in 18th century England. Furthermore, Scottish hockey affiliates have been key stakeholders in a number of important events throughout the years. Initially competitive field hockey in Scotland began in 1891 when the first game was played between Fettes College and Loretto School. In 1900 the Scottish Hockey Association (SHA) and Scottish Women's Hockey Association (SWHA) formed and international games were played two years later against England, Wales and Ireland. Later the SWHA played a role in the formation of the FIH (FIH website; http://www.fih.ch/en/fih/history).

Further to this, Scottish teams and players have been important contributors to the sports Olympic participation. Field hockey's inaugural participation in the Olympic schedule in 1908 saw a Scotland team have its first Olympic involvement. In later years when Great Britain entered its first Olympics, five Scottish players made the men's squad. This tradition has continued throughout the years with players from Scotland playing in successful Great Britain's medal winning teams. The most recent being Laura Bartlett and Emily Maguire winning bronze medals at the London Olympics in 2012.

The men's team have dropped to the second tier of European competition, Euro division B (2nd tier), and provided no players to the London 2012 squad. At the time of study the mens senior international team sit in the middle of the current world rankings at 22nd.

The country’s low world ranking is, in part, due to the Great Britain team and the allocation of points to the four home nations when Great Britain plays. Points are allocated to each nation depending on the amount of players supplied to Great Britain by that country. So as Scotland currently have limited players in either of the two Great Britain squads very few points are given to Scotland on the occasions that Great Britain play.

However this is only a small issue which should not be used to mask the level of field hockey in Scotland. National league hockey is of a poor standard and the top players leave to further their careers. Currently no club team plays in the top level of the European club hockey league – men’s or women’s - and this highlights the level at which hockey is played in Scotland. Further to this a Sportscotland investigation into sports participation in Scotland showed field hockey to have an extremely small percentage of participants compared to other sports (Sportscotland, 2008). It showed the majority of people who play field hockey are between 8 - 15 years old with markedly reduced numbers post-school years. Furthermore, it reported that the majority of adult players are male but this still only accounted for 0.6 % of the total male participants in sport. In comparison there were 17.8 % of participants who played soccer and 5.8 % who played snooker on a regular basis.

In addition to this issue there is a lack of support for players in terms of physiology and sports science and a spreading of talent among a large club and league structure. The majority of Sportscotland funding is given to the two senior international teams. These players are given Sportscotland Institute of Sport support which consists of full time coaches, strength and conditioning coaches, physiologists, physiotherapists, nutritionists and psychologists. This support is given to approximately 40 - 50 players – male and female combined. Players in the tiers below the senior team are supported through the Scottish Hockey Union. Some of these are given strength and conditioning and physiotherapy provision but the larger majority rely on their domestic clubs to provide them with support systems, training programmes, facilities, medical care and hockey education. At the time of this study the quantity and quality of support at club level is one of the reasons for the inability to produce world class players from the small player pool in Scotland.

1.2 Physiology

Field hockey players are required to produce high speeds greater than 30 $km \cdot hr^{-1}$ (Lythe and Kilding, 2011), repeat sprints up to seven times in a row with limited recoveries (Spencer *et al*, 2004) and cover up to 8 km in a game (Gabbett, 2010; Lythe and Kilding, 2011; Macutkiewicz and Sunderland, 2012). This Chapter will describe the physiological requirements for this type of activity and the relevance of laboratory and field based testing of these parameters in field hockey players. It will also consider the physiological abilities of field hockey players in comparison to other athletes including those from other team sports.

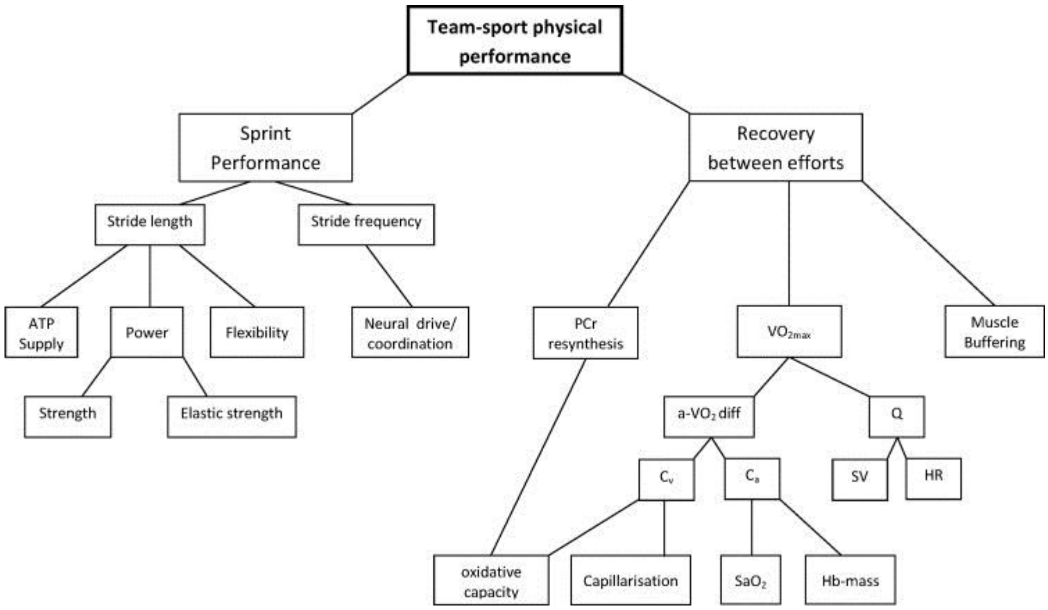

Figure 1.1 The physiological factors required for team sport performance as displayed by Bishop and Girard (2013)

1.2.1 Energy Systems

Team sport performance requires the utilisation and resynthesis of adenosine triphosphate (ATP) during the seventy minutes of a game (Bishop and Girard, 2013). For the majority of the game – approximately 70 – 80 % of the game - aerobic metabolism is the main source of energy (Reilly and Borrie, 1992). The remaining 20 - 30 % of the game is a mixture of ATP, phosphocreatine (PCr) and anaerobic glycolysis. Initially during periods of repeat sprint exercise (RSE), PCr and anaerobic glycolysis provide the largest proportion of ATP resynthesis with an increased reliance on PCr during subsequent efforts (Girard, Mendez-Villanueva and Bishop, 2011). As such all of these energy systems are utilised during different portions of competition depending on the type and intensity of physical activity.

In a review by Stone and Kilding (2009) aerobic fitness was identified as a key facet required by team sport athletes to be able to cope with the demands of competition. The maximal oxygen consumption (VO_{2max}) of players has been assessed via direct laboratory measures and indirect field based measures. Table 1.1 and 1.2 shows the VO_{2max} of male and female players reported in the literature. It can be seen here that VO_{2max} values for elite male players range from approximately 55 to 65 $mL \cdot kg^{-1} \cdot min^{-1}$. The most recent values reported using maximal treadmill tests on male international players show players to have mean VO_{2max} values towards the higher end of this range (64.2 $mL \cdot kg^{-1} \cdot min^{-1}$ Jennings *et al*, 2012a). This is similar to the reported VO_{2max} of elite soccer players with similar body composition (62 - 64 $mL \cdot kg^{-1} \cdot min^{-1}$, Tonneson, Hem, Leirsten, Haugen and Seiler, 2013 $mL.kg^{-1}.min^{-1}$, Reilly, Bangsbo and Franks, 2000) and larger semi-professional rugby league players using maximal treadmill tests (~57.9 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$, Coutts, Raeburn and Abt, 2003). Contrary to this when comparing VO_{2max} values predicted by multi stage fitness test (MSFT) the values reported on professional rugby league backs and forwards are less than those in field hockey (~51 $mL \cdot kg^{-1} \cdot min^{-1}$ and 50 $mL \cdot kg^{-1} \cdot min^{-1}$, backs and forwards respectively, Gabbett, 2002).

The similarities to soccer players and differences to rugby league players may be due to the interaction of the testing procedure and the body composition of the players. Soccer and field hockey players usually fit a similar anthropometric profile – average height and lean build (see more in body composition Chapter 1.1.4.5). On the other hand rugby league players are generally shown to be larger athletes (Gabbett, 2000 and Gabbett, 2007). The MSFT which is used in these to predict maximal oxygen consumption involves 180 degree turns every 20 m. During every turn a player must decelerate their mass to the same speed (0 km·hr^{-1}) which is easier for smaller players due to Newtons second law of physics [Force = mass x acceleration (Gamble, 1986)] and the increased force required by the bigger players to slow down (O'Gorman, Hunter, McDonnacha and Kirwan, 2000). If you consider an average sized car performing a U-turn in the road compared to a van or a lorry and you can visualise the increased forces required and subsequently imagine the demands that are placed on the bigger rugby players compared to the smaller soccer and field hockey players. It has been shown previously that the larger rugby league players are poorer at changing direction than the smaller players within a squad (Gabbett, Kelly and Pezet, 2008). Additionally it has been reported that there is a greater physiological demand during shuttle running (Bucheit, Bishop, Haydar, Nakamura and Ahmaidi, 2010). As such it may not be that the cardiovascular system has reached a maximum for these players but that other muscular factors have caused the athletes to end the test. The influence of the types of movement on the cardiovascular system and maximal oxygen consumption highlights the need to consider this during other areas such as competition and training. For instance carrying out small sided games (SSGs) in confined areas, requiring many changes of direction will have a greater demand on large players resulting in a reduced activity.

In sub-elite male field hockey the VO_{2max} of players have previously been shown to be similar to that of their elite counterparts. This phenomenon was present during the 1970s, '80s and '90s when sub-elite aerobic capacities were reported to be greater than 60 $mL \cdot kg^{-1} \cdot min^{-1}$ (see Table 1.1). However in recent times the distinction between the two is more marked. For instance, Lythe and Kilding (2011) and Jennings and colleagues (2012a) show mean VO_{2max} values around 64 $mL \cdot kg^{-1} \cdot min^{-1}$ in elite players. Whereas Franke and colleagues (2010) and Indranil and colleague (2011) show sub-elite players to have aerobic capacitates in the mid-50s ($mL \cdot kg^{-1} \cdot min^{-1}$).

Level	*n*	Mean VO_{2max} (± SD) ($mL \cdot kg^{-1} \cdot min^{-1}$)	Method Obtained	References
Sub-Elite (Australia)*	9	64.1	TM	Withers *et al*, 1977
Sub-Elite (Australia)*	14	60.7	TM	Roberts & Morton, 1981
Elite (UK)*	20	62.2	TM	Hargreaves, 1983
Elite (England)	12	45.7 ± 8.9	SM	Reilly & Bretherton, 1986
Sub-Elite (England)	12	40.6 ± 6.1	SM	Reilly & Bretherton, 1986
Elite (West Germany)*	5	63.5	TM	Rost, 1987
Elite and Sub-Elite (Spain)*	26	59.7	TM	Drobnic *et al*, 1989
Sub-Elite (UK)	7	69 ± 5	TM	Reilly & Seaton, 1990
Unknown (India)	29	53.8		Ghosh *et al*, 1991
Elite (Unknown)	9	61.8 ± 1.8	TM	Boyle *et al*, 1994
Elite	14	55.7	MSFT	Spencer *et al*, 2004b
Sub-Elite (England)	9	60.1 ± 7.6	TM	Stagno *et al*, 2005
Elite (Poland)	10	54.3 ± 3.0	TM	Konarski *et al*, 2006
Elite (Germany)	17	55.8 ± 4.0	TM	Hinrichs *et al*, 2010
Sub-Elite (Germany)	17	56.0 ± 6.1	TM	Franke *et al*, 2010
Elite (New Zealand)	18	64.9 ± 1.9	MSFT	Lythe & Kilding, *2011*
Sub-Elite (India)	30	54.1 ± 4.0	TM	Indranil *et al*, 2011
Elite (Australia)	15	64.2 ± 3.1	MSFT	Jennings *et al*, 2012a

Table 1.1. Collated maximal aerobic capacities in elite and sub-elite male field hockey players (**taken from Reilly & Borrie, 1992).TM = Maximal Treadmill Test, SM – Sub-maximal Test, MSFT = Multi Stage Fitness Test*

Female aerobic capacities have been shown to be slightly lower than males and range from 40 to 59 mL·kg^{-1}·min^{-1}. The most recent values reported for elite female players are 52.9 ± 2.9 mL·kg^{-1}·min^{-1} (MacLeod and Sunderland, 2012). This is not much different from previous studies in elite men and women in the early '80s (Hargreaves, 1983 and Reilly *et al* 1985; values taken from Reilly and Borrie, 1992) and may suggest that the development of the physical condition of female field hockey players has not been significant during this time. However, these values are still comparable to modern elite female soccer players (51.4 ± 5.4 mL·kg^{-1}·min^{-1}, Gabbett and Mulvey, 2008). The reported VO_{2max} values of sub-elite players ranges from approximately 39 to 54 mL·kg^{-1}·min^{-1}. Even in the early 1980s, VO_{2max} values of 50.1 mL·kg^{-1}·min^{-1} where reported in a group of sub-elite Australian players (Rate and Pyke, 1981; values taken from Reilly and Borrie, 1992). Compare this to the most recent literature in sub-elite players, De Souza and colleagues (2010), who reported VO_{2max} of collegiate American players to be 53.6 mL·kg^{-1}·min^{-1}and it can be suggested that very little change has occurred over this time period. It can also be suggested from these values that elite and sub-elite players have similar VO_{2max} capacities and like their male counterparts these are similar to soccer players of the same gender.

Level	*N*	Mean VO_{2max} (± SD) ($mL \cdot kg^{-1} \cdot min^{-1}$)	Method Obtained	References
Sub-Elite (USA)*	10	42.9	TM	Maksaud *et al*, 1976
Elite and Sub-Elite (USA)*	10	51.7	TM	Zeldis *et al*, 1976
Sub-Elite (Australia)*	6	50.1	TM	Rate & Pyke, 1981
Sub-Elite (USA)	18	47.9	TM	Babcock *et al*, 1984
Elite (Canada)*	10	54.5	TM	Reilly *et al*, 1985
Elite (Canada)*	16	59.3	TM	Ready & van der Merwe, 1986
Sub-Elite (England)*	12	52.2	TM	Cheetham & Williams, 1987
Sub-Elite (USA)	37	42.9 ± 9.1	QCST	Wassmer *et al*, 2002
Elite (Australia)	35	43.7 ± 1.2	MSFT	Keogh, Weber and Dalton, 2003
Sub-Elite (Australia)	39	38.9 ± 1.3	MSFT	Keogh, Weber and Dalton. 2003
Sub-Elite (England)*	9	50.3 ± 1.1	MSFT	Sunderland & Nevill, 2005
Sub-Elite (UK)	20	48.6 ± 1.0	MSFT	Leslie *et al*, 2008
Elite (Australia)	14	53.5 ± 4.3	MSFT	Gabbett, 2010b
Elite (Germany)	17	46.6 ± 2.9	TM	Hinrichs *et al*, 2010
Sub-Elite (USA)	17	53.6	MSFT	De Souza *et al*, 2010
Elite (UK)	8	52.9 ± 2.9	TM	MacLeod & Sunderland, 2012

Table 1.2. Collated maximal aerobic capacities in elite and sub-elite female field hockey players (**taken from Reilly & Borrie, 1992). TM = Maximal Treadmill Test, SM – Sub-maximal Test, MSFT = Multi Stage Fitness Test, QCST = Queens College Step Test*

The differences in VO_{2max} values reported between field hockey players at each level may be due to the prediction of VO_{2max} from the MSFT which has been shown to be 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ lower than a direct measurement from a treadmill test (Grant, Corbett, Amjad, Wilson and Aitchison, 1995). The discrepancy between the MSFT and laboratory treadmill tests has been reported again in more recent literature which stated an under prediction of 1.8 $mL \cdot kg^{-1} \cdot min^{-1}$ from individuals with VO_{2max} values similar to those of male field hockey players – 55 - 57 $mL \cdot kg^{-1} \cdot min^{-1}$ (Cooper, Baker, Tong, Robert and Hanford, 2005). These amount to an approximate reduction 1 – 3 % of VO_{2max} during the MSFT compared to the direct treadmill assessments in both studies. However, if the MSFT values presented in Table 1.1 and 1.2 were to be increased by 1.8 to 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ or 1 – 3 % the inferences presented above would not change. This is because the MSFT values in the males athletes are greater than those reported using treadmill testing and the female values would continue to show that elite and sub-elite have similar VO_{2max} results.

In a review by Reilly and Borrie (1992) the estimated oxygen uptake during field hockey match play was 2.26 $L \cdot min^{-1}$. Further to this, Boyle, Mahoney and Wallace (1994) used VO_{2max} values from treadmill tests and competition HR data to estimate oxygen consumption during competition. This group of male players had VO_{2max} values of 61.8 $mL \cdot kg^{-1} \cdot min^{-1}$ which is amongst the highest values reported in the literature (Table 1.1). The mean estimated oxygen uptake reported by Boyle and colleagues (1994) during competition was 78 % of the average VO_{2max} value of the group (48.2 $mL \cdot kg^{-1} \cdot min^{-1}$). Lothian and Farrally (1995) used the same method of estimating competition oxygen consumption via a direct assessment of oxygen kinetics during a treadmill test and HR data with female team sport players. Their results showed HR analysis to overestimate the oxygen uptake by a mean of 4.3 % (0.09 $L \cdot min^{-1}$). These values are similar to those found in competitive soccer (Bangsbo, 1994) which is played for 90 minutes and requires players to maintain energy throughout this period. Subsequently this would suggest that field hockey is of a lower intensity. However Boyle and colleagues (1994) study was conducted 20 years ago before the removal of the off side rule in 1997 and open substitutions in 1999 (Cooper, 2011). The mean HR reported in modern literature is higher suggesting an increased overall demand and increased mean oxygen consumption during these games (Lythe and Kilding, 2011 and Macutkiewcz and Sunderland, 2011).

Lythe and Kilding (2011) reported mean HR of 161 $b \cdot min^{-1}$ which corresponded to 85.3 ± 2.9 % HR_{max} during international male competition. The peak HR reported in the same competition 196 $b \cdot min^{-1}$ or 96.3 ± 2.7 % HR_{max} In the women's game, Macutkiewicz and Sunderland (2011) recorded mean HR as 172 ± 8 $b \cdot min^{-1}$ during international matches. This is similar to those shown in rugby union (Duthie, Pyne and Hooper, 2003) and soccer (Stølen, Chamari, Castagna, and Wisløff, 2005). Additionally the peak HR is similar to those shown in soccer (Stølen, Chamari, Castagna, and Wisløff, 2005) and higher than those reported in rugby union (Duthie, Pyne and Hooper, 2003). This data suggests that field hockey players play at similar HR intensities to soccer players – both across the whole period (mean HR) and during the most intense periods (peak HR). However with the increased duration of soccer games (90 mins versus 70 mins) there is a more prolonged aerobic demand on soccer players.

The mean estimated energy expenditure during field hockey has been shown to be 5.19 MJ with rates ranging from 61to 83 $kJ \cdot min^{-1}$ (Boyle, 1994). Reilly and Borrie (1992) reported estimated energy expenditure to range from 36 to 50 $kJ \cdot min^{-1}$. It has also been reported that energy expenditure is increased by 15 - 16 $kJ \cdot min^{-1}$ due to the semi-crouched posture resulting from running with a field hockey stick (Reilly and Seaton, 1990 and Wdowski and Gittoes, 2013). However the mean energy expenditure during soccer has been reported to be higher – at 6.55 MJ for a 90 - minute game (Shephard, 1992). This is largely due to the increased playing time as both VO_{2max} values and mean HR data reported by Shephard and colleagues (1992) during competition is similar to that reported by Boyle (1994). In addition, semi-professional rugby league competition has been shown to have greater energy expenditure than both field hockey and soccer - 7.9 ± 0.4 MJ during an 80-minute game (Coutts, Raeburn and Abt, 2003). These players have similar VO_{2max} values (57.9 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$) and mean HR during competition (167 $b \cdot min^{-1}$) as both field hockey players and soccer players however use a greater percentage of VO_{2max} (81.1 ± 5.8 %). This difference may be due to the contact element of rugby league which was reported as a limitation of the study by Coutts and colleagues (2003). It may also be that during rugby league repeated efforts may involve contact and running based exercise (Austin, Gabbett and Jenkins, 2011) whereas in field hockey and soccer the exercise is predominantly running based.

All of the studies that have been mentioned in the previous paragraph reported energy expenditure estimated during match play from the HR data obtained via treadmill running tests. This has been shown to be a valid measurement for energy expenditure estimation (Strath, Bassett, Thompson and Swartz, 2001) but has limitations.. For instance HR response can be altered due to emotional stress, temperature, humidity, dehydration, posture and illness and as such will give an inappropriate energy expenditure (Ainslie, Reilly and Westerterp, 2003). In addition the size of the muscle group used my alter the HR response – it has been shown that arm-only, leg-only and whole body exercise have different exercise responses (Astrand and Saltin, 1961). As such using this method for field hockey a whole body exercise where posture changes regularly occur may be less accurate than in sports such as soccer.

As has previously been mentioned the aerobic energy producing system in field hockey players provides 60 % of energy during competition resulting in players maintaining mean HR of over 160 $b \cdot min^{-1}$ and 78 % VO_{2max} during competition (Reilly and Borrie, 1992; Lythe and Kilding, 2011 and Macutkiewicz and Sunderland, 2011). Further to supplying energy for the low intensity activity below ventilatory threshold and moderate intensity activity between ventilatory threshold and respiratory compensation point (Esteve-Manao, San Juan, Earnest, Foster and Lucia, 2005) the aerobic capacity of field hockey players is important for recovery during repeat sprint exercise (RSE) (Spencer, Lawrence and Bishop, 2003). The aerobic energy contribution can reach 40 % during repeat sprint ability (RSA) testing and athletes can reach VO_{2max} during later sprints (Girard, Mendez-Villanueva and Bishop, 2011). RSE has been reported in field hockey competition - Spencer and colleagues (2004) reported 17 RSE occasions, involving between 3 and 7 sprints with an average recovery period of 14.9 seconds. The relationship between VO_{2max} and recovery between sprints has been suggested to be due to muscle oxidative capacity, capillarisation and haemoglobin mass and not changes to cardiac output (Bishop and Girard, 2013). In agreement with this, muscle buffering capacity – specifically buffering of hydrogen (H+) ions - and not VO_{2max} was correlated to recovery during RSA testing - laboratory based cycle ergometer testing involving 6 x 5 second repeat sprints (Bishop, Lawrence and Spencer, 2003).

In addition RSE exercise requires up to 40 % of ATP to be supplied via anaerobic glycolysis. Higher percentages (40 %) are found in the first sprints of RSE with a reduced demand (8 %) on anaerobic ATP with increasing numbers of sprints (Girard, Mendez-Villanueva and Bishop, 2011). A study comparing two RSA tests with identical total sprint distances (6 x 40 m versus 12 x 20 m, both equalling 240 m) produced differing physiological responses. It was reported that aerobic metabolism was involved to a greater extent in the higher repetition, short distance test and the lower repetition, long distance exercise was more of an anaerobic activity (Meckel, Machnai and Eliakim, 2009). This is in agreement to Girard and colleagues (2011) and may suggest that field hockey players are more reliant on their anaerobic energy producing system during RSE in competition as the maximum number of sprints reported by Spencer and colleagues (2004) is less than the high repetition test used by Meckel and colleagues (2009). During repeat sprint running test (6 x 40 m and 12 x 20 m) peak HRs of ~179 b·min^{-1} in the longer distance, low repetitions test and 184 b·min^{-1} in the short distance, high repetitions test were shown (Meckel, Machnai and Eliakim, 2009). This is likely due to the shorter rest periods between efforts (30 s versus. 20 s, low to high repetition respectively) which has been shown to increase the initial HR on subsequent bouts compared to longer rest periods (Mavrommataki, Bogdanis, Kaloupsis and Maridaki, 2006).

The small number of RSA studies specifically investigating field hockey is displayed in Table 1.3. These studies reported decrement scores during cycle based testing (Bishop, Lawrence and Spencer, 2003 and Spencer, Bishop and Lawrence, 2004) and running tests (Keogh, Weber and Dalton, 2003). The running decrement scores tend to report higher decrement scores (~ 13 % versus ~9 %, running and cycling respectively) for a 6 - 7 second effort. This is converse to the theory of task dependency reported by Girard and colleagues (2011). They reviewed all RSA literature and reported cycling to produce larger decrement scores. The running decrement scores in field hockey fall within the 5 – 15 % zone given by Girard and colleagues (2011). However the cycling scores are lower than the 10 – 25 % zone reported. This may be due to the field hockey players being unable to exhibit enough power during cycling testing as the power output during the initial sprint has been reported to correlate with the eventual decrement score (Girard, Mendez-Villanueva and Bishop, 2011). They also report the La accumulation post-exercise. The fatigue index and decrement scores have suggested to be able to show the performance of the both the aerobic and anaerobic energy producing systems depending on the protocol (Meckel, Machnai and Eliakim, 2009). However reliability of this decrement scores of information has been questioned due to the large CV of testing - up to 37 % in male soccer players carrying out a 6 x 40 m (Impellizzeri, Rampinini, Castagna, Bishop, Ferrari Bravo, Tibaudi and Wisloff, 2008) and CV of 50 % during 10 x 20 m testing (Oliver, Williams and Armstrong, 2006). In a review the usefulness of the fatigue index and decrement score has also been questioned due to unreliable nature of the mathematical equations used to derive both indices (Oliver, 2009).

Level	*n*	Gender	Decrement (%)	Method	References
Elite (Australia)	35	F	10.1 ± 1.4	RSA Decrement 6x10m Run	Keogh *et al,* 2003
Elite (Australia)	35	F	13.1 ± 1.0	RSA Decrement 6x40m Run	Keogh *et al,* 2003
Sub-Elite (Australia)	39	F	12.7 ± 1.4	RSA Decrement 6x40m Run	Keogh *et al,* 2003
Sub-Elite (Australia)	39	F	10.3 ± 1.1	RSA Decrement 6x10m Run	Keogh *et al,* 2003
Elite (Australia)	14	F	9.0 ± 2.4	RSA Decrement 5x6s Cycle	Bishop *et al,* 2003
Elite (Australia)	18	F	8.7 ± 3.6	RSA Decrement 5x6s Cycle	Bishop *et al,* 2004

Table 1.3. Anaerobic capacities, as measured by percentage decrement, of female field hockey players

ISE in field hockey occurs in the form of high speed running which has been shown to be a differentiator between elite and sub-elite field hockey players (Jennings, Cormack, Coutts and Aughey, 2012). Energy is supplied for these types of activity from immediate muscle ATP stores and PCr supply (Gastin, 2001). The resynthesis of PCr has been reported to be related to the ability to maintain power outputs during ISE with > 3 minute recoveries (Bogdanis, Nevill, Boobis, Lakomy and Nevill, 1995 and Spencer, Bishop, Dawson and Goodman, 2005). The speed test times reported in field hockey players in the literature are shown in Table 1.4. The 10 m sprint times are comparable to those of elite male soccer players (Wisloff, Castanga, Helgerud, Jones and Hoff, 2004). The 40 m sprint times are comparable to junior elite rugby league players aged ~ 16 years old (Gabbett, Kelly, Ralph and Driscoll, 2009). This suggests a reduced ability over longer distance however these occur rarely during a game (Spencer, Lawrence, Rechichi, Bishop, Dawson and Goodman, 2004). The distance covered during high speed efforts is too short to allow for maximal speed as athletes will still be in their acceleration phase. Thus being able to quantify acceleration as well as speed is important for field hockey. It is likely that maximal speed is more important when considering RSA as a higher max speed is correlated to an increased decrement score (Girard, Mendez-Villanueva and Bishop, 2011).

Level	*n*	0-10m (s)	0 - 40m (s)	References
Elite (England)	12	-	6.99 ± 0.44*	Reilly & Bretherton, 1986
Sub-Elite (England)	12	-	7.77 ± 0.65*	Reilly & Bretherton, 1986
Elite (Australia)	35	2.01 ± 0.02	6.53 ± 0.09	Keogh, Weber and Dalton, 2003
Sub-Elite (Australia)	39	2.16 ± 0.03	7.09 ± 0.11	Keogh, Weber and Dalton, 2003
Sub-Elite (South Africa)	12	-	6.37 ± 0.27	Boddington *et al,* 2004

Table 1.4. The speed characteristics of elite and sub-elite female field hockey players (*50 yards sprint equivalent to 45.54 m).

The cause of fatigue – the reduction in muscular function and performance (Abbiss and Laursen, 2005) - during field hockey is likely to be multifactorial. It is unlikely that fatigue will result from any one system such as energy supply, neuromuscular, cardiovascular or central drive (Abbiss and Laursen, 2005). Fatigue after RSE has been reported to be caused by a number of factors including muscular factors, neural factors, environmental factors and/or biomechanical factors (Girard, Mendez-Villanueva and Bishop, 2011). It is unlikely to be due to cardiovascular factors such as cardiac output as it has been shown that left ventricular systolic function was unaffected by competitive rugby union and soccer games (George, Dawson, Shave, Whyte, Jones, Hare, Gaze and Collinson, 2004). However it has been suggested that muscular factors - either the reduction in sarcolemma excitability because of ion accumulation (Girard and Millet, 2009) or reduced excitation contraction coupling due to decreased calcium release from the sarcoplasmic reticulum (Westerblad, Allen and Lannergren, 2002) – may be a cause of fatigue post-RSE. It has also be suggested that temporal neuromuscular fatigue could be caused due an accumulation of metabolites in the periphery (Girard and Millet, 2008). The exact mechanisms of fatigue have been described in the literature yet the contribution each of these systems has during fatigue in team sports is still relatively unknown. The physical impact the physiology of an athlete has on performance and subsequently competition outcome is the most important differentiator. As such being able to quantify the distances, speeds, accelerations and decelerations – and therefore infer physiological abilities, pacing and fatigue – is hugely important for practitioners to improve performance.

The current understanding of the interaction of physiology and performance in field hockey players is best described in three studies in the literature, namely Gabbett (2010b), Lythe and Kilding (2011) and Macutkiewicz and Sunderland (2011). The latter two studies quantify the physical demands of male and female competition using HR and GPS data. This provides a good overview of what happens on the field (further described in Chapter 1.2.5) but removes all bench time from the competition data. This means exercise-to-rest ratios and thus the energy system utilisation is reported differently than it would be if the whole game was viewed. As such the conclusions made about the physiological demands may be very different. Furthermore these studies display their data by positions which may not be appropriate for field hockey due to the large variations in description of these positions (e.g. Lythe and Kilding (2011) describe positions as Full Back, Half Back, Inside Forward and Striker whereas Macutkiewicz and Sunderland (2011) use the terms Defenders, Midfielders and Forwards). Although limited solely to competition both studies report five or more matches - increasing the number of observations - and reducing the effect of contextual variables (Castellano, Casamichana, and Dellal, 2013).

Gabbett (2010b) attempts to compare competition and game-based training as a way of explaining and describing the differences in physiological demands of the two activities. The conclusions of this study suggest large differences in the physiological demand of the two even during the specific preparatory phase of a season. However only speed zone data was used to come to this conclusion with no data presented on the type of movements required in each activity which limits the understanding of physiological demand of field hockey activity.

To better understand the interaction of physiology in field hockey a more focused approach is required which can reported the physical activities of players in competition and training under the most controlled situations possible in the applied setting. To achieve this it will require tournament play with a discrete squad over a short time scale - to avoid changes in fitness – similarly ranked opposition and meaningful games comparable to the design of Lythe and Kilding (2011) and Macutkiewicz and Sunderland (2011). Reporting data as an average across the team is likely to offer a better explanation than positional data due to the differences in description of position. Furthermore subsequent investigations must include training data as this activity is less influenced by contextual variables and at times will be supramaximal in comparison to competition and as such will display greater physiological demand and offer greater insight into the physiology of field hockey players.

1.2.2 Strength & Power

Strength - or specifically the ability to exert force - and power are important physical facets required for any team sports players to allow them to sprint, change direction, jump, pass, tackle or evade (Komi, 1993). These actions are dependent on concentric, isometric and eccentric actions of the musculature at various speeds and in various postures (Komi, 1993). As such strength and power testing using each of these muscular actions is regularly carried out by practitioners. The type of tests reported in the literature and used with field hockey players include handgrip dynamometry, bench press, leg press, countermovement jumps (CMJ) and standing long jumps (SLJ). These tests are able to display whole body strength (handgrip), upper and lower body strength (bench and leg press respectively) and power (CMJ and SLJ).

Field hockey is no different in this respect and also has additional physical challenges requiring specific strength such as the ability to carry and manipulate the hockey stick whilst playing. The strength of field hockey players has been referred to in the literature and provides an indication of the abilities of these players (see Tables 1.4 and 1.5). However due to the variety of tests which have been used to describe both strength and power attributes comparison across groups is difficult.

The most regularly used test for strength in field hockey players is handgrip strength which is tested using handgrip dynamometers. The literature shows elite and sub-elite female players to have grip strengths of ~ 34 kg to 38 kg (Nakamoto *et al*, 1988, Cochrane & Stannard, 2005; Wassmer *et al*, 2002; Keogh, Weber and Dalton, 2003 and Reinders *et al*, 1999). Additionally male players have been shown to have grip strengths of 50.8 kg (Katsumura *et al*, 1986) and 54 kg (Scott, 1991).These values are similar to recreational tennis players (Vodak, Savin, Haskell and Wood, 1980) and black belt Taekwon-do athletes (Heller, Petric, Dlouha, Kohlikova, Melichna and Novakova, 1998). The male results are also greater than those reported in soccer players (Manna, Khanna and Dhara, 2010). Conversely powerlifters and American football players have greater grip strength scores (Caterisano, Yurich, Bonfiglio, Fowler, Greer, and Brown, 2001). As most grip scores are reported as absolute values the similarities and differences between sports may be expected due to differences in body weights (Vanderburgh, Mahar and Chou, 1995)

Level	*N*	Whole Body (kg)	Method	Lower Body (kg)	Method	Upper Body (kg)	Method	Power (W) or (cm)	Method	References
Elite (England)	12	38.1 ± 3.9	GS	98.0 ± 26.6	LE			200.2 ± 17.9/40.3 ± 6.0	SLJ/CMJ	Reilly & Bretherton, 1986
Sub-Elite (England)	12	35.2 ± 4.2	GS	89.8 ± 15.4	LE			179.9 ± 17.3/36.6 ± 4.2	SLJ/CMJ	Reilly & Bretherton, 1986
Elite (Japan)	194	34.2 ± 4.2	GS	57.5 ± 15.5	Unknown	16.3 ± 4.1	Unknown	43.8 ± 4.4	CMJ	Nakamoto *et al*, 1988
Sub-Elite (USA)	14	38 ± 3	GS					248 ± 52	BT	Reinders *et al*, 1999
Sub-Elite (USA)	37	33.9 ± 5.7	GS							Wassmer *et al*, 2002
Elite (Netherlands)	18							33.3	CMJ	Hofman *et al*, 2002
Elite (Australian)	16							756.0 ± 110.6	LP	Hopper *et al*, 2003
Elite (Australia)	35	36 ± 1	GS					35 ± 1	CMJ	Keogh, Weber and Dalton, 2003
Sub-Elite (Australia)	39	34 ± 1	GS					29 ± 1	CMJ	Keogh, Weber and Dalton, 2003
Sub-Elite (USA)	13			220	LP	44	BP			Astorino *et al*, 2004
Elite (New Zealand)	18	37	GS					29	CMJ	Cochrane & Stannard, 2005

Table 1.5. Collated strength and power results in elite and sub-elite female field hockey players. GS = Grip Strength, LP = Leg Press, LE = Leg Extension, BP = Bench Press, SLJ = Standing Log Jump, CMJ = Countermovement Jump, BT = Bench Throw

Handgrip strength has been suggested as a method of deriving whole body strength (Wind, Takken, Helders and Engelbert, 2010) and has been used as a talent identification tool for young field hockey players (Keogh, Webber and Dalton, 2003). Wind and colleague (2010) reported correlation coefficients of between 0.736 to 0.890 which suggests a strong relationship between total body strength and grip strength. However this study – and the study by Keogh, Webber and Dalton (2003) – used a juvenile population, aged between 8 to 20 yrs. They also reported a reduction in the relationship (correlation coefficient of 0.485 to 0.564) when controlled for body mass. As such with the onset of puberty, the associated secondary sex characteristics and subsequent increases in body mass this measure of whole body strength may have reduced validity in adult field hockey players.

Level	*n*	Whole Body (kg)	Method	Lower Body (kg)	Method	Upper Body (kg)	Method	Power (W) or (cm)	Method	References
Elite (Japan)	122	50.8 ± 5.8	GS	80.5 ± 16.0	Unknown	26 ± 4.0	Unknown	56.9 ± 4.6	CMJ	Katsumura *et al*, 1986
Sub-Elite (South Africa)	162	54.0 ± 7.7	GS					230.0 ± 0.18	SLJ	Scott, 1991
Elite (Netherlands)	18							50	CMJ	Hofman *et al*, 2002

Table 1.6. Collated strength and power results in elite and sub-elite male field hockey players. GS = Grip Strength, CMJ = Countermovement Jump, SLJ = Standing Long Jump

Other methods utilised such as leg press and bench press may be a more appropriate measure to assess whole body strength in field hockey players. It has previously been quoted that laboratory based dynamometry is the gold standard for assessing strength (Verdijk, Van Loon, Meijer and Savelberg, 2009). This study showed a correlation between leg press and isokinetic and isometric dynamometry in male (r = 0.50 to 0.64 isokinetic and isometric respectively) and female adults (r = 0.61 to 0.75 isokinetic and isometric respectively). However leg extension was shown to have a stronger correlation to isometric dynamometry in both male and females (r = 0.83) and may be a better method of testing maximal force. This is expected due to the similarities and postures used when completing dynamometer testing and leg extensions.

Upper body strength in field hockey players has been measured using the free weight bench press exercise. This has been used in a number of team sports including male rugby league players (Coutts, Reaburn, Piva, and Murphy, 2007), male American footballers (Mayhew, Ware, Bemben, Wilt, Ward, Farris, Jurasek and Slovak, 1999) and female handball players (Hoff, and Almåsbakk, 1995). The relationship between this gym-based exercise to that of laboratory measures has been tested by Hortobagyi and colleagues (1989). They showed one repetition maximum free weight bench press had a strong correlation (r = 0.75 to 0.82) to laboratory tested isokinetic bench press, slow hydraulic bench press at 0.037 $m.s^{-1}$ and fast hydraulic bench press at 0.126 $m{\cdot}s^{-1}$(Hortobagyi, Katch and LaChance, 1989).

Astorino and colleagues (2004) reported the bench press and leg press scores of sub-elite female field hockey players. They reported average leg press loads of 220 kg and average bench press load of 44 kg. In comparison to other literature these values - when reported relative to body mass (60.86 kg) – are greater than both male and female adults of various ages (Brown and Miller, 1998 and Verdijk, van Loon, Meijer and Savelberg, 2009). However these gym-based measures do not provide a specific quantification of force – these tests provide information on the mass of the object which has been moved and not the force that was required to move it. To measure the actual force, measured in Newtons, produced by an athlete a force plate is required. None of the field hockey specific literature reports strength in this way.

The measurement of power in field hockey players in the literature is most often reported using the counter movement jump (CMJ) exercise heights. The CMJ is more specifically a measure of take-off velocity and flight time which can be used to calculate jump height (Komi and Bosco, 1978) and not Watts as is the specific measurement unit of power. The countermovement jump utilises the stretch-shortening cycle – the interaction of the eccentric phase and concentric phase (Komi, 2008). This coupling of eccentric to concentric muscle action provides elastic recoil and transfer of energy through the system to produce a forceful jumping action (Anderson and Pandy, 1993). Power output can be measured from CMJ by completing these on a force platform (Harman, Rosenstein, Fryckman, and Rosenstein, 1990). Additionally jump heights can be used to derive power output by using the Lewis formula and nomogram (Harman, Rosenstein, Fryckman, Rosenstein and Kraemer, 1991).

The values reported in field hockey player only provide the CMJ heights and not power outputs. For elite female players range from 29 cm (Cochrane & Stannard, 2005) to ~ 44 cm (Nakamoto *et al*, 1988). Sub-elite players have been reported to be between 29 cm (Keogh, Weber and Dalton, 2003) and ~ 31 cm (Reilly and Bretherton, 1986). Male elite players have been shown to have jump heights between 50 and 57 cm (Hofman *et al*, 2002 and Katsumura *et al*, 1986, respectively).

Other methods used include standing long jump (SLJ), bench throw, and leg press. The SLJ scores reported were from a sub-elite South African group of players and reported distances of 230.0 ± 0.18 cm (Scott, 1991). This uses a similar method or derivation of power through jumping distance as CMJ does with height. More specific measures have directly reported power in Watts for field hockey players. Both bench throw and leg press power has been used to report power in female field hockey players. The bench throw power of sub-elite female players was 248 ± 52 W (Reinders *et al*, 1999). The leg press power of elite Australian female players was 756.0 ± 110.6 W (Hopper *et al*, 2003).

Although the strength and power data of field hockey players in the literature is quite sparse both facets of physical ability are important for performance (Reilly and Borrie, 1992) and have been shown to discriminate between levels (Keogh, Weber and Dalton, 2003 and Reilly and Bretherton, 1986). As such differences in power measures between the two levels may be expected however due to the lack of conclusive evidence it would be inappropriate to make any further conclusions. Instead it is more appropriate to investigate the time motion analysis data and assess the high speed and sprint speeds at the two levels as these have been previously correlated to CMJ heights (Cronin and Hansen, 2005) so will give an indication of power whilst providing more specific data on the activities which impact on sport performance.

1.2.3 Body Composition

The body composition of male and female field hockey players have been described in the majority of studies providing an insight into the shape and size of these athletes. In addition to this data, a select few have specifically studied and reported the physical characteristics of players (Toriola, Salokun and Mathur, 1985; Nakamoto, Nakanishi, Katsumura, Ikeda, Miyate and Hiraoke, 1988; Calo, Sannan, Piras, Pavan and Vana, 2009 and Manna, Khanna and Dhara, 2011). These studies provide information on the body mass, height, body fat percentage and body mass index of elite and sub-elite players.

The elite and sub-elite female players' body composition data is shown in Table 1.7. This data suggests that players at both levels are of a similar size with slightly more variability in the sub-elite group. For instance the elite players range in height from ~ 159 cm to ~ 169 cm and body mass from ~ 56 kg to ~ 64 kg. Whereas sub-elite players range from ~ 161 cm to ~ 170 cm and ~ 56 to ~ 68 kg. The upper and lower limits are largely due to the international array of studies – the smallest values come from Japanese internationalists (Nakamoto, Nakanishi, Katsumura, Ikeda, Miyake and Hiraoka, 1988) and the larger values from Dutch international players (Hofman, Smeets, Verlaan, vander Lugt and Verstappen, 2002). The body fat percentages are also varied across both levels and range from 18 – 26 %. Body mass index (BMI) is reported in two instances in elite players - Hofman and colleagues (2002) reported a BMI of 22.7 and Hopper and colleagues (2003) reported similar, 20.8. No BMI data was reported in the sub-elite group however using the BMI calculation it can be calculated that these would be similar to both elite studies.

Level	*n*	Age	Height (cm)	Body Mass (kg)	Body Fat (%)	BMI	References
Sub-Elite (England)*	43		164.6 ± 5.0	60.2 ± 5.2	22.7	22.2†	Bale & McNaught-Davis, 1983
Sub-Elite (USA)	18	20.2	162.8	60.2	23.9	22.7†	Babcock *et al*, 1984
Elite (Wales)*	10			59.0 ± 3.2	25.8 ± 2.7		Reilly *et al*, 1985
Elite (England)*	12	22.7 ± 2.8	164.3 ± 5.6	60.6 ± 3.8	23.0 ± 1.9	22.4†	Reilly & Bretherton, 1986
Sub-Elite (England)	12	24.1 ± 3.7	161.3 ± 4.7	59.5 ± 5.2	22.9 ± 2.9	22.9†	Reilly & Bretherton, 1986
Sub-Elite (England)*	12		162.5 ± 5.7	61.0 ± 5.6		23.1†	Cheetham & Williams, 1987
Elite (Australia)*	16		165.8 ± 4.8	61.8 ± 7.4		22.5†	Telford *et al*, 1988
Elite (Japan)	194	19.9 ± 2.1	159.2 ± 5.5	55.7 ± 6.23	18.2 ± 3.2	22.0†	Nakamoto *et al*, 1988
Elite (USA)	12	27 ± 3	165 ± 6	59.6 ± 3.6	16.1 ± 4.4	22.0 ± 1.3	Sparling *et al*, 1998
Sub-Elite (USA)	14	19.6 ± 1.1	167 ± 0.04	64.4 ± 5.7	23.6 ± 3.3	23.1†	Reinders *et al*, 1999
Elite (Netherlands)	17	22.1	169	64.25		22.7	Hofman *et al*, 2002
Sub-Elite (USA)	37		164.3 ± 5.2	63.1 ± 8.6	17.3 ± 3.8	23.4	Wassmer *et al*, 2002
Elite (Australia)	16	21.1 ± 3.7	170 ± 0.08	60.4 ± 5.4		20.8 ± 1.4	Hopper *et al*, 2003
Elite (Australia)	35	19.4 ± 1.0	164.7 ± 0.7	58.7 ± 1.2	24.8 ± 0.7	21.6	Keogh, Weber and Dalton, *2003*
Sub-Elite (Australia)	39	20.3 ± 1.5	163.5 ± 1.1	56.5 ± 0.5	27.4 ± 0.8	21.1	Keogh, Weber and Dalton, 2003
Sub-Elite (USA)	13	19.7 ± 1.4	164.0 ± 0.06	60.7 ± 5.84	19.2 ± 4.45	22.6†	Astorino *et al*, 2004
Sub-Elite (England)	9	21.7 ± 0.4	167.0 ± 0.02	68.5 ± 3.6		24.6†	Sunderland & Nevill, 2005
Elite (New Zealand)	18	21.8 ± 5.9	166.0 ± 0.06	63.7 ± 7.6		23.1†	Cochrane & Stannard, 2005
Sub-Elite (USA)	22	26.1 ± 4.5	170 ± 0.9	62.8 ± 7.4		21.7	Chapman *et al*, 2009
Elite (Germany)	17	24.8 ± 3.0					Hinrichs *et al*, 2010
Elite (UK)	8	22.4 ± 4.1	166.7 ± 5.2	61.9 ± 5.4		22.3†	MacLeod & Sunderland, 2012

Table 1.7. The body composition of elite and sub-elite female field hockey players reported in the literature (**taken from Reilly & Borrie, 1992).* † Calculated BMI using figures reported in literature [BMI = (weight/height)/height]

The data in Table 1.8 shows the elite and sub-elite male body composition data in the literature. The elite male players range in height from ~ 167 cm to 184 cm and have body masses of between 61 and 79 kg. This is similar to sub-elite players – height range ~ 166 to 182 cm and body mass ~ 63 to 81 kg. The geographical distribution of the athletes reported is widespread – similar to the female data - and this is the main reason for the wide range of heights and weights. The body fat percentage of the elite players was reported as 12.4 ± 2.4 % by Boyle, Mahoney and Wallace (1994). In comparison the sub-elite population ranges from 9.7 ± 1.7 % (Toriola, Salokun and Mathur, 1985) to 12.0 ± 0.5 % (Manna, Khanna and Dhara, 2011). Only one study in the literature reported male BMI – this was shown to be 23.4 by Hofman and colleagues (2002).

Level	*N*	Age	Height (cm)	Body Mass (kg)	Body Fat (%)	BMI	References
Sub-Elite (Sub-Elite)*	27			62.7 ± 5.4			Bhanot & Sidhu, 1983
Sub-Elite (Nigeria)	14	25.3 ± 1.4	166.3 ± 6.9	63.7 ± 5.4	9.7 ± 1.7	23.0†	Toriola *et al*, 1985
Elite (Japan)	122	20.6 ± 1.9	170 ± 5.6	64.2 ± 6.5		22.2†	Katsumura *et al*, 1986
Elite (Australia)*	17		180.7 ± 5.1	75.9 ± 4.6		23.2†	Telford *et al*, 1988
Elite and Sub-Elite (Spain)*	24		176 ± 4.5	70.6 ± 7.2		22.8†	Drobnic *et al*, 1989
Elite (India)*	27		168.7 ± 5.9	61.0 ± 5.4		21.4†	Sidhu *et al*, 1989
Sub-Elite (South Africa)	162		176.3 ± 6.5	75.2 ± 8.1	11.1 ± 3.3	24.2†	Scott, 1991
Elite (Various)	9	26 ± 4.5	177.3 ± 3	75 ± 5.4	12.4 ± 2.4	23.9†	Boyle *et al*, 1994
Sub-Elite (German)	89	16.8 ± 1.4	179.6 ± 6.3	73.9 ± 8.9		22.9†	Groger *et al*, 2001
Elite (Netherlands)	18	23.3	183.5	78.6		23.4	Hofman *et al*, 2002
Sub-Elite (Scotland)	15	19.5 ± 2.5	179.0 ± 0.1	80.0 ± 2.5		25.0†	Johnston *et al*, 2004
Sub-Elite (England)	9	24 ± 4	181.8 ± 3.9	80.8 ± 5.2		24.4†	Stagno *et al*, 2005
Elite (Australia)	14	26 ± 3		76.7 ± 5.6			Spencer *et al*, 2005
Elite (Poland)	10	26.6 ± 4.6	176.1 ± 4.76	71.4 ± 5.6	13.8 ± 5.5	23.1 ± 1.1	Konarski *et al*, 2006
Sub-Elite (USA)	22	22.1 ± 3.2	180 ± 0.5	74.9 ± 5.4		23.1†	Chapman *et al*, 2009
Sub-Elite (Australia)	22	22.1 ± 3.2	180 ± 0.5	74.9 ± 5.4		23.1†	Chapman *et al*, 2009
Elite (Germany)	17	24.2 ± 2.9					Hinrichs *et al*, 2010
Sub-Elite (India)	30		173.3 ± 3.2	64.9 ± 4.4	12.0 ± 0.5	21.6†	Manna *et al*, 2011
Elite (New Zealand)	18	24 ± 4.5	180.1 ± 4.9	78.4 ± 6.5		24.2†	Lythe & Kilding, 2011
Sub-Elite (Australia)	16	22 ± 4	178 ± 8	78 ± 9		24.6†	Jennings *et al*, 2012b
Elite (Australia)	16	27 ± 4	179 ± 5	77 ± 5		24.0†	Jennings *et al*, 2012b
Elite (Italian)	12	25.1 ± 3.8	174 ±5.2	70.3 ± 2.6		23.2†	Buglione *et al*, 2013
Sub-Elite (Italian)	10	22.2 ± 4.0	172 ± 1.8	66.7 ± 5.6		22.5†	Buglione *et al*, 2013

Table 1.8. The body composition of elite and sub-elite female field hockey players reported in the literature (**taken from Reilly & Borrie, 1992)***.** † Calculated BMI using figures reported in literature [BMI = (weight/height)/height]

In comparison to some of the other physiological facets mentioned previously, the body composition of field hockey players is relatively well understood. Due to the methodological description of subjects and the more specific body composition investigations there is a relatively large amount of information on both male and female body compositions. It can be suggested that elite and sub-elite female hockey players are of average height and have healthy to lean body types. Players range in height from 163 – 170 cm and have body masses of 57 – 69 kg with a tendency for sub-elite players to be towards the upper limit of these values. The body fat and BMI data suggests that players have a lean physique in comparison to the average population. In the male population elite and sub-elite players are averagely built athletes who have low body fat percentages and generally stand 6 ft (182 cm) or less. In addition there may be a geographical influence on body composition for both male and female players – Asian players have smaller body compositions than Caucasian players.

The measures of body fat are largely derived from the sum of four skinfolds (SF) and the equations developed by Durnin and Wormersley (1974). The four sites used are all on the upper body - bicep, triceps, suprailiac, and subscapular skinfolds – which is a limitation of this method especially in a predominantly running based sport. It has been suggested that SF measurements have an error of ± 3.5 % in women and ± 5% in men (Brodie, Moscrip and Hutcheon, 1994). This is due to the callipers used, testers accuracy and the subject's state of hydration. It must also be considered that the equations developed use SF thickness - a measure of subcutaneous fat - to derive total body fat. Further to this, accuracy and reliability of results are reliant on the type of calliper (Sloan and Shapiro, 1972) as well as the consistency of tester

(Jackson, Pollock and Gettman, 1978 and Lohman and Pollock, 1981). The inter-rater reliability coefficients have been shown to be between 0.62 to 0.85 for individual sites and 0.79 to 0.91 for the sums of the three measurements when 8 qualified practitioners tested 20 individuals (Kispert and Merrifield, 1987). This was suggested to be unacceptable for use within a sporting population when the changes in body composition due to intervention are small.

Astorino and colleagues (2004) used the sum of four SF and bioelectrical impedance (BIA) to estimate body fat within their population of sub-elite female hockey players. BIA calculates fat free mass (FFM) and body water by passing a current through the body and measuring the resistance of the tissues and height of the individual (Kyle *et al*, 2004). BIA involves the assumption that the body which the current is passing through is cylindrical, however the human body is essentially five cylinders (two legs, two arms and trunk, excluding head) (Brodie, Moscrip and Hutcheon, 1994). As such the geometry of the body can limit this method. Other limitations such as volume, temperature, and electrolytic concentration have been reported in the literature (Kyle *et al*, 2004). However in comparison to dual energy x-ray absorption (DEXA) BIA been shown to have a small error (~ 1.8 %) in 132 female athletes (some being field hockey players) of similar build to field hockey players reported in Table 1.7 (Fornetti, Pivarnik, Foley and Fiechtner, 1999).

In addition a study on female USA field hockey players has shown that skinfold measurements provide similar results to other more accurate measures of body composition. Sparling, Snow, Rosskopf, O'Donnell, Freedson and Byrnes (1998) used DEXA, hydro static weighing (HW) and seven site SF and showed % BF as 16.1 ± 4.4, 17.4 ± 3.2 and 16.9 ± 2.6 respectively. These athletes were of similar body mass and BMI as the other studies mentioned (59.6 ± 3.6 kg and 22.0 ± 1.3). DEXA uses x ray technology to partition the body into three components - bone mineral, fat and lean tissue. HW uses Archimedes' principle is to compare the mass of a subject in air and under water and has been suggested to be the most valid and reliable method of percentage body fat estimation (Brodie, Moscrip and Hutcheon, 1998). These findings suggest that the values reported using SF thickness give valid measurement. The sum of seven sites has been suggested to have similar accuracy as the sum of four sites when compared to HW (Eaton, Israel, O'Brien, Hortobagyi and McCammon, 1993). The similarities across all studies, no matter the methods used allows for a reliable conclusion to be made.

1.2.4 Time Motion Analysis

The physiological demands of elite and sub-elite field hockey have been described in the literature by video and notational analysis and more recently by GPS analysis. These tools have provided valuable insight into the physical activity requirements of players during competition and training which was previously poorly understood prior to a study by Boddington and colleagues in 2002. Table 1.9 shows the studies which have been published using either video analysis or GPS analysis. Time motion analysis provides both qualitative and quantitative data on the physical activity demands of field hockey. This Chapter will attempt to describe the physical activity of players reported in the literature using both video and GPS analysis. Variables such as distance covered and time spent in specific locomotor activities as well as acceleration data will be assessed. Furthermore, the reported physical activity requirements of different positions will also be examined.

Authors	Gender	Level	Method
Boddington *et al*, 2002	F	Sub-Elite	VA
Johnston *et al*, 2004	M	Sub-Elite	VA
Spencer *et al*, 2004b	M	Elite	VA
Spencer *et al*, 2005	M	Elite	VA
Gabbett, 2010b	F	Elite	GPS
Lythe and Kilding, 2011	M	Elite	GPS
Macutkiewcz and Sunderland, 2011	F	Elite	GPS
Jennings *et al*, 2012a	M	Elite	GPS
Jennings *et al*, 2012b	M	Elite & Sub-Elite	GPS
Boran, 2012	F	Sub-Elite	GPS
Lui *et al*, 2013	M	Sub-Elite	VA

Table 1.9. Current available literature utilising time motion analysis for the study of field hockey. VA = Video Analysis, GPS = Global Positioning System

1.2.4.1 Distance

The majority of studies using time motion analysis, particularly GPS analysis, report the distance covered by players as a marker of a player's physical activity. This parameter is described in three ways – absolute, relative and as a percentage of total distance. Furthermore, distance is usually categorized based on locomotor activities such as walking, jogging and sprinting. Describing activities in this way provides lay terminology which is understandable to coaches and provides a suggestion of the physiological demand. For instance two players covering the same distance may cover this distance in different ways: if one covers 400 m at jogging speeds and one at sprinting speeds the athlete who jogs will generate a greater amount of energy via the aerobic energy producing system whereas the person who is sprinting will utilise greater percentages of PCr and anaerobic energy (Gastin, 2001).

Table 1.12 shows the absolute distances covered in specific speed zones reported in the literature. The mean distance covered in any position during a seventy minute game – summative value of all players who play in that position during the game - was reported as approximately 8.1 km in elite male players from the Southern Hemisphere (Lythe and Kilding, 2011). When specific individual distances were reported the mean was nearer 6.7 km. A recent video analysis study using computer generated player coordinates to calculate distance covered showed sub-elite male Chinese players to cover ~ 7.3 km in their national championships (Lui *et al*, 2013). On average the data shown in Table 1.12 shows that elite male field hockey players all cover a similar distance – most within a range of 7 – 8 km in a game.

There are fewer studies which specifically report the physical activity patterns of players during competition in elite female field hockey. However the studies available (shown in Table 1.12) are more explicitly separated meaning a greater positional and speed specific understanding is presented. It can be seen from this data that the range of distances covered during games is more varied (in comparison to male field hockey) with values ranging from 4.7 km (Macutkiewcz and Sunderland, 2011) to 6.9 km (Gabbett, 2010b). Further to this Gabbett (2010b) reported defenders to cover on average 6.1 km per game, midfielders 6.9 km and attackers 6.6 km (Table 1.10).

	Striker		Midfielder		Defender	
Velocity ($m \cdot s^{-1}$)	Distance (m)	Distance (%)	Distance (m)	Distance (%)	Distance (m)	Distance (%)
0 to 1	728 ± 231	11.8 ± 3.3	681 ± 243	9.8 ± 1.8	841 ± 229	12.8 ± 2.4
1 to 3	3,017 ± 247	49.1 ± 5.0	3,422 ± 989	49.3 ± 2.6	3,618 ± 821	54.8 ± 3.5
3 to 5	1,941 ± 198	31.5 ± 2.3	2,181 ± 558	31.7 ± 2.4	1,763 ± 566	26.2 ± 3.4
5 to 7	423 ± 195	6.9 ± 3.0	571 ± 244	8.2 ± 2.7	369 ± 178	5.5 ± 1.7
>7	46 ± 57	0.8 ± 1.0	77 ± 69	1.1 ± 1.0	52 ± 62	0.8 ± 0.9
Total	6,154 ± 271	100.0 ± 0.0	6,931 ± 1882	100.0 ± 0.0	6,643 ± 1618	100.0 ± 0.0

Data are mean ± *SD*.

Table 1.10. Distance covered in specific speed zones in women's field hockey competition.
Reproduced from Gabbett (2010b)

Position-specific data from Gabbett (2010b) shows defenders to have the highest percentage of distance covered whilst walking and jogging (0 - 3 $m \cdot s^{-1}$). Midfielders cover the greatest distance whilst high-speed running and sprinting. Attackers complete more walking than midfielders but less than defenders and complete more sprinting than defenders but less than midfielders. Macutkiewcz and Sunderland (2011) also reports the positional effects on activity patterns (Figure 1.3). This shows some similarities across all positions – defenders and midfielders cover a similar percentage of their total distance walking and sprinting whilst midfielders and attackers cover similar distances jogging and fast running. However attackers complete less walking and more running and sprinting. The data from these two studies is quite different highlighting the effect that other factors (opposition, tactics, weather, etc) may have on the resultant activity patterns. These studies agree that midfielders cover the largest distance in the moderate to high-speed zones and defenders tend to complete the majority of their activity at lower speeds. In comparison to soccer these differences are limited. A study on 300 elite soccer players showed greater differences between positions than shown in field hockey (Di Salvo, Baron, Tschan, Calderon Montero, Bachl and Pigozzi, 2007). This is likely due to more distinct formations and structured roles in soccer. Australian rules football has also been studied to see if positional differences occur during competition (Dawson, Hopkinson, Appleby, Stewart and Roberts, 2004). This showed similar findings to field hockey – positional differences but similarities across all positions. Only one category of position was shown to be clearly different, with reduced estimated total distance compared to the other positions. This position, full forward/full backs, was classified due to its specific more static role within the team (Dawson, Hopkinson, Appleby, Stewart and Roberts, 2004). This suggests that structured formations and roles have greater influences on the physical activity of players and that field hockey may be more interchangeable resulting in more comparable activities.

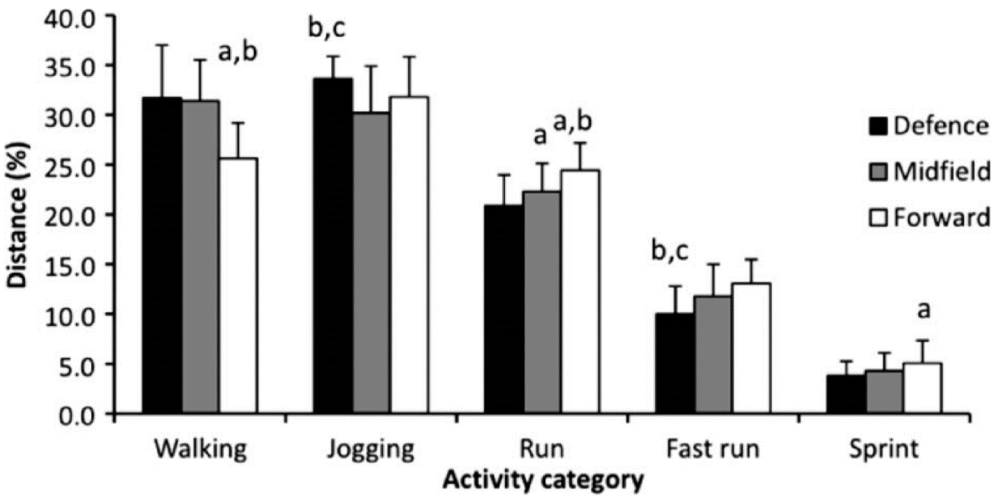

Figure 1.2. The percentage of distance covered in locomotor activities by position. [a] $P \leq 0.05$ difference to defenders, [b] $P \leq 0.05$, deference to midfielders. *Reproduced from Macutkiewicz and Sunderland (2011).*

Lui and colleagues (2013) reported the positional differences in men's hockey and showed that full backs completed significantly less slow, moderate, fast and sprint speed running than other positions (Table 1.11). Halves (equivalent to right and left backs in soccer) and midfielders were shown to complete less moderate and high speed running than strikers. Additionally strikers covered the most distance at moderate, high and sprint speeds and the least walking. This data is similar to Macutkiewcz and Sunderland (2011) mentioned previously and highlights the increased workload for attackers and halves. This suggests that these playing positions have more involvement in the game possibly due to a more significant role in attack for halves and a larger role in defence for attackers. It may be that these results are due to more modern tactics and "positional flexibility" demanded by coaches such as Ric Charlesworth (previous Australian mens coach) which requires more interchanging of positions on the field and a greater emphasis on players supporting in both attack and defence.

Position	Period	Distance	Sprinting	HSR	MSR	LSR	Jogging	Walking	Total
Forward	First Half	Distance(m)	42±12	308±57	558±94	801±111	889±94	1286±106	3884±372
		%TD	1.1±0.2	7.9±0.8	14.3±1.4	20.6±1.7	22.9±1.0	33.4±4.2	100
	Second Half	Distance(m)	31±11	294±55	552±97	782±118	885±92	1281±89	3825±349
		%TD	0.8±0.2	7.6±0.8	14.3±1.5	20.4±2.0	23.1±1.0	33.8±4.6	100
Midfielder	First Half	Distance(m)	26±9	313±63	582±97	822±146	942±113	1205±94	3889±366
		%TD	0.7±0.2	8.0±1.0	14.9±1.3	21.0±2.6	24.2±1.0	31.4±5.0	100
	Second Half	Distance(m)	25±8	295±63	567±98	801±145	930±112	1225±94	3843±363
		%TD	0.6±0.2	7.6±1.0	14.6±1.4	20.7±2.6	24.1±1.1	32.2±5.1	100
Defender	First Half	Distance(m)	17±7	254±59	418±94	583±97	740±60	1349±150	3362±368
		%TD	0.5±0.2	7.5±1.2	12.3±2.0	17.3±1.6	22.1±1.8	40.3±3.5	100
	Second Half	Distance(m)	19±6	232±50	398±95	563±99	738±62	1360±162	3309±378
		%TD	0.6±0.2	6.9±1.0	11.9±2.1	16.9±1.7	22.4±2.0	41.2±3.7	100

HSR= high-speed running; MSR= moderate-speed running; LSR= low-speed running.

Table 1.11. Distance covered and percentage of total distance covered (% TD) at different intensities of both halves depending on players' position. *Reproduced from Liu et al* (2013)

In summary, the current available data suggests that the majority of physical activity during field hockey competition is low intensity in nature. Up to fifty percent of physical activity during pitch time - irrespective of gender, level or method of analysis - is completed walking and jogging. The amount of moderate and high speed distance falls between similar ranges for all studies (Moderate speed – 20 to 30 %; High Speed – 5 to 10 %). However sprinting activities are more varied with ranges from ~ 50 m (~ 0.5 %) in a game to more than ~ 200 m (~ 2 %). This fourfold difference may be due to a number of reasons such as opposition tactics, game status and skill level (Marcelino, Mesquita and Sampaio, 2011 and Bradley and Noakes, 2013) and not solely the different physical abilities of players. A limitation of time motion analysis information is the lack of standardization of speed thresholds for each locomotion activity (Dwyer and Gabbett, 2012). For ease of review the zones reported have been grouped together as best as possible. However this is far from accurate as, for instance, the sprint threshold of studies ranges from 5.2 m·s^{-1} (19 km·hr^{-1}) to 8.2 m·s^{-1} (29.5 km·hr^{-1}) depending on gender and observers (values from female study by Macutkiewcz and Sunderland, 2011 and male study by Lui *et al*, 2013). This variability makes comparisons difficult and subsequent analysis based on assumptions of physical capacity. Furthermore, the accuracy of GPS analysis in sprint speed thresholds is variable and can be inherently over or under-estimated (this will be more thoroughly described in 1.3.2 and 1.3.3).

Level	Method	Gender	Position	Walk (m)	Jog (m)	Low (m)	Mod (m)	High (m)	Sprint (m)	Total (m)	Reference
Elite (Australia)	GPS	F	Def	841 ± 229	3618 ± 821	N/A	1763 ± 566	369 ± 178	52 ± 62	6643 ± 1618	Gabbett, 2010b
Elite (Australia)	GPS	F	Mid	681 ± 243	3442 ± 989	N/A	2181 ± 558	571 ± 244	77 ± 69	6931 ± 1882	Gabbett, 2010b
Elite (Australia)	GPS	F	Att	728 ± 231	3017 ± 247	N/A	1941 ± 198	423 ± 195	46 ± 57	6154 ± 271	Gabbett, 2010b
Elite (UK)	GPS	F	Def	N/A	N/A	N/A	N/A	N/A	231 ± 92	6170 ± 977	Macutkiewicz & Sunderland, 2011
Elite (UK)	GPS	F	Mid	N/A	N/A	N/A	N/A	N/A	236 ± 90	5626 ± 787	Macutkiewicz & Sunderland, 2011
Elite (UK)	GPS	F	Att	N/A	N/A	N/A	N/A	N/A	232 ± 70	4700 ± 918	Macutkiewicz & Sunderland, 2011
Elite (UK)	GPS	F	Team	1653 ± 547	1780 ± 420	N/A	1226 ± 249	620 ± 172	232 ± 96	5541 ± 1144	Macutkiewicz & Sunderland, 2011
Elite (New Zealand)	GPS	M	Per70 mins	2410 ± 95	2585 ± 258	1424 ±124	1232 ± 263	355 ± 110	124 ± 69	8130 ± 360	Lythe & Kilding, 2011
Elite (Australia)	GPS	M	Def							5255 ± 4843	Jennings *et al*, 2012a
Elite (Australia)	GPS	M	Mid							5625 ± 5182	Jennings *et al*, 2012a
Elite (Australia)	GPS	M	Att							5506 ± 4984	Jennings *et al*, 2012a
Sub-Elite (China)	VA	M	Team	2580 ± 261	1693 ± 243	1434 ± 321	1013 ± 241	560 ± 126	53 ± 23	7334 ± 877	Lui *et al*, 2013
Elite (Italian)	GPS	M	Team							7062 ±1363	Buglione *et al*, 2013
Sub-Elite (Italian)	GPS	M	Team							6186 ± 1615	Buglione *et al*, 2013

Table 1.12. Male and female time motion analysis data of physical activity during competition using video analysis (VA) and global positioning systems (GPS. Collated data reported in the literature on the absolute distance covered in specified thresholds by male and female field hockey players. N.B Thresholds grouped by description given and not specific speed thresholds due to variety of cut offs used for each activity.

1.2.4.2 Time

Time is a well-documented parameter used to describe the physical activity of players on the pitch. This is an artefact of the first time-motion analysis studies which were unable to accurately report distance so instead measured the time players spent in each locomotor activity (Boddington *et al*, 2002, Johnston *et al*, 2004, Spencer *et al*, 2004b and Spencer *et al*, 2005). For instance, the observer would subjectively decide that an individual was walking, jogging or sprinting and then record the time spent in each activity as it happened on the field. With the advent of GPS analysis this method was carried over but with greater accuracy. It is still widely used today as a marker of total physical load as it is logically expected that increased time in the higher speed zones or decreased time in low intensity activities will have a resultant physiological impact. Time-dependent data is shown in Tables 1.13 and 1.14.

The absolute time in the specific speed zones reported by Gabbett (2010b) in elite female field hockey players playing in their national league is shown in Table 1.13. It can be seen that 40 to 49 minutes of game time is spent standing, with defenders stationary for the shortest time and attackers the most. Contrary to this defenders spend the most time walking and attackers the least. Midfielders spend the majority of their time jogging or high speed running. This highlights some of the effects of tactical roles on the resulting physical activity requirements. For instance, midfielders are required to move from box to box and are regularly involved in game play whereas defenders and attackers can have reduced roles depending on the team's tactics and the nature of the game. This is very similar to soccer and provides a slightly different picture in comparison to the distance data previously mentioned where players in different positions were more akin to one and other.

However, due to differing playing periods, absolute time is a limited parameter for comparison across studies or games. As such the majority of studies utilise the percentage time in specific speed zones (as seen by the increased number of studies shown in Table 1.14). The previously mentioned study by Gabbett's showed the largest percentage time was spent walking and jogging (as seen by Figure 1.4) with markedly less of a percentage spent in activities over 3 $m.s^{-1}$ (10.8 $km.hr^{-1}$).

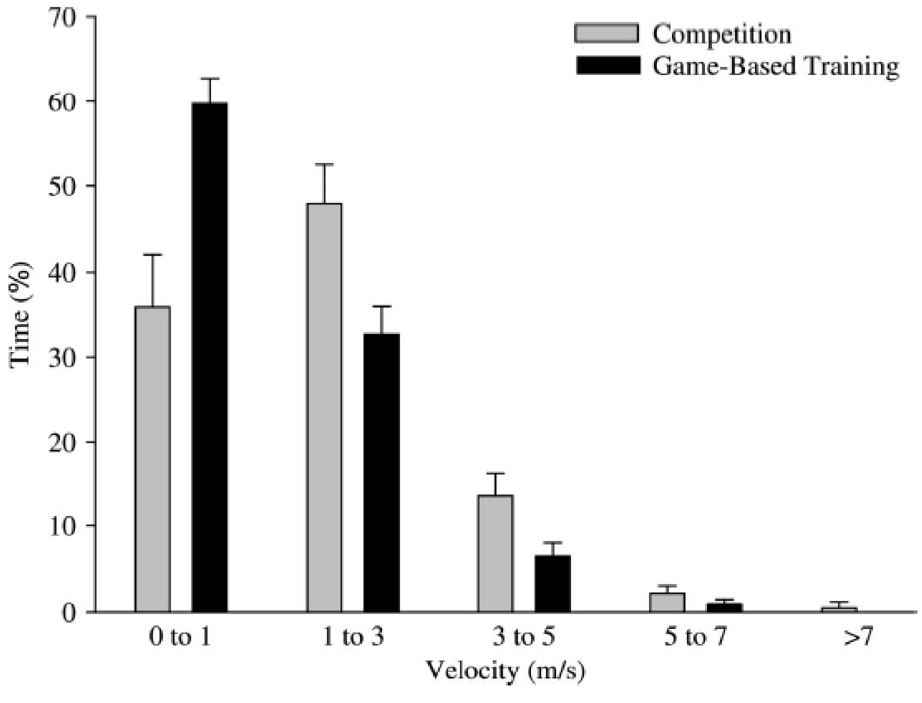

Figure 1.3. The percentage time spent in specific speed zones from walking to sprinting in elite female field hockey players during competition and game-based training. *Reproduced from Gabbett (2010b).*

More recently, Macutkiewicz and Sunderland (2011) reported similar findings in a different group of elite female players. It showed mean values for the whole team to follow a similar pattern to Gabbett - players spent the majority of time walking and jogging with the least amount of time sprinting (49.7 ± 5.6 %, 25.8 ± 3.5 % and 1.5 ± 0.6 %, respectively). Furthermore Figure 1.5 shows the percentage time in each of the six locomotor activities and the similarities and differences between positions. It can be seen here that defenders and midfielders are similar for all but one of the movement categories (fast running) and jogging was similar for all positions. However, attackers recorded more running, fast running and sprinting and less walking than the other two positions.

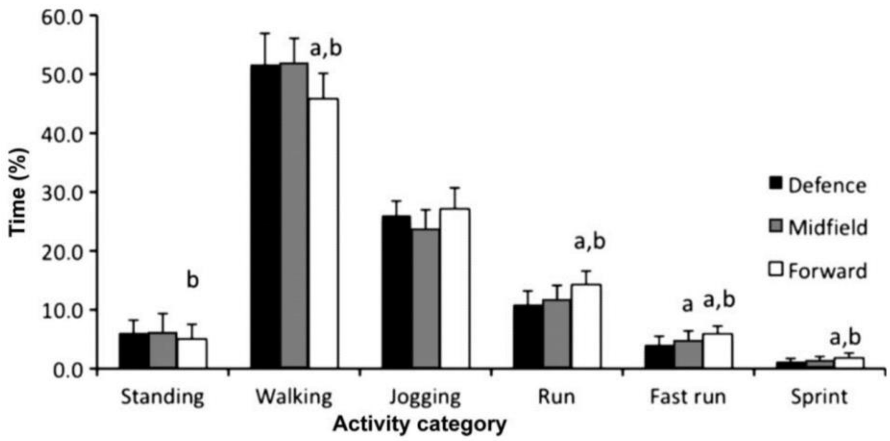

Figure 1.4. The percentage of time spent specific speed zones from walking to sprinting in elite female field hockey players during competition by position. [a] $P \leq 0.05$ difference to defenders, [b] $P \leq 0.05$, difference to midfielders. *Reproduced from Macutkiewicz and Sunderland (2011).*

The physical activity of players, reported as either absolute or percentage time in each activity, provides a similar illustration of competition as the distance specific parameters mentioned in the previous Chapter (1.2.5.1). The time specific data suggests that players in any position spend large quantities of the game stationary or walking around the pitch. Defenders and midfielders have been shown to spend similar amounts of time in each of the speed categories. However the data suggests that attackers spend more time in high intensity activities interspersed with more standing and walking than jogging and running. The data presented shows the variety of tactics employed. For instance, the defence and midfield data suggests that ‘total hockey’ requires players to be more alike with each position playing a large role in both attack and defence. However the time specific data suggests that attackers (strikers) still perform a very specialised role and do not have a prominent role in defensive situations. These results are dependent on the tactical roles of players, formations, strategies and may also be influenced by the categorisation of players from different teams and publications.

Level	Gender	Method	Position	Standing (s)	Walking (s)	Jog (s)	High (s)	Sprint (s)	References
Elite (Australia)	F	GPS	Def	2423 ± 577	2094 ± 481	487 ± 153	66 ± 30	7 ± 8	Gabbett, 2010b
Elite (Australia)	F	GPS	Mid	2674 ± 585	1901 ± 566	595 ± 145	101 ± 42	11 ± 9	Gabbett, 2010b
Elite (Australia)	F	GPS	Att	2934 ± 339	1697 ± 104	530 ± 66	76 ± 34	6 ± 7	Gabbett, 2010b

Table 1.13. Female time motion analysis data of physical activity during competition using video analysis (VA) and global positioning systems (GPS. Collated data reported in the literature on the absolute time spent in specified thresholds by female field hockey players. N.B Thresholds grouped by description given and not specific speed thresholds due to variety of cut offs used for each activity.

Level	Gender	Method	Standing (%)	Walking (%)	Jog (%)	Low (%)	Mod (%)	High (%)	Sprint (%)	References
Sub-Elite (Australia)	F	VA	1.5 ± 0.3	82.3 ± 2.1	13.7 ± 1.6	-	-	1.9 ± 0.4	0.7 ± 0.1	Boddington *et al*, 2002
Sub-Elite (Scotland)	M	VA	4.0 ± 1.2	50.9 ± 5.7	29.6 ± 4.8	-	-	10.1 ± 2.6	4.7 ± 0.9	Johnston *et al*, 2044
Elite (Australia)	M	VA	7.4 ± 1.2	46.5 ± 0.8	40.5 ± 7.3	-	-	4.1 ± 1.3	1.5 ± 0.8	Spencer *et al*, 2005
Elite (Australia)	M	VA	11.2 ± 2.7	47.7 ± 5.6	34.8 ± 7.4	-	-	5.1 ± 0.9	1.2 ± 0.4	Spencer *et al*, 2005
Elite (Australia)	M	VA	15.5 ± 5.6	48.3 ± 9.9	29.4 ± 5.7	-	-	5.8 ± 1.4	1.0 ± 0.3	Spencer *et al*, 2005
Elite (UK)	F	GPS	5.8 ± 2.7	49.8 ± 5.6	25.9 ± 3.5	-	12.3 ± 2.9	4.9 ± 1.4	1.5 ± 0.6	Macutkiewicz & Sunderland, 2011
Sub-Elite (China)	M	VA	-	35.7 ± 5.8	23.1 ± 1.6	19.3 ± 2.6	13.6 ± 2.0	7.6 ± 1.0	0.7 ± 0.3	Lui *et al*, 2013

Table 1.14. Female time motion analysis data of physical activity during competition using video analysis (VA) and global positioning systems (GPS. Collated data reported in the literature on the percentage time spent in specified thresholds by female field hockey players. N.B Thresholds grouped by description given and not specific speed thresholds due to variety of cut offs used for each activity.

1.2.4.3 Acceleration Data

Acceleration data from team sport competition is more widely available due to the recent utilisation of microtechnology in time motion analysis studies. Most GPS devices now contain accelerometers, gyroscopes and magnetometers which allow for more detailed analysis of an individual's movement. These devices record at a much higher frequency - how many data points are recorded within a second i.e. 10 Hz is equal to 10 data points a second - than the currently available GPS (100 Hz versus 10 Hz, accelerometer and GPS respectively) which mean short movements which can be physically demanding can be reported. For instance, in team sports which require changes of direction - sometimes at high speed - there is a requirement for eccentric strength [lunging involves eccentric loads (Riemann, Lapinski, Smith and Davies, 2012) which produce more damage than other muscle actions (Cheung, Hume and Maxwell, 2003)] but have not been previously quantified in time motion analysis studies. Spencer and colleagues (2004b) reported a change in movement patterns every 5 – 7 s suggesting a large physical demand on players but were unable to quantify the type, speed or time of the accelerations and decelerations. This is now possible but the use of microtechnology for team sports is a fledgling technology and has only been reported in some published articles.

Gabbett (2010b) reported the high-acceleration activities of female players. This showed players to complete a total of ~ 36 - 44 accelerations over 0.5 $m \cdot s^{-2}$ with midfielders completing the most accelerations (see Table 1.15). The majority of acceleration efforts covered 6 to 20 m and were similar to the number of high speed efforts which suggests that these were sprints of some sort (Gabbett, 2010b). The threshold for a high-acceleration set by Gabbett (2010b) requires the movement to last at least 2 seconds which removes the ability to detect lunges, sharp changes of direction and bending. As a result the numbers of efforts are low – in comparison to Lythe and Kilding (2011) who reported greater than 1000 changes in motion during elite male field hockey competition (Lythe and Kilding, 2011). Further to this, Buglione and colleagues (2013) showed elite players to complete more accelerative events than sub-elite players.

	High-acceleration activities*		
Distance (m)	Striker	Midfielder	Defender
0 to 5	0 ± 1	2 ± 2	3 ± 2
6 to 10	21 ± 1	25 ± 7	19 ± 6
11 to 20	16 ± 6	16 ± 6	13 ± 5
21 to 30	1 ± 1	1 ± 1	1 ± 2
31 to 40	0 ± 0	0 ± 0	0 ± 0
>40	0 ± 0	0 ± 0	0 ± 0
Total	38 ± 6	44 ± 12	36 ± 10

Table 1.15. High-acceleration activities during female field hockey competition. High acceleration activities > 0.5 $m \cdot s^{-2}$ lasting 2 or more seconds. *Reproduced from Gabbett (2010b)*

1.2.4.4 Fatigue

Fatigue can be described as a reduction in muscular function and performance (Abbiss and Laursen, 2005). In team sports has previously been described by the reduction in physical activity and/or the reduction in high intensity exercise such as sprinting (Aughey, 2010 and Bishop, 2010). However it is difficult to ascertain if fatigue has occurred or whether it is a change in tactics at the end of a game. As a consequence of this neuromuscular fatigue and muscular fatigue have been measured post competition using rate of force development, peak force and peak power in countermovement jumps (McLellan, Lovell and Gass, 2011). This reported reductions of peak force and peak rate of force development from 30 mins to 24 hours post-game suggesting that both neuromuscular and muscular fatigue occurred post game. This type of study has not been repeated in field hockey but suggests that fatigue may be present and not just changes in tactics. The potential mechanisms of fatigue in team sports has been discussed in Chapter 1.1.4.

Field hockey is played for seventy minutes which is separated into two periods of thirty five minutes. This is similar to other team sports such as rugby union (two forty minute periods) and soccer (two forty-five minute periods). The effect of fatigue on the physical activity of players during team sport competition has been well documented in soccer (Mohr, Krustrup and Bangsbo, 2003), rugby union (Cahill, Lamb, Worsfold, Headey and Murray, 2013), rugby league (Sykes, Twist, Nicolas and Lamb, 2011) and Australian rules (Mooney, Cormack, O'Brien and Coutts, 2013). Mohr and colleagues (2003) showed a decrease in high intensity running and sprinting from the first 15 minute period to the last in elite male soccer competition (Figure 1.6). This phenomenon is similar to that of the current literature in field hockey which will be discussed in more depth in this Chapter.

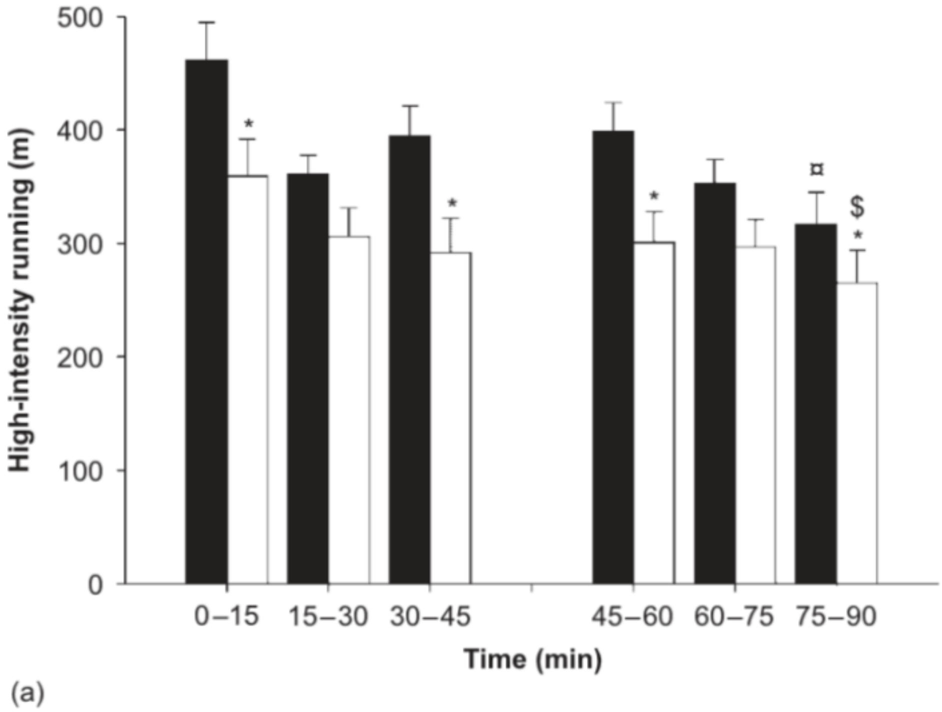

Figure 1.5. High-intensity running in 15- min intervals for top-class soccer players (dark bars) and moderate class soccer players (white bars) (mean ± SD). *Significant difference ($P \leq 0.05$) between top-class and moderate players. ¤ Significantly different ($P \leq 0.05$) from the first four 15-min periods of the game. $ Significantly different ($P \leq 0.05$) from the first 15-min period of the game. *Reproduced from Mohr, Krustrup and Bangsbo, 2003.*

The presence of fatigue, similar to the findings in soccer, rugby union, rugby league and Australian Rules football have been shown in a number of field hockey studies. Boddington and colleagues (2002) showed a significant drop in the activity of female field hockey players from the first to second half of three different matches. The mean distance covered for the first halves of all three matches was ~ 2 km which was reduced to ~ 1.9 km in the second. This was reported as significantly different but the practical significance of 100 m can be argued. In agreement with the difference in total distance, the relative distance per minute of game time was also higher in the first half compared to second half (62 ± 6 versus 59 ± 6 m, first and second half respectively). However no difference was shown in mean speed or percentage time in any of the high speed activities for both halves. This suggests the 100 m difference between first and second half distances are unlikely to be due to the high speed running and as such are not as significant to performance.

A study on elite male players during competition shows a similar pattern of physical activity throughout the game – majority of time spent in low intensity activity with smaller percentage of high speed running and sprinting (Figure 1.5; Spencer, Lawrence, Rechichi, Bishop, Dawson and Goodman, 2004). This observation highlights the temporary fatigue during each half with the highest activity levels in the first five to fifteen minutes of each half. Further to this, the largest amount of low intensity activity – standing and walking – occurs in the last period of the game. With the percentage time spent walking increased throughout the second half alongside a steady decline in the percentage time spent jogging.

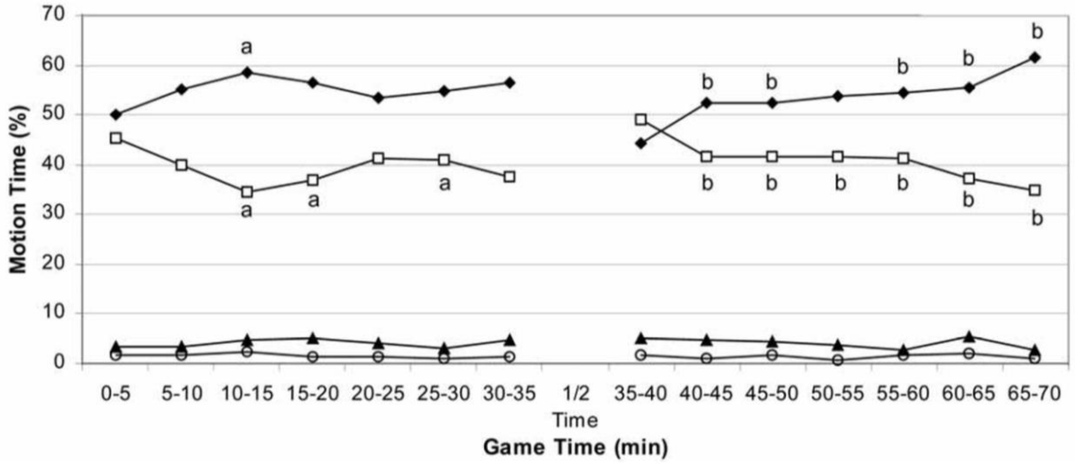

Figure 1.6. Player motion as a percentage of 5-min game time. Data are mean values. Filled diamonds - standing/walking; empty squares - jogging; filled triangles - striding; empty circles - sprinting. a Significantly different from 0 – 5 min. b Significantly different from 35 – 40 min ($P \leq 0.05$). Reproduced from Spencer *et al* (2004b)

A more recent study on sub-elite Chinese players showed similar results to that of the other previously mentioned studies (Lui *et al*, 2013). It was reported that players covered less distance in the second half of matches. Moreover the distance covered at every speed of locomotion was significantly less in the second half – except for walking which showed no difference. This study and the others mentioned are just short of 10 years apart and interestingly show very similar patterns of fatigue. This is evidence of a very definite fatigue produced during field hockey.

Lythe and Kilding (2013) investigated the best way of utilising the unlimited substitution rule to try and prevent the build-up of fatigue during competition. This study attempted to provide a substitution strategy that would help to improve performance and technical outputs of strikers during five field hockey games. GPS analysis, HR monitoring and video analysis was used to assess physical performance and technical outputs. A limitation of the methodology was the removal of time on the bench for both GPS and HR – this recovery period could be an extremely important factor for the subsequent playing period. For instance, whether athletes utilise active recovery strategies rather than passive recovery between sprint protocols has been shown to produce better power outputs in subsequent efforts (Signorile, Tremblay and Ingalis, 1993) or conversely reduce power outputs (Spencer, Bishop, Dawson, Goodman and Duffield, 2006). Not knowing the method with which these athletes recover may result in inappropriate conclusions being drawn as to the effectiveness of the substitution strategy.

Furthermore removing the HR data from this period means that the HR recovery of the substituted players is unknown and thus the condition of the player as they re-enter the field is also unknown. Immediately post-exercise - for 10 seconds to a few minutes - there is fast recovery involving quickly reducing HR (Tomlin and Wenger, 2001). Additionally, other measures of cardiovascular function and recovery such as HR variability can be used during this period to inform conclusions on recovery (Aubert, Seps and Beckers, 2003 and Achten and Jeukendrup, 2003).

The study involved three different substitution strategies - three strikers with no substitutions, four strikers with a moderate amount of substitutions (8) and five strikers with a high amount of substitutions (15). The results reported the greatest decrement in physical output when no substitutions were used, a small decrement with a high number substitutions and maintenance in distance covered with the moderate strategy (18 % , 0 % and 4 % decrement first versus second half, no, moderate and high strategies respectively). However distance covered doesn't necessarily mean increased performance and the quantity high speed running has been shown to be an important discriminator of field hockey performance (Jennings, Cormack, Coutts and Aughey, 2012). Interestingly both high speed running (> 19 $km \cdot hr^{-1}$) and sprint speed running (> 23 $km \cdot hr^{-1}$) were better in the second half with the moderate strategy (improve by 25.5 % and 27.5 %, 19 $km \cdot hr^{-1}$and 23 $km \cdot hr^{-1}$ respectively). The high number substitution strategy resulted in increased sprint distance but a 2 % reduction in high speed running first to second half.

HR data showed a similar average HR throughout the game as the rest of the team. The HR training zones where differences were reported were below 75 % HR_{max} and > 95 % HR_{max} – strikers in both of these zones spent a higher percentage of time in these zones than the rest of the team. As all three strategies should the same results it is inconclusive whether the substitutions helped to reduce low intensity activity and increase high intensity activity. The results may suggest that in this study GPS data is more appropriate for analysing physical changes during competition. GPS can show differences in both volume of work (total distance) and changes in intensity of work (speed zones) whereas HR data in this study is unable to show differences between those in the intervention group (strikers) and the rest of the team.

In addition to the physical outputs the video analysis used during the study was able to identify changes to technical outputs. The technical output data reported the highest contributions by the strikers when the high substitution strategy was used

(241 ± 35 versus 207 ± 38 and 173, high, moderate and no substitutions respectively). The also had a higher aggregate score during attacking versus defensive contributions with moderate substitutions just less and no substitutions resulting in a greater defensive contribution. This method of reporting technical output is questionable as it is dependent on the game outcome and tactics. The total number of contributions better illustrates whether athletes are being affected by fatigue as it can be presumed that players who are less fatigued will be more involved in the game.

Using GPS analysis Lythe and Kilding (2013) were able to show that increasing the use of substitutions was able to reduce the effects of fatigue on physical outputs. This is an interesting finding and shows the potential for reducing the amount of fatigue which occurs in international field hockey. It also presents a method of improving performance and suggests that teams should utilise the rotation of players to maximise performance – whether this is currently done is debateable given the previously mentioned literature.

1.2.5 Skill and Technique

Field hockey requires a large skill set comprising of various passing, shooting and tackling techniques. These include trapping, front and reverse stick passing, front and reverse stick shooting, aerials, drag flicks, jab and sweep tackles, dribbling and other tactical skills such as channelling opponents and marking. All of these skills are unique to field hockey due to the specific equipment and rules of the game. In this Chapter these skills will be briefly described, however it is not within the scope of this thesis to go into the intricacies of each skill.

Field hockey requires stick speed and ball control. The ability to control the ball at speed has been used to separate novice and sub-elite players using one specific method of testing field hockey skill (Thiel, Tremayne and James, 2012). This test has been shown to be a reliable measure of field hockey skill (Chapman, 1982) Other studies have tried to assess the sprint and dribbling ability using field hockey specific tests due to its unique skill requirement (Lemmink, Elferink-Gemser and Visscher, 2004 and Sunderland, Cooke, Milne and Nevill, 2006). Both of which have been shown to be valid due to their ability to report differences in field hockey skill levels and reproducible over 2 and 3 occasions, respectively (Pearson correlation coefficient between 0.73 to 0.91). However all three of these tests are drills which involve specific courses so are not a valid test to show competition skill level and reduce the variation and need for decision making.

Other skills fundamental to field hockey include front and reverse stick passing and receiving, tackling and shooting. These are less well reported in the literature but well-documented in coaching textbooks. Each skill requires basic stick control which is encompassed in the skill tests mentioned above. As such, basic skill level is the most significant separator of playing levels, especially at younger ages. Further to this Elferink-Gemser and colleagues (2007) showed psychological skills and field hockey understanding were key discriminators between novices and sub-elite players.

1.2.6 Summary

Field hockey is a unique team sport requiring a specific physiology as well as tactical awareness and skill. The field hockey players described in the literature are of average to small build with low body fat percentages. They have average to good aerobic capacities with maximal aerobic capacities ranging from 40 - 65 $mL·kg^{-1}·min^{-1}$. This is largely due to the aerobic nature of field hockey competition where players are required to play at up to 80 % HR_{max} and cover between 5 and 8 km in a game. The anaerobic and speed characteristics of players are less well understood. The literature suggests that players have a reasonable lactate tolerance and that female players may be able to tolerate more lactate accumulation than men. However the speed data reported suggests players have poor maximal speeds over 40 m. Strength and power results – although sparse – show players to have good grip strengths and average to above average countermovement jumps.

Time motion analysis data shows the majority of competition is carried out at low speeds with the greatest distance covered and time spent standing and walking. However there is a small - and physiologically costly - percentage of activity completed at high speeds. Furthermore, changes to tactics and rules mean that defenders have similar activity characteristics to midfielders – increased time jogging and high speed running. Another notable finding in the literature is that fatigue occurs from the first to the second half of competition which is very similar to that of soccer. However one study has shown the ability to reduce this through the manipulation of the unlimited substitution rule. Finally, there are two studies which highlight the effect of skill on the playing level of field hockey players. Due to its unique nature – playing equipment and crouched posture – skill and technique are important factors which discriminate between elite, sub-elite and novice player.

1.3 Global Positioning System Analysis

1.3.1 History

GPS are an established technology in modern society with most people carrying one in their pocket or bag, some without knowing it. Most smart phones will carry the capabilities to utilise GPS to find their position on the ground and direct them to their required place. However this technology is relatively young and has only been available for commercial use since the early 2000s.

The earliest attempts to accurately define a bodies position using radio signals were during the First World War when the USA LORAN radio navigation system was used (Kumar, and Moore, 2002). Modern GPS has arisen from this type of military technology and has been advanced by USA and specifically the USA-Soviet Union Cold War (Figure 1.8).

Although USA was the main driving force behind the development of GPS receivers on Earth it was Soviet Union who first showed the possibility of being able to send and receive radio signals from space when they launched Sputnik into orbit in 1957 (Figure 1.8). This was a trigger for US military forces to create a national council to study and develop a navigation system based in space. This council commissioned studies into the type, number and orientation of satellites required to accurately define a body's position on Earth down to less than 100 m. From this council, Navstar GPS (Navigation System Using Timing and Ranging) was developed and the first satellites were launched into orbit in 1978 (Figure 1.8) (Kumar and Moore, 2002).

The principle of GPS is based on trilateration and the speed, distance, time equation (Speed = Distance/Time) to work out the position of a receiver on Earth. Figure 1.6 shows trilateration in a 2D scenario. GPS works by signals coming from 3 or more satellites to a receiver point on Earth. The central dot spot in this Figure is the receiver on Earth and A, B and C are the satellites in space. Each satellite produces a circular signal and the point at which these crossover can be used to calculate the position. The actual signals are sent in a spherical shape (not a 2D circle) as can be seen by Figure 1.7. The satellites produce 3D spheres which intersect at two points. However as one of these points is in space it is disregarded and the point on Earth is used to define the bodies position (Bajaj, Ranaweera and Agrawal, 2002).

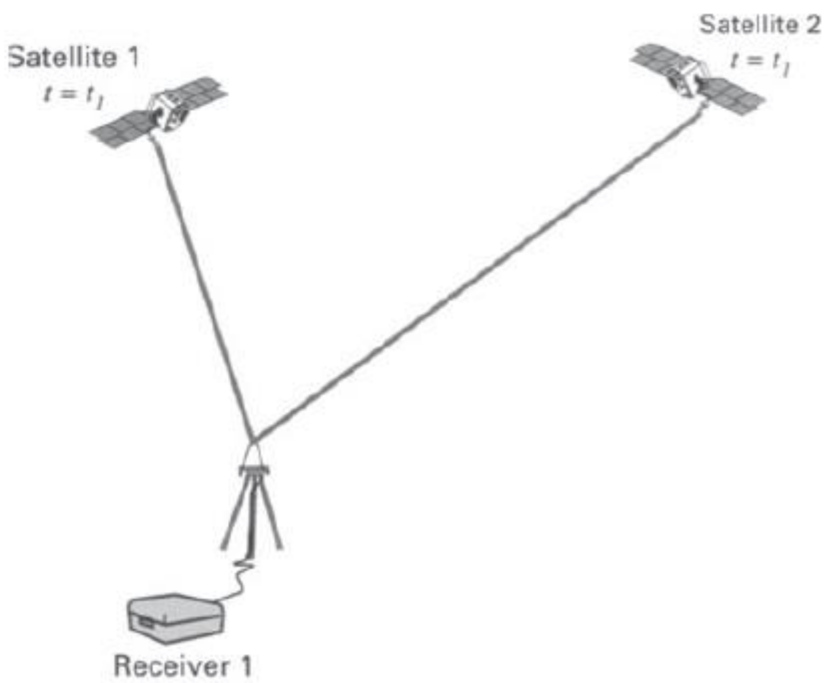

Figure 1.7. A basic 2-Dimensional model of GPS satellites and the use of trilateration to calculate a position on Earth. Reproduced from Dzurisin (2006)

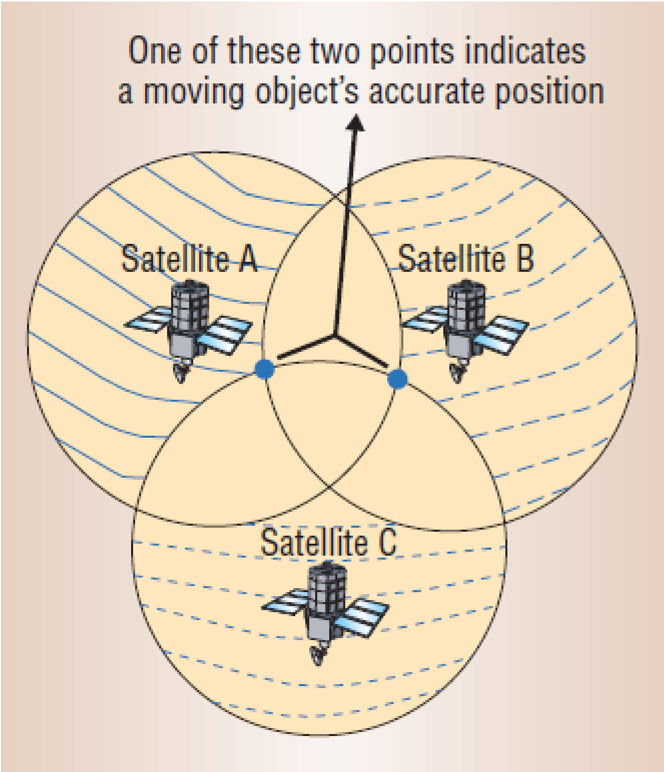

Figure 1.8. The interaction GPS satellites and the use of trilateration to calculate a position on Earth. Reproduced from Bajaj, Ranaweera and Agrawal (2002)

To calculate the distance, and subsequently the position of the object on Earth, accurate speeds and times are required from each of the satellites. This is acquired via the use of radio waves and atomic clocks. Both of these provide accurate data on the speed of signal (speed of light) and the time which it is sent and received. Calculation provides a distance for each satellite and this is used to define the position on Earth. Although it is possible to do this with three satellites it is more accurate when more satellites are used. A minimum of 24 satellites are required for the network to function, however currently there are 32 functioning satellites in orbit with 27 of these operational (Dzurisin, 2006). At most points on Earth there are between 8 and 11 satellites visible at any one time allowing for greater accuracy.

Figure 1.9. NAVSTAR satellite constellation. Reproduced from Dzurisin (2006)

Initially GPS was only for military use. However in 1983 an attack on a Korean airliner by Soviet Union air defences resulted in the US president of the time, Ronald Reagan, to open up the network to commercial airlines (Figure 1.8). The first prominent use of the newly developed US Global Navigation Satellite System (NAVSTAR) GPS network was the Persian Gulf War in 1990 (Figure 1.8). It allowed military forces to be able to accurately direct personnel and ammunition towards their opposition. Post-war the US authorities degraded the signal for commercial users meaning only the US military were able to accurately use the system. This brought about the development of deferential GPS devices which were ground based technologies to increase the signal accuracy. Eventually the US government removed this degradation and commercial use increased exponentially. In 2004 the first mobile telephones were tested with GPS devices leading to a wide variety of publicly available GPS-enabled devices (Figure 1.8) (Kumar and Moore, 2002).

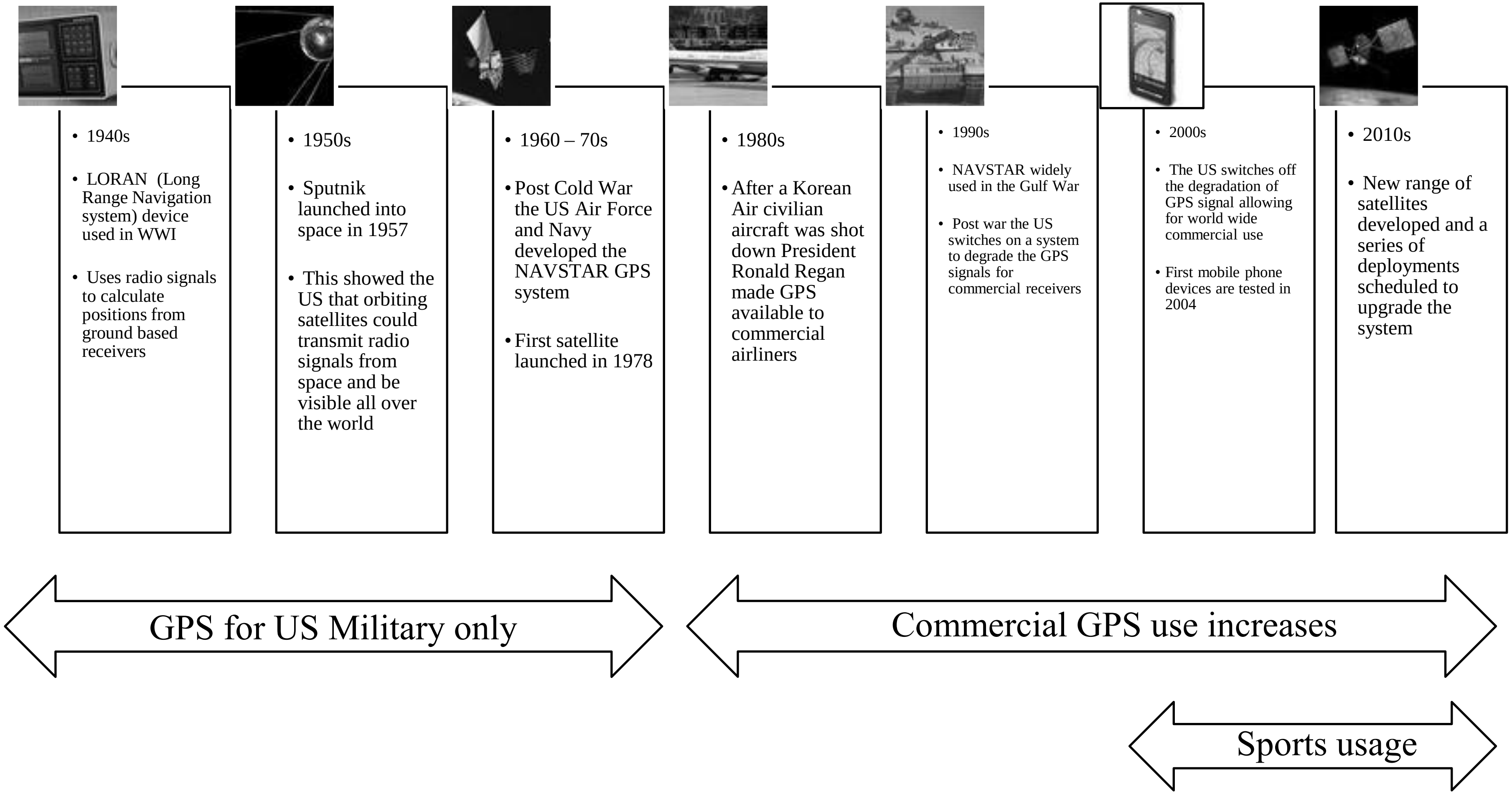

Figure 1.10. An overview of the history of Global Positioning Systems (GPS).

1.3.2 Validity, Specificity, Reproducibility and Reliability

A valid measure is one that describes the outcome appropriately but not necessarily specifically. For instance, the v-slope to determine ventilatory threshold does not specifically measure the lactate threshold but has been suggested to be a valid measure due to its ability to indicate changes in the process which it is attempting to describe (Bosquet, Leger and Legros, 2002). Using this terminology the question of GPS validity studied in the literature will be considered.

Table 1.16 displays the current literature where the validity of GPS technology has been discussed. These studies attempt to assess whether the distances and speeds reported by GPS are accurate compared to criterion measures and thus can be considered to be a valid measure as they can then be said to be able to indicate whether players have run more or run faster within different situations. These situations have been standardised within each study to attempt to answer the question of validity without other variables confounding the results. However this reduces the specificity of the measurement resulting in the validity being situation specific and not necessarily sport specific. For instance the results displayed in Table 1.16. Show GPS to be valid during linear running at constant speeds with increased accuracy when using higher frequency devices, however this does not mean that it is valid during random movements with variable speeds such as during team sport competition.

Method	Frequency	Comparison	Typical Error (CV/ICC/SEE/LoA/ %Bias)	Author
Running (AFL Specific)	1Hz	Trundle Wheel	CV; 6.3 ± 6.0%	Edgecomb & Norton, 2006
Running (Field Hockey Specific)	1Hz	Trundle Wheel	LoA; Total = 2.5 ± 15.8m; T-drill = 0.1 ± 0.91m; Straight = 0.2 ± 1.09m; Sprint Shuttle = 0.1 ± 0.94m; Zigzag = -0.1 ± 0.81m	MacLeod *et al*, 2009
Walking/Running (Soccer Specific)	1Hz & 5Hz	Audio/ProZone	SEM; 1Hz Linear = 2.6 to 2.7%, 5Hz Linear = 2.9 to 3.1%; 1Hz Multi = 1.8 to 6.9%; 5Hz Multi = 2.2 to 4.4%; 1Hz Sport = 1.3 to 3.0%; 5Hz Sport = 1.5 to 2.2%	Portas *et al*, 2010
Walking/Running (Cricket Specific)	5Hz	Running Track/Timing Gates	SEE; Walking = 0.4 ± 0.1 to 3.8 ± 1.4%; Sprinting = 2.6 ± 1.0 to 23.8 ± 8.8%	Petersen *et al*, 2009
Walking/Running	1Hz	Theodolite	% Bias; Linear: Walk = 2.8%, Jog = 0.8%, Run = 1.5%, Sprint = 2.5%; Multi-Directional: Walk = -0.5%, Jog = -5.8%, Run = -7.7%, Sprint = -9.8%	Gray *et al*, 2010
Walking/Running (Team Sports Specific)	1Hz & 5Hz	Timing Gates	SEE; 1Hz (Walk to Sprint) 10m = 23.8 ± 5.9 to 32.4 ± 6.9%, 20m = 17.4 ± 3.7 to 22.3 ± 4.7%, 40m = 9.6 ± 2.0 to 12.2 ± 2.4%, 20-40m = 15.0 ± 3.2 to 18.5 ± 3.9%; 5Hz (Walk to Sprint) 10m = 21.3 ± 5.8 to 30.9 ± 5.8%, 20m = 16.6 ± 3.5 to 17.0 ± 3.6%, 40m = 9.8 ± 2.0 to 11.9 ± 2.5%, 20-40m = 11.9 ± 2.5 to 12.9 ± 2.7%	Jennings *et al*, 2010
Running (Team Sport Specific)	1Hz	Measuring tape & Timing Gates	CV; SPI-10 = -4.1 ± 4.6%, SPI Elite = -2.0 ± 3.7%, WiSPI = 0.7 ± 0.6%	Coutts & Duffield, 2010
Running (Tennis Specific)	1Hz & 5Hz	VICON motion analysis	CV; 1Hz Distance; Slow = 3.6, Fast = 9.5, 2m Tennis = 3.6, 4m Tennis = 5.8, Random = 7.6; 5Hz Distance: Slow = 9.8, Fast = 17.8, 2m Tennis = 3.5, 4m Tennis = 11.0, Random = 16.8	Duffield *et al*, 2010
Running	5Hz	Timing Gates	CV; 10m = 8.06%, 20m = 8.09%, 30m = 5.00%, Moving 10m = 4.81%	Waldron *et al*, 2011
Running	10Hz	Measuring tape & Timing Gates	% Bias; 15m = 11.9%, 30m = 6.5%	Castellano *et al*, 2011

Table 1.16. Summary of results from published literature reporting the validity of GPS distance measurements.

The validity of GPS for measuring distances has been studied using simple straight line walking tasks as well as running drills and sport specific circuits and games. To measure the validity of devices these studies have compared the GPS distances to those measured by trundle wheels, measuring tapes, theodolites (a precision instrument for measurement) and motion analysis software. Each of these provides an accurate representation of the criterion variable. However, these devices contain some inherent error themselves such as user-error in the case of trundle wheels and measuring tapes. As such this must be considered when making conclusions based on the values presented. The studies reviewed show greater validity with higher measurement frequencies (10 Hz > 5 Hz >1 Hz), linear paths, longer distances and slower speeds.

The currently available literature reporting the validity of a variety of GPS devices during different activities can be seen in Table 1.16. A number of studies have assessed the validity of the GPS systems available on linear courses – either along a straight line or around a running track. These studies have shown limits of agreement of 0.2 m for a 1 Hz device during straight line shuttles within a field hockey specific circuit (MacLeod *et al*, 2009). Other 1Hz devices have been shown to have standard estimate of error (SEE) of 32.4 % for 10 m courses, 9.6 % for 40 m courses (Jennings *et al*, 2010) and as low as 2.6 % for a 51 m linear course (Portas *et al*, 2010). Further to this, Gray and colleagues (2010) reported a percentage bias of 0.8 to 2.8 % during a 200 m course which was completed at speeds from walking to sprinting. 5 Hz devices were shown to have SEE of up to 30.9 % for 10 m courses, 9.6 % for 40 m courses (Jennings *et al*, 2010) and between 2.9 and 3.1 % on a 51 m course (Portas *et al*, 2010). These SEE are marginally lower for shorter distance efforts in comparison to 1 Hz devices but similar or higher for the longer courses. Waldron and colleagues (2011) published coefficients of variation (CV) of 5 to 8.09 % for 5 Hz devices during maximal sprint testing. The comparison across studies is complicated by the different devices used and the protocols employed resulting in varying levels of validity across all studies. However a common finding is an increased validity of GPS units at slower speeds and longer distances with 5 Hz devices showing greater validity in short courses. This hypothesis is supported by a recent study using 10 Hz devices which shows percentage bias of 11.9 % for a 15 m linear course and 6.5 % for a 30 m linear course (Castellano *et al*, 2011).

In absolute terms, the error reported in these studies can display the practical significance of the reported accuracies of these units. Over 10 m runs inaccuracies can be as high as 3 m which is reduced with the sampling frequency (5 Hz < 1 Hz) (Jennings *et al*, 2010). This could mean 7 to 13 m runs being recorded in a sprint effort which will be practically significant if this is being used alongside time to calculate mean speed. For example during constant speed running the mean speed for someone running 7 m in 2 seconds is equal to 3.5 $m \cdot s^{-1}$ whereas running 13 m in 2 seconds would equal 6.5 $m \cdot s^{-1}$. In 51 m runs the inaccuracy was ~ 1.5 m as reported by (Portas *et al*, 2010). Further to this 10 Hz units have been shown to have inaccuracies of ~ 1.95 m during 30 m linear courses (Castellano *et al*, 2011). In terms of validity it has been suggested by each of these authors that the results produced by the GPS units are accurate enough to be considered valid measurements of distance. The absolute numbers suggest there is an improvement in accuracy with increasing distance.

A small number of studies have devised multi-directional courses to assess the validity of distance measurements when athletes are required to complete a number of changes of direction. Edgecomb and Norton (2006) recorded fifty-nine trials around a predetermined course using a 1 Hz device and compared the distance measurements to those measured by a trundle wheel. A difference was shown between the distance reported by the GPS device in comparison to the trundle wheel (6.3 % CV; $P \leq$ 0.001). Another study found 1 Hz systems to over-estimate distances during T-drill courses (LoA 0.1 ± 0.91 m) and under-estimate distance during zigzag courses (- 0.1 ± 0.81 m; MacLeod *et al*, 2010). Furthermore, during a 200 m non-linear course Gray and colleagues (2010) reported 1 Hz devices under-estimated the distance covered by up to 9.8 % (reported as percentage bias). These results suggest that during multi-directional activities 1 Hz devices are likely to under-estimated the distance covered by up to 10 %. Unfortunately no studies using higher sampling frequencies have specifically reported multi-directional course. More recent literature has been focused on the validity of GPS during sports specific circuits or non-prescribed activities such as match-play and training drills.

The sport specific studies in the literature include general team sport focused analyses (Jennings *et al*, 2010 and Coutts and Duffield, 2010) as well as studies focused on Australian rules (Edgecomb and Norton, 2006), field hockey (MacLeod *et al*, 2009), cricket (Petersen *et al*, 2009), soccer (Portas *et al*, 2010) and tennis (Duffield *et al*, 2010). The general team sport specific studies reported SEE of 9.6 to 32.4 % (Jennings *et al*, 2010) and CVs of between - 4.1 to 0.7 % (Coutts and

Duffield, 2010) for 1 Hz devices. The study by Jennings and colleagues (2010) compared 1 Hz device with 5 Hz devices and on the same multi-directional circuit and showed the 5 Hz devices to have slightly reduced SEE. During sport specific tasks 1 Hz devices have been shown to have standard error of mean (SEM) of between 1.3 to 3.0 % across different soccer positions (Portas *et al*, 2010), CV of 7.6 % for random tennis specific movements (Duffield *et al*, 2010) and CV of 6.3 % for Australian rules football movements (Edgecomb and Norton, 2006). 5 Hz devices produced SEM of 1.5 to 2.2 % (Portas *et al*, 2010) and CV of 16.8% (Duffield *et al*, 2010) in soccer and tennis respectively. Further to this, Petersen and colleagues (2009) reported SEE of 0.4 ± 0.1 to 3.8 ± 1.4 % for low speed cricket specific movement patterns and 2.6 ± 1.0 to 23.8 ± 8.8 % for sprinting distances. This information suggests that 5 Hz devices have greater accuracy during sport specific motions than the older 1 Hz devices. However the 5 Hz devices still reported errors of up to ~ 31 % and are less accurate at higher speeds. Furthermore, there are large variations in accuracy amongst types of 1 Hz and 5 Hz devices as shown by Coutts and Duffield's study using three different GPSports devices (2010) and Petersen and colleagues comparison of Catapult MinimaxX devices with GPSports. Similar to the relationship between lactate threshold and ventilatory threshold - where ventilatory threshold doesn't specifically measure lactate but indicates changes in lactate production - these results suggest that although accuracy is reduced with higher speeds GPS is a valid tool for the purpose of quantifying movements during team sports.

The accuracy of the numbers produced during multi-directional courses and sport specific circuits is highlighted when viewing the results in absolute terms. For instance during Gray and colleagues (2010) reported a 9.8 % under estimation during a which is equal to 19.6 m . In the studies on sport specific circuits differences of ~ 13 to 45 m over 140 m (Jennings *et al*, 2010), 18 m over a mean distance of 283 m (Edgecomb and Norton, 2006) and ~ 4 m over a 197 m course (Portas *et al*, 2010). All of these studies further highlighted the increased accuracy with increased sampling frequencies and increased distances – even with non-linear running and changing speeds. However although classed as random and/or sport specific movements these courses were standardised and not specific to competition or SSGs.

Similar to the validity of distance measure the validity of GPS for measuring speeds has been studied using constant speed runs, multi-directional circuits and drills including accelerations and decelerations. The accuracies of devices has been measured against speeds reported by timing gates, motion analysis software and laser testing systems. Each of these provides an accurate representation of the criterion variable with small variation due to software errors. The studies reviewed show greater validity with higher collecting frequencies (10 Hz > 5 Hz > 1 Hz), linear paths, longer distances, constant velocities and slower speeds.

The first study reporting the validity of GPS for measuring speed was conducted in 1997 by Schutz and Chambaz. This study used a Garmin device and reported a strong correlation to speed measured by chronometry (r = 0.99). Witte and Wilson (2004) studied the ability of differential GPS receivers to accurately assess speed. The device examined produced values with a standard error of measurement of between 4.0 and 4.8 %. However both of these studies were conducted before the removal of the US degradation of signal and are quite different from modern devices. Interestingly, very few modern devices have shown better accuracy.

Two studies have reported the validity of speed measurements recorded by 1 Hz and 5 Hz devices (MacLeod *et al*, 2009 and Barbero-Alvarez *et al*, 2010). The studies compared the GPS speeds to those recorded by timing gates. MacLeod's group showed a strong correlation over 26.15 m ($R^2 = 0.99$; $P \leq 0.001$). Barbero-Alvarez's groups showed similarly high correlations for a 30 m sprint ($R^2 = 0.94$; $P \leq 0.001$) but less during 15 m sprints ($R^2 = 0.87$; $P \leq 0.001$). Jennings and colleagues (2010) reported greater error for sprinting movements over 10 to 30 m and more accuracy for slower speeds and longer distances in both 1 and 5 Hz devices. Further to this, during gradual and tight change of direction circuits the 5 Hz devices were shown to be more accurate for all speeds (Table 1.17). Another study utilised 5 Hz devices and timing gates to validate the GPS devices for sprints up to 30 m (Waldron *et al*, 2011). The results from this study showed increased validity over 30 m compared to 20 m and 10 m (CV; 9.81 %, 8.54 % and 6.61 %; 10 m, 20 m and 30 m respectively). Furthermore accuracy was increased over a moving 10 m sprint (CV = 5.68 %) rather than standing start. Accuracy during this test was potentially increased due to the moving 10m reducing the effect of acceleration. This hypothesis may be confirmed by Varley and Aughey's (2012) analysis of 5 and 10 Hz units during constant speed, acceleration and deceleration runs which showed the highest variations with 5 Hz devices during accelerations between 1 and 3 $m \cdot s^{-1}$ and decelerations between 5 and 8 $m \cdot s^{-1}$. The 10 Hz devices were shown to be more accurate for all runs with the highest variation being 11.3 % for decelerations (compared to 33.2 % for 5 Hz).

Method	Frequency	Comparison	Correlation	Typical Error (CV/ICC/SEE/LoA/ %Bias)	Author
Walking/Running/ Cycling	1Hz	Chronometry	R = 0.99, $P \leq 0.001$	SEE; Walk = 1.1 km.hr^{-1}, Run = 0.7 km.hr^{-1}, Cycle = 0.8 km.hr^{-1}	Schutz *et al*, 1997
Cycling	5Hz	Speedometer		SEM; Straight = 4.8 ± 7.8%, Wide Circle = 4.0 ± 4.7%, Tight Circle = 4.8 ± 4.3%	Witte & Wilson, 2004
Running (Field Hockey Specific)	1Hz	Timing Gates & Trundle Wheel	R = 0.99, $P \leq 0.001$	LoA; 0.0 ± 0.9 km.hr^{-1}	MacLeod *et al*, 2009
Walking/Running (Cricket Specific)	5Hz	Running Track/Timing Gates		SEE; MinimaxX A/B: Walking = 3.8 ± 1.4%/2.0 ± 0.8%, Jogging = 2.6 ± 1.0%/1.8 ± 0.7%, Running = 2.8 ± 1.0%/3.0 ± 1.1%, Striding = 1.7 ± 0.6%/1.8 ± 0.7%, Sprinting = 15.2 ± 5.6/23.8 ± 8.8, Run-A-Three = 12.7 ± 4.7%/5.3 ± 2.0%; SPI Pro A/B: Walking = 1.0 ± 0.4%/0.5 ± 0.2%, Jogging = 3.7 ± 1.4%/1.5 ± 0.5%, Running = 2.4 ± 0.9%/0.7 ± 0.2%, Striding = 3.0 ± 1.1%/0.4 ± 0.1%, Sprinting = 5.5 ± 2.0/10.5 ± 3.9, Run-A-Three = 6.7 ± 2.5%/2.6 ± 1.0%	Petersen *et al*, 2009
Running & RSA	5Hz	Timing gates	15m: $R^2 = 0.87$, $P \leq 0.001$; 30m: $R^2 = 0.94$, $P \leq 0.001$		Barbero-Alvarez, 2010
Walking/Running (Team Sports Specific)	1Hz & 5Hz	Timing Gates		Straight Line: SEE; 1Hz (10-40m): Walk = 23.8 ± 5.9 to 9.6 ± 2.0, Jog = 25.7 ± 5.5 to 11.5 ± 2.4, Stride = 31.1 ± 6.6 to 11.3 ± 2.4, Sprint = 32.4 ± 6.9 to 12.2 ± 2.4; SEE; 5Hz (10-40m); Walk = 21.3 ± 5.8 to 9.8 ± 2.0, Jog = 23.2 ± 4.9 to 10.7 ± 2.3, Stride = 27.4 ± 6.6 to 11.5 ± 2.4, Sprint = 30.9 ± 5.8 to 11.9 ± 2.5; COD: SEE; 1Hz (Gradual – Tight): Walk = 9.1 ± 2.4 to 12.6 ± 3.3, Jog = 10.2 ± 2.7 to 9.0 ± 2.3, Stride = 11.5 ± 3.0 to 10.4 ± 2.7, Sprint = 12.7 ± 3.0 to 12.5 ± 3.3; SEE; 5Hz (Gradual – Tight): Walk = 8.9 ± 2.3 to 9.9 ± 3.1, Jog = 9.7 ± 2.8 to 10.6 ± 2.8, Stride = 11.0 ± 3.1 to 10.8 ± 2.8, Sprint = 11.7 ± 3.0 to 11.5 ± 3.0	Jennings *et al*, 2010
Running (Sport Specific)	1Hz	Measuring tape & Timing Gates	R = -0.4 to -0.53, $P \leq 0.001$		Coutts & Duffield, 2010
Running (Tennis Specific)	1Hz & 5Hz	VICON motion analysis		CV; 1Hz Mean Speed: Slow = 2.1, Fast = 11.1, 2m Tennis = 3.9, 4m Tennis = 5.6, Random = 19.3; 5Hz Mean Speed: Slow = 9.1, Fast = 17.1, 2m Tennis = 3.4, 4m Tennis = 15.6, Random = 16.9; 1Hz Peak Speed: Slow = 2.3, Fast = 15.3, 2m Tennis = 5.8, 4m Tennis = 12.6, Random = 26.7; 5Hz Peak Speed: Slow = 17.6, Fast = 31.7, 2m Tennis = 20.3, 4m Tennis = 24.5, Random = 35.3	Duffield *et al*, 2010
Running	5Hz	Timing Gates		CV; 10m = 9.81%, 20m = 8.54%, 30m = 6.61%, Moving 10m = 5.68%	Waldron *et al*, 2011
Running	5Hz & 10Hz	Laser		CV; 5Hz Constant Speed: 1-3 m.s^{-1} = 11.1 ± 0.58, 3-5 m.s^{-1} = 10.6 ± 0.59, 5-8 m.s^{-1} = 3.6 ± 0.26; 5 Hz Acceleration: 1-3 m.s^{-1} = 14.9 ± 1.16, 3-5 m.s^{-1} = 9.5 ± 0.79, 5-8 m.s^{-1} = 7.1 ± 0.87; 5Hz Deceleration: 5-8 m.s^{-1} = 33.2 ± 1.64; 10Hz Constant Speed: 1-3 m.s^{-1} = 8.3 ± 0.27, 3-5 m.s^{-1} = 4.3 ± 0.15, 5-8 m.s^{-1} = 3.1 ± 0.13; 10 Hz Acceleration: 1-3 m.s^{-1} = 5.9 ± 0.23, 3-5 m.s^{-1} = 4.9 ± 0.21, 5-8 m.s^{-1} = 3.6 ± 0.18; 10Hz Deceleration, 5-8 m.s^{-1} = 11.3 ± 0.44	Varley & Aughey, 2012

Table 1.17. Summary of results from published literature reporting the validity of GPS speed measurements.

The validity of GPS speed measurements during sport specific tasks has been studied in general team sports, field hockey, cricket, and tennis. Unfortunately these studies still require an element of standardisation to allow for ‘true’ values to be provided from timing gates and laser analysis. During a series of cricket specific drills five different devices from two different manufacturers were studied to assess their accuracy over long distance walking (8800 m), jogging (2400 m), running (1200 m) striding (600 m), sprinting over 20, 30 and 40 m and ‘run-a-three’ sprint (three lengths of wicket which requires two 180 degree turns) (Petersen *et al,* 2009). Two devices (SPI Pro A and B 5 Hz, GPSports) showed good accuracy – SEE of 10.5 % and less for all movements. The other manufacturer (Catapult MinimaxX 5Hz) showed much less accuracy with SEE as high as 23.8 % during 20 m sprints. A similar study compared three GPSports models to assess the validity of speed measurements (Coutts and Duffield, 2010). This showed all three devices to be correlated to 20 m sprint time (r = - 0.40 to - 0.53; $P \leq$ 0.001). However one device was significantly different from the other two devices when reporting the peak speed (SPI-10 versus SPI Elite and WiSPI; $P \leq$ 0.05). Lastly, a study of tennis movement patterns showed 5 Hz devices to more accurately measure mean speed than 1 Hz devices across and range of activities from slow movements to random tennis specific movements (Duffield, 2010). However in the same study, with the same devices, peak speed was more accurately measured by 1 Hz devices.

The practical significance of these findings are better understood when the values are reported in absolute terms rather than the statistical values given previously. Waldron and colleagues (2011) showed CV of 9.81 %, 8.54 % and 6.61 % over 10 m, 20 m and 30 m respectively. However these values mean nothing in terms of speeds. The absolute values show differences of approximately 2 km·hr^{-1} at each distance even though the CVs are distinctly different. Barbero-Alvarez and colleagues (2010) RSA testing reported CV of 1.2 % for maximum speed which in practical terms was 0.29 km·hr^{-1} of the maximal speed 24.6 km·hr^{-1}. This is a minimal difference and is likely to have less practical significance compared to a difference of 2 km·hr^{-1} reported in Waldron and colleagues (2011) study. The differences in results may be due to the testing procedure as the RSA study included 6 sprints which increased the sample size compared to the 2 maximal sprints in Waldron and colleagues (2011) study. Further to this, although both units were GPSports 5 Hz units they were two different versions GPSports-Elite versus GPSports-Pro. This is similar to the findings of Buchheit and colleagues (2014) who showed variations in maximal speed when 50 identical units were towed during simulated soccer activities. These findings suggest that although the practical significance of the speeds reported may a degree of accuracy and thus validity it is only specific to the units used.

The information presented here on the validity of GPS devices suggests that there is a large variation in testing protocols, gold standards for comparison, distances, speed and courses. Furthermore there is also variation across manufacturers, within different manufacturer's models and within the same devices. The lowest variations are shown in devices sampling at 10 Hz and on straight line courses (Varley and Aughey, 2012). The biggest variations came at sprinting speeds over short distances (Jennings *et al*, 2010). Additionally tight changes of direction, accelerations and decelerations increase error. However, it can be suggested that over longer distances and/or during longer duration recording the results produced by GPS devices over 5

Hz are valid. These studies highlight the inconsistencies in both the scientific literature and the GPS technology itself. It does not rule out GPS as a strategy for recording physical activity of team sports athletes. Most authors suggest it is useful for gross identification of activities yet concede that at high speeds (> 20 $km \cdot hr^{-1}$) all data must be viewed with caution.

This information suggests that GPS technology has been shown to be valid and specific in certain circumstances but not during competition. When testing team sport athletes we want to be specific to the situations within which they perform. Like the example of VT used previously, as scientists we want VT to equal LT but accept that VT correlates to LT so is still a valid - but not specific – measurement. This can be said for the distance and speed measurements from GPS – distances may not be specific for the individuals movements patterns because of the random nature of competition and training however increasing sample numbers should help to decrease the impact of the lack of specificity (Hopkins, Marshall, Batterham and Hanin, 2009). As such using team averages allows for the identification of variations in activities giving the values greater validity. This is important in a practical sense as it is common practice for practitioners to attempt to get individual players to accumulate high intensity distances for a session with specific thresholds. These are derived from competition where increased pitch sizes and unknown accuracy making these specific but invalid thresholds.

Other criteria which are required to be tested for a testing procedure to be considered to be useful are the reproducibility and reliability of the results it produces.

Reproducibility describes whether a test will give the same output if the same procedure is used. Whereas reliability is a measure of the consistency of results. For instance completing a cycle ergometer test of maximal oxygen uptake with specific protocols had good reproducibility due to the standardised procedures and good reliability due to the consistent accuracy of the system used (Anderson, 1995). Due to the random nature of field hockey competition and training the reliability of results is unknown – you cannot repeat the game or small sided game with exactly the same movements. The information displayed in Table 1.18 shows the within-device (intra-) reliability and between-device (inter-) reliability during specific tasks such as linear running or sport specific circuits. In addition but not specifically reported in any of the literature the data shows that GPS technology is reproducible when used under specific circumstances and as such if used with the same procedures should be reproducible in competitive situations.

The reliability of GPS for measuring distances has been studied using simple straight line walking tasks as well as running drills and sport specific circuits and games. To measure the reliability of devices these studies have compared a number of devices worn simultaneously by an individual during drills and across different sessions and chronological times. These methodologies allow for accurate comparisons of devices, reducing error and standardising protocols. The studies reviewed below show greater reliability with higher collecting frequencies (10 Hz > 5 Hz > 1 Hz), slower speeds and within-devices (more than between-devices).

The ability to produce reliable results across testing sessions is important for all quantitative measurements of physical activity. Two studies have tested the test-retest reliability of GPS devices in the literature. Gray and colleagues (2010) completed a 200 m linear and non-linear circuit on multiple occasions. The test retest reliability was assessed using the 95 % coefficient of variation (CV). The results reported within receiver reliability of 2.66 %. In actual terms this equated to 5.32 m of the 200 m circuit. Jennings and colleagues (2010) reported the within device reliability of 1 and 5 Hz devices and showed increased reliability when the distance travelled increased. The shortest distances produced the biggest variability – up to 77.2 % for 10 m sprints. The most reliable speed and distance for both devices was walking 40 m.

The previously mentioned study by Jennings and colleagues contained a change of direction (COD) element which showed decreased reliability for tight COD circuits compared to gradual CODs with a variation of up to 17.5 % for the 1 Hz devices and 15.2 % for the 5 Hz devices. Interestingly the poorest reliability of both devices on both courses was during walking activities and not sprinting. Another study used multidirectional courses based on the pitch markings of a soccer field and showed variation of between 3.1 and 7.7 % for 1 Hz devices and 3.4 to 6.1 % for 5 Hz devices.

The majority of reliability studies have focused on the application of GPS devices within the team sport environment (all data shown in Table 1.18). This is due to the increasing usage of this data produced by this technology and the need for comparison across sessions and players. A study in soccer showed CV of between 2.0 to 4.9 % for 1 Hz device and 2.2 to 4.5 % for 5 Hz devices during a soccer specific circuit. This variation is similar to those seen in low intensity movement during cricket movement patterns (Petersen *et al*, 2010) and team sport patterns (Johnston *et al*, 2012) using 5 Hz devices.

However the variation in distance values greatly increases at higher speeds – between 23 and 43 % in sprinting in cricket and 112 % in team sport activities (Petersen *et al*, 2010 and Johnston *et al*, 2012 respectively). Similarly, Duffield and colleagues (2010) reported that distance measurements produced during slow movements were more reliable than during fast movements. Interestingly in this study the lower frequency devices were more reliable – typical error as shown by CV was 7.6 % for 1 Hz and 16.8 % for 5 Hz devices during random tennis movements. Another study by this group showed 1 Hz devices to have poor reliability over six laps of a 128.5 m team sport specific running circuit (CV from 3.6 to 7.2 %).

Method	Frequency	Comparison	Typical Error (CV/ICC/SEE)	Author
Run		Trundle Wheel	CV; 5.50%	Edgecomb & Norton, 2006
Walking/Running	1Hz & 5Hz	Audio/ProZone	CV; 1Hz Linear = 4.4 to 4.5%, 5Hz Linear = 4.6 to 5.3%, 1Hz Multi = 3.1 to 7.7%, 5Hz Multi = 3.4 to 6.1%; 1Hz Sport = 2.0 to 4.9%, 5Hz Sport = 2.2 to 4.5%	Portas *et al*, 2010
Walking/Running (Cricket Specific)	5Hz		CV; Walking = 0.3 (0.2 to 0.4) to 2.9% (2.3 to 4.0), Sprinting = 2.0 (1.6 to 2.8) to 30.0% (23.2 to 43.3)	Petersen *et al*, 2009
Running & RSA	5Hz	Timing gates	CV; Maximal Speed = 1.7%, Peak Speed = 1.2%, Fatigue Index = 36.2%	Barbero-Alvarez, 2010
Walking/Running	1Hz	Theodolite	CV; Within receivers = 2.6%, Between receivers = 2.8%	Gray *et al*, 2010
Walking/Running (Team Sports Specific)	1Hz & 5Hz	Timing Gates	CV; 1Hz Linear (10-40m): Walk = 7.0 to 30.8%, Jog = 9.4 to 34.7%, Stride = 10.5 to 58.8%, Sprint = 11.5 to 77.2%; 5Hz Linear (10-40m): Walk = 6.6 to 23.3%, Jog = 9.1 to 22.8%, Stride = 8.0 to 33.4%, Sprint = 9.2 to 39.5%; 1Hz COD: Walk = 11.6 to 17.5%, Jog = 8.6 to 9.0%, Stride = 10.8 to 12.2%, Sprint = 10.7 to 12.0%; 5Hz COD: Walk = 11.5 to 15.2%, Jog = 8.6 to 10.0%, Stride = 9.7 to 9.9%, Sprint = 7.9 to 9.2%	Jennings *et al*, 2010
Running (Sport Specific)	1Hz	Measuring Tape & Timing Gates	CV; Lap (128.5m): SPI-10 = 6.4 (5.7 to 7.4), SPI Elite = 4.0 (3.6 to 4.5), WiSPI = 7.2 (6.4 to 8.4)); Bout (771m): SPI-10 = 4.5 (3.5 to 6.6), SPI Elite = 3.6 (2.8 to 5.2); WiSPI = 7.1 (5.3 to 10.9)	Coutts & Duffield, 2010
Running (Tennis Specific)	1Hz & 5Hz	VICON motion analysis	1Hz Distance: 2m Tennis = 3.6%, 4m Tennis = 5.8%, Random = 7.6%; 5Hz Distance: 2m Tennis = 3.5%, 4m Tennis = 11.0%, Random = 16.8%	Duffield *et al*, 2010
Running	5Hz	Timing Gates	CV; 10m Sprint = 1.99%, 20m Sprint = 2.06%, 30m Sprint = 1.84%, Moving 10m = 2.30%	Waldron *et al*, 2011
Running	10Hz	Measuring Tape & Timing Gates	15m = 1.3%, 30m = 0.7%	Castellano *et al*, 2011
Running (Team Sport Specific)	5Hz	Measuring tape & Timing Gates	Sports Circuit: Overall = 2.0%, Walking = 7.5%, Jogging = 8.2%, Running = 5.6%, High Speed Running = 10.8%, Sprinting = 112.0%, Low Intensity = 4.3%, High Intensity = 7.9%, V.High Intensity = 12.7%: Flying 50m: V.High Intensity = 20.1%, Sprinting = 59.3%	Johnston *et al*, 2012

Table 1.18. Summary of results from published literature reporting the reliability of GPS measurements.

Similar to distance reliability, the reliability of speed results is important to allow for accurate comparisons across training sessions and between individuals. The retest reliability is important when using GPS devices to assess speed characteristics, repeated sprint ability or competition specific speed characteristics. As such the current literature focuses on these activities when analysing the reliability of different GPS devices. The results reported below show greater reliability with higher collecting frequencies (10 Hz > 5 Hz > 1 Hz), low speed movements, constant velocities and peak speed during repeated sprints.

Jennings and colleagues (2010) reported reliability results for 1 and 5 Hz devices during linear tasks at walking, jogging, striding and sprinting speeds (all self-selected). The 1 Hz devices utilised showed wide variation at all intensities with walking providing the lowest CV (7.0 %) but not the tightest range of values (walking 7.0 to 40.0 % versus jogging 9.4 to 34.7 %). Striding and sprinting had the poorest reliability up to 58.8 % and 77.2 % respectively. The 5 Hz devices were lower for all intensities but still produced values ranging from 23.3 % for walking and 39.5 % for sprinting. Another study in the literature investigated the reliability of 5 Hz units to measure sprinting speed in rugby league players (Waldron *et al*, 2011). This study reported increased reliability in 10, 20 and 30 m sprints. The CV across two tests was between 1.62 to 2.06 %. Additionally peak speed produced the lowest variation (0.78 %) – better than timing gate reliability. However for all other variables timing gate reliability was greater than that of the GPS devices.

One study has recently reported the reliability of 5 and 10 Hz devices during a straight line running task involving acceleration, constant speed and deceleration – the like of which is apparent in most sports (Varley and Aughey, 2012). The results reported lower variation for 10 Hz devices across all activities and speeds. The 5 Hz devices reported variation of between 6.3 and 12.4 % at constant speed, 9.5 to 16.2 % during the acceleration phase and 31.8 % during deceleration. The 10 Hz units have no variation over 6.0 % for any speed and had CV of 1.9 and 2.0 % for accelerating and high speed running respectively.

Two more studies have attempted to assess the reliability of GPS units for recording speed during more practical activities. Duffield and colleagues (2010) analysed the reliability of 1 and 5 Hz units for measuring speed during court-based tennis movements. This showed greatest reliability over slow prescribed movements but this was greatly reduced as speed was increased. Another investigation reported the test retest reliability of GPS devices during a 7 x 30 m repeated sprint ability test (Barbero-Alvarez *et al*, 2009). The distance measurements reported by GPS were compared across sessions and showed CV of 1.7 %, 1.2 % and 36.2 % (maximal speed, peak speed and fatigue index respectively).

Method	Frequency	Comparison	Typical Error (CV/ICC/SEE)	Author
Running & RSA	5Hz	Timing gates	CV; Maximal Speed = 1.7 (1.2 to 2.8%), Peak Speed = 1.2 (0.9 to 2.0%), Fatigue Index = 36.2 (29.6 to 81.6%)	Barbero-Alvarez, 2010
Walking/ Running (Team Sports Specific)	1Hz & 5Hz	Timing Gates	CV; 1Hz: Walk = 7.0 to 40.0%, Jog = 9.4 to 34.7%, Stride = 10.5 to 58.8% Sprint = 11.5 to 77.2%; 5Hz: Walk = 6.6 to 23.3%, Jog = 9.1 to 22.8%, Stride = 8.0 to 33.4%, Sprint = 9.2 to 39.5%	Jennings *et al*, 2010
Running (Sport Specific)	1Hz	Measuring tape & Timing Gates	CV; Low Intensity: SPI-10 = 5.3 (4.1 to 7.7), SPI Elite = 4.3 (3.3 to 6.2), WiSPI = 12.5 (9.3 to 16.6); High Intensity: SPI-10 = 32.4 (24.3 to 49.7), SPI Elite = 11.2 (8.6 to 6.5), WiSPI = 15.4 (11.7 to 22.9); Very High Intensity: SPI-10 = 30.4 (22.8 to 46.4), SPI Elite = 15.4 (11.7 to 22.9), WiSPI = 11.5 (11.5 to 25.4); Peak Speed: SPI-10 = 5.8 (5.2 to 6.6), SPI Elite = 2.3 (2.1 to 6.6), WiSPI = 4.9 (4.3 to 5.7)	Coutts & Duffield, 2010
Running (Tennis Specific)	1Hz & 5Hz	VICON motion analysis	1Hz Mean Speed: Slow = 2.1%, Fast = 11.1%; 5Hz Mean Speed: Slow = 9.1%, Fast = 17.1%; 1Hz Peak Speed: Slow = 2.3%, Fast = 15.3%; 5Hz Peak Speed: Slow = 17.6%, Fast = 31.7%	Duffield *et al*, 2010
Running	5Hz	Timing Gates	CV; 10m Sprint = 2.06%, 20m Sprint = 1.92%, 30m Sprint = 2.02%, Moving 10m = 1.62%, Peak Speed = 0.78%	Waldron *et al*, 2011
Running	5Hz & 10Hz	Laser	5Hz Constant Speed: 1-3 $m.s^{-1}$ = 12.4 ± 1.18, 3-5 $m.s^{-1}$ = 6.7 ± 0.68, 5-8 $m.s^{-1}$ = 6.3 ± 0.83; 5 Hz Acceleration: 1-3 $m.s^{-1}$ = 16.2 ± 1.99, 3-5 $m.s^{-1}$ = 9.5 ± 1.18, 5-8 $m.s^{-1}$ = 11.0 ± 2.29; 5Hz Deceleration: 5-8 m.s-1 = 31.8 ± 2.99; 10Hz Constant Speed: 1-3 $m.s^{-1}$ = 5.3 ± 0.22, 3-5 $m.s^{-1}$ = 3.5 ± 0.20, 5-8 $m.s^{-1}$ = 2.0 ± 0.12 10 Hz Acceleration: 1-3 $m.s^{-1}$ = 4.3 ± 0.24, 3-5 $m.s^{-1}$ = 4.2 ± 0.26, 5-8 $m.s^{-1}$ = 1.9 ± 0.15; 10Hz Deceleration: 5-8 $m.s^{-1}$ = 6.0 ± 0.33	Varley & Aughey, 2012

Table 1.19. Summary of results from published literature reporting the reliability of GPS speed measurements.

1.3.3 Utilisation

The utilisation of GPS devices is extensive and varied. A number of sports teams have been reported to be using GPS systems including Australian rules football, rugby union, rugby league, soccer, NFL and cricket teams (Catapult Sports and GPSports http://gpsports.com/). Each sport utilises the technology in different ways and many have published literature with their findings. The young age of the technology and its diverse applications mean that no standard methods of use are apparent.

The main usage of GPS for most sports teams and individuals is to monitor physical activity of players during training and competition. Its ability to quantify pitch based efforts which cause a load on the body is the main rationale for using such technology. In addition to the gross physical load on athletes it allows intensity of effort to be derived from speed data. GPS data is an additional tool for sports scientists to use that has the ability to derive or estimate the mechanical load on the muscles which can be subsequently used for recovery strategies, training prescription or return to play protocols.

Additionally some studies have tried to assess the ability of GPS to test 30 m speeds and repeated sprint ability (RSA) (Barbero-Alvarez, 2009). The rationale for this type of practice is the time efficient nature of GPS – a whole squad can run through a 30m sprint at the same time instead of individuals running through timing gates at different intervals. The study reported mean and peak speed during the 30m repeat sprint test to be valid. However, most other studies have questioned the ability to accurately assess high speed efforts using GPS. As such it may be sometime before GPS can be used instead of timing gates for speed testing large groups of athletes.

The parameters used by each sport to assess the physical load range from basic distance covered, meters per minute and time spent in speed zones to more derived parameters such as total external load (accumulation of accelerations) and impact scores. Even within these parameters there is a variety of zones, cut-offs, standards and protocols set to try and marry the numbers to our subjective impressions of effort and application. For instance, one practitioner may think that an effort lasting 2 seconds at 21 $km \cdot hr^{-1}$ is a sprint but another may only require 1 second for an effort to be recorded with a cut off of 23 $km \cdot hr^{-1}$. For this reason GPS results are difficult to compare across teams and even within teams where individual differences make quantifying effort very difficult.

1.4 Microtechnology

GPS devices have dramatically shrunk over their short lifespan and are now as small as a mobile phone and weigh less than 100 g. In built into these devices are not only GPS transmitters and memory hardware but accelerometers, gyroscopes and magnetometers. These pieces of technology provide a greater depth of information for sports practitioners to assess the physical movements of athletes during their training and in competition. The main benefit of microtechnology is the higher sampling rates in comparison to GPS transmitters – the highest available GPS sampling rate is 10 Hz compared to the basic sampling rate of accelerometers 100 Hz.

1.4.1 Validity, Specificity, Reproducibility and Reliability

The microtechnology available allows accelerations, decelerations and mechanical load to be quantified alongside distance and speed during competition and training. Catapult MinimaxX systems report total external load (Player Load) by using an algorithm which combines accelerations in all planes (further explained in Chapter 2.4.1.3). This parameter is suggested by the manufacturers to display similar trends to total locomotor distance from GPS between playing positions. Further to this the Player Load$_{SLOW}$ parameter (all accelerations under 2 $m \cdot s^{-2}$) is suggested to be a parameter for displaying information on small, low speed movements such as lunging or changing direction (Catapult Innovations Help Document, 2013).

The validity of accelerometer data has been reported in a small number of studies within the literature. Akenhead and colleagues (2013) assessed the accuracy of acceleration data in comparison to laser timing. The GPS unit was attached to a monorail and towed behind an athlete. As the unit was attached to a monorail acceleration was restricted to one plane. SEE of the accelerations were low although increased when above 4 $m \cdot s^{-2}$ (0.12 ± 0.02 to 0.32 ± 0.06, 0 - 1 $m \cdot s^{-2}$ and > 4$m \cdot s^{-2}$ respectively). Overall SEE was 0.19 ± 0.01 for all trials. The authors concluded that accelerometer accuracy is good up to 4 $m.s^{-2}$ but anything over this and the accuracy of findings is reduced. In comparison to GPS accuracy the accuracy of accelerometer data is far superior. However similar to the findings in GPS the validity is very specific and not in a competitive environment.

However, Gabbett (2010c, 2011 and 2013) reported on the validity of microtechnology to measure the number and magnitude of impact during collision sports such as rugby league. One of these studies, in rugby league skills training, a positive relationship was shown between the number of collisions recorded by Catapult MinimaxX devices and by video analysis (Gabbett, 2010a). This was during drills which were focused on improving skills such as passing, catching, tackling, support play, defensive skills and ball control. However it is not reported if the outputs of MinimaxX units and video outputs were similar during small-sided games or competition. Both of these situations are more random than skill practice and may be more susceptible to inaccuracies such as opposition players pulling the shirt of the player making the unit experience an acceleration which would not be classed as a contact when viewed using video analysis.

In a review on the subject Gabbett (2013) discussed the ability of current systems to measure impact loads. It was reported that head mounted accelerometers in the NFL which measure at a greater frequency than those used in the GPS-accelerometer combined units (MinimaxX and GPSports) had been validated and shown to be acceptable for use in this environment. However he reported that only the MinimaxX unit had been validated in the other systems - this study also conducted by Gabbett (2010a) is discussed above. In the review it was concluded that only the Catapult MinimaxX devices, and not GPSports devices, are capable of giving a valid measurement of impact loads during contact sports.

Boyd and colleagues (2011) assessed the reliability of a GPS device with in built microtechnology – the Catapult MinimaxX 5 Hz device. The validity of the devices was assessed in a laboratory setting as well as during Australian rules football games. Lab based testing involved static and dynamic testing. Static testing – units secured in a vertical position using a specifically designed cradle on a level surface - was conducted on 10 units, each of which were recorded during 6 periods of 30 seconds with 2 minutes. Dynamic testing involved 8 units being taken through a protocol consisting of a range of accelerations on a hydraulic shaker. The results of the study showed both static and dynamic CV of between 0.91 to 1.10 %. The reliability during sport specific games was similar (1.94 %).

This study is one of the first to attempt to describe the reliability of accelerometers during competition. By attaching the two units together during games the between-unit reliability was assessed. This means that the inaccuracy of each unit compounds the reliability results. However in this case it was reported that the between-device CV was less than the within-device reliability (1.05 % versus 1.02 %, within-device and between-device respectively) during the dynamic laboratory test. This study is limited by the size of the sample used – 8 units tested during static testing, 10 during dynamic testing and on 10 players during competitive games. The authors allude to the need for test within specific populations when determining the validity and reliability of the accelerometer data (Boyd, Ball and Aughey, 2011). This concurs with the previous assertions made that GPS validity must be considered within the specificities of the situation with which it is used. The literature perhaps more strongly evidences the reliability of accelerometer data in comparison to GPS data however both technologies require more specificity and as such it may be more appropriate to utilise mean values rather than those of individuals.

1.5 Statement of Problem

In reviewing the literature, it is apparent that the current literature does a poor job of describing the physiological demands of field hockey due to a lack of appreciation in the validity of the technology and how its applied given the specific context of competition and training. That is to say, that some data looks at position specific demands where in actual fact the roles of hockey players are more interchangeable than in other sports. Furthermore, applying and validating speed and acceleration zones from competition could be misleading because restricting the playing area in training will prevent these zones being achieved. In addition, the problems with specificity of individual movement patterns make it difficult to monitor individual patterns of activity.

Current analysis of field hockey has been a replication of the methods used in soccer which has been inappropriately considered to be a similar sport. For instance both field hockey and soccer studies report on position specific demands without considering the differing contexts with which these sports play. Soccer tactics mean players have quite specific roles – you either play defence, midfield or attack with fewer nuances where players play between the lines (Reilly, 1997a and Mohr, Krustrup and Bangsbo, 2003). However in field hockey positional data is less specific with a variety of positions played on the pitch and large amounts of rotation expected by coaches (Reilly and Borrie, 1992). Reporting these position specific demands becomes blurred in field hockey where it is not uncommon for midfielders to play in what we would consider an attacking role. Inappropriately we may pigeon hole them into either role instead of considering them as individual field hockey player irrespective of position. Utilisation of team averages may be more appropriate especially when considering the players across teams with differing tactics and in comparison to drills such as SSGs which remove positional intricacies.

Further to this, the technology used in the most recent literature – GPS – has been used to specifically report positional data as well and compare competition to training drills such as SSGs. This technology has been report as valid for team sport performance (Aughey, 2011 and Cummins, 2012) but lacks the accuracy and specificity to display individual data with confidence. However GPS and its built in microtechnology reports important movements such as acceleration and decelerations which have been previously unquantifiable with other methods of TMA including heart rate and video analysis. We believe that the technology is not specific enough to determine individual differences but has huge potential for the comparison of activity demands across levels and activities. As such the mean data from each of these specific observations is proposed as the best method to answer the questions of this thesis.

In addition the current literature presents GPS data which has been analysed using the same procedures as those used on soccer. The results reported in the literature suggest that physiologically poorer athletes – field hockey players of both genders - play at a higher intensity than other sports people, namely soccer players (Cummins, 2012). This can be explained by the differing rules of these sports. For instance rolling substitutions in field hockey allow for periods of absolute rest resulting in higher intensities when they return to play (Spencer, Lawrence, Rechichi, Bishop, Dawson and Goodman, 2004). However is it appropriate to remove these rest periods from the analysis and restrict the observations to the field of play? Changing the time of the observation logically results in relative intensities which are higher but this does not mean that field hockey players play at a higher intensity or have greater physiological and physical capacity. For this reason the aim is to analyse data specific to field hockey and the context of competition and training.

The physiological ability of players of different levels and their physical activity during competition and training have been reported in the literature. The one study on Scottish players (Johnston, Sproule, McMorris and Maile, 2004) suggests poorer ability than the top ranked teams in the world studied by Spencer and colleagues (2004), Gabbett (2010b), and Lythe and Kilding (2011). The contribution of physiological differences, physical activity differences and skill level on the ability of Scottish players compared to the top elite players is unknown. The reason for the difference could be due to differences in skill level and the inability to perform at high intensity without skill breakdown, poorer physiology limiting the volume and intensity of their activity during game play or possibly down to contextual variables such as opposition ability and tactics. Further to this, it may be the level of training and/or club competition which affects the experience level, skills under pressure and physiological training stimulus provided to Scottish players. As such assessing competition and training with a view to comparing between levels may allow for some of these questions to be answered.

Additionally, the ability to maintain performance levels throughout a game has been reported in the literature as an important factor in the eventual outcome of competition. Fatigue has been shown to occur during laboratory studies of RSE in field hockey players (Spencer, Bishop, Dawson, Goodman and Duffield, 2006 and Spencer, Fitzsimons, Dawson, Bishop and Goodman, 2006) but maintenance of activity has been shown in individual games (Spencer, Lawrence, Rechichi, Bishop, Dawson and Goodman, 2004) Only across a tournament have players shown decreased physical outputs (Spencer, Rechichi, Lawrence, Dawson, Bishop and Goodman, 2005). This is different to the soccer data reported where it is a common observation that players reduce their activity in the second half of games. The use of rolling substitution and the way they are used may be the key differentiator between the two sports and have a large effect on the ability to maintain performance late in the game. One study has looked at this in field hockey and substitutions were shown to impact on both physical activity and involvement in the game (Lythe and Kilding, 2013). Although this is a very important question to answer this study only looked at one position at one level of the game which offers very little insight into the wider use of rolling substitutions and their effect on fatigue. The way in which the field hockey specific rules are utilised must be assessed on the large scale to see if players of different levels and playing in different levels of competition alter their pacing strategies to suit their own circumstances.

The current perception of field hockey competition and training is largely based on the potentially inappropriate GPS data reported in the literature. Recent studies have criticised the intensity of training in comparison to competition with inappropriate foundations (Gabbett, 2010b). The observation of SSGs - which are restricted to playing size - and competition is an unfair comparison and is logically going to have differing physical demands. To the authors knowledge no study in field hockey has observed the whole training session and the elements which make it up to assess the contribution of drills to physical activity. Furthermore no study has assessed whether these drills have the potential to elicit a training stimulus. This type of information may be more appropriate for coaches and practitioners when prescribing training practices rather than a blanket criticism of training intensity in comparison to competition.

2. Methodology

2.1 Subjects

The comparative nature of this series of investigations meant that a number of groups of participants were used. The specific characteristics of each group will be described fully in each Chapter. Below is an overview of the participants who took part (Table 2.1). All participants were given a synopsis of the study and were explained their right to remove themselves from the testing or remove their data from the analysis (see Appendix i). All testing was completed on participants over the age of 18 unless otherwise stated. Any under 18s were asked to provide parental consent (see Appendix ii). The University of Glasgow ethics committee approved all procedures.

The data in Table 2.1 gives a basic outline of the players in involved in the series of studies. Only elite players were tested for body mass and maximal oxygen consumption via the MSFT. This was due to time constraints within the sub-elite environment.

Level	Gender	*n*	Age (yrs)	Body Mass (kg)	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
Elite	M	16	25 ± 4	70.9 ± 6.6	61.0 ± 2.1
Elite	F	17	25 ± 3	64.0 ± 5.8	52.9 ± 4.5
Sub-Elite	M	131	25 ± 4	-	-
Sub-Elite	F	108	26 ± 7	-	-

Table 2.1 Overview of participants. Mean ± SD

2.2 Timeline

The schematic below (Figure 2.1.) shows the timeline of research activities during the period from June 2010 to March 2013. The study numbers - in italics - on the schematic relate to the Chapter and study described in future Chapters of this thesis.

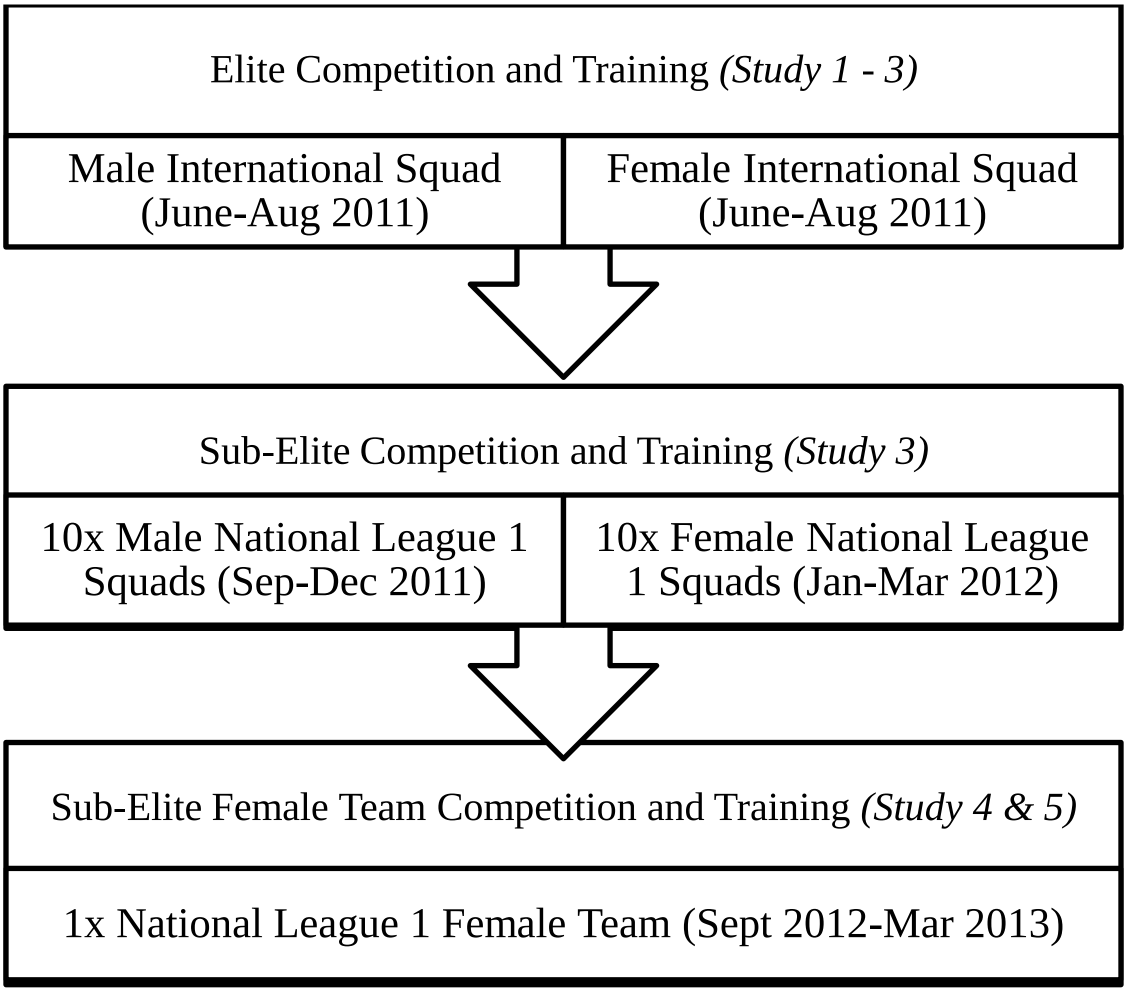

Figure 2.1. Schematic of the research activities involved in this doctoral thesis.

2.3 Protocols

2.3.1 GPS Analysis of Competition

The GPS was worn as per manufacturer's instructions, within a specifically designed bib with neoprene pouch that holds the unit between the shoulder blades of the wearer. Players wore these from the start of their warm-up to allow familiarization and time for adjustments before playing.

Two analysis procedures were utilised in the initial study (see Chapter 3). Full game (FG) analysis recorded both halves with all bench time included (see 2.3.1.1 below). Time on Pitch (TOP) analysis was carried out using the same procedures as used in soccer (see 2.3.1.1 below). All downloading and reporting of data were carried out immediately postgame by the same observer. The same written record of GPS time and GMT, as well as pitch coordinates, was used for both methods so that the only difference between methods was the inclusion or exclusion of bench time. All physiological parameters (i.e., speed zones) were standardized and downloaded and zones were set as $km \cdot hr^{-1}$.

2.3.1.1 Full Game and Time On Pitch Analysis Procedures

During the game, the following procedure was used for FG and TOP analysis:

Full Game Analysis	Time On Pitch Analysis
1. Stopwatch started when GPS units are switched on. 2. Written record of GPS time and Greenwich Mean Time (GMT) for start and end of each half.	1. Stopwatch started when GPS units are switched on. 2. Written record of GPS time and Greenwich Mean Time (GMT) for start and end of each half. 3. Written record of GPS time and GMT for rotations—at the start and end of bench time.

Table 2.2. During game protocols for Full Game (FG) and Time On Pitch (TOP) analysis procedures .

After the game, the following procedure was used:

Full Game Analysis	Time On Pitch Analysis
1. Full game downloaded to Logan Plus.	1. Full game downloaded to Logan Plus.
2. GPS coordinates used to create pitch (this is only completed for 1 method, and subsequently the same pitch is used).	2. GPS coordinates used to create pitch (this is only completed for 1 method, and subsequently the same pitch is used).
3. Pitch selected.	3. Pitch selected.
4. Time of commencement of game and second half identified on smooth speed graph and GPS pitch diagram of an individual player. The point at which a player is stationary on the pitch that corresponds to written record of both GPS start time and GMT is selected as the start point.	4. Time of commencement of game and second half identified on smooth speed graph and GPS pitch diagram of an individual player. The point at which a player is stationary on the pitch that corresponds to written record of both GPS start time and GMT is selected as the start point.
5. Termination of pitch time for halftime or full time is taken from smooth speed graph and GPS pitch diagram of 1 player who is on the pitch in last play of the half—preferably the player used in step 4. This is checked using the written record of GPS time and GMT.	5. Termination of pitch time for halftime or full time is taken from smooth speed graph and GPS pitch diagram of 1 player who is on the pitch in last play of the half—preferably the player used in step 4. This is checked using the written record of GPS time and GMT.
6. The start and end points of first and second halves are saved and used for each individual.	6. The start and end points of first and second halves should be noted and reproduced for each individual.
	7. Individual player substitutions and enforced bench time removed using methods 4 and 5 above.
	8. Repeat step 7 for all players.
	9. Rotations reviewed using written record.

Table 2.3. Post-game protocols for Full Game (FG) and Time On Pitch (TOP) analysis procedures.

2.3.2 GPS Analysis of Training

GPS was worn from the start of the warm-up to allow familiarization and time for adjustments before playing. The specific aim of the training sessions being monitored was determined by the head coach with no input from the observers. Training data was collected in the training session prior to the competition data observed. As such the main focus tended to be technical/tactical development and improvement of player ‘sharpness’ ahead of competition. Training data were split into individual drills and further classified into four categories: running, technical/tactical, small-sided games (SSGs) and full pitch practice. Classifications were based on coaches descriptions of drills alongside subjective criteria shown below (Table 2.4).

Drill	Coaches Descriptors	Subjective Criteria
Running	"running "speed work" "sprints" "fitness" "conditioning" "blow-out" "jog"	Any jogging, running or sprinting with no equipment
Technical/Tactical	"skills" "passing" "walk-through" "aerials" "patterns" "penalty corners"	Any drill which was based around 1-3 skills Any drill with very specific rules/outcomes
Small Sided Games	"1v1" "2v2" "3v2" "3v3" "4v3" up to "10v10" "overload game" "small game"	Any games with reduced player numbers (≤ 10) Any game played on a pitch which was ≤ the full regulation pitch
Full Pitch Practice	"team practice" "full game" "full pitch drill" "team run" "team patterns"	Any drill completed on the full pitch Opposed game play or unopposed gameplay

Table 2.4. Training drill classification criteria.

Only one category, the running drills, was used for conditioning and aimed to maintain fitness levels achieved in the previous months. Running drills consisted of short sprints with active recovery. Technical/tactical drills tended to involve either fairly static specific skill work or low intensity patterning drills. The most varied drills across all studies were SSGs – a large number of variants were used by each group observed with the emphasis either on conditioning or competition specific skill development. The smallest and largest pitch sizes seen for SSGs were between 14.6 x 22.9 m and 45.6 x 45.0 m. Lastly, full pitch practices were used to develop full pitch spatial awareness in unopposed situations or where numbers allowed full pitch opposed games.

Rest periods within each drill were retained but transitions between drills were omitted (to replicate the competition analysis where only the half time rest period was omitted). The recovery periods allowed within specific drills have been included but the short periods of time between drills omitted (e.g. when the players stopped to retrieve sticks and put on shin guards not used during running drills). The data omitted were not sport specific and represented a significantly lower proportion of the training time compared to the half-time rest period during competition.

2.4 Equipment

2.4.1 Catapult MinimaxX 5 Hz GPS

The monitoring system used in this doctoral study was the Catapult MinimaxX 5 Hz device (Catapult Sports, Melbourne, Australia). This combines 5 Hz (sampling 5 times per second) GPS with 100 Hz 3-axis accelerometer, 100 Hz 3-axis gyroscope and 30 Hz 3-axis magnetometers. The GPS device provides real time or post-activity information on position, speed, acceleration and distance. The inclusion of the other pieces of microtechnology allows acceleration, deceleration, impact forces, jump height, angular motion, rotation, direction and orientation to be assessed to provide an in-depth analysis of physical activity during sporting activities.

The Catapult MinimaxX 5 Hz GPS system has been previously shown to be valid for team sports (Portas, Harley, Barnes, Rush, 2010) and field hockey (MacLeod, Morris, Nevill, Sunderland, 2009 and Gabbett, 2010c). Furthermore, it has been suggested as the best devices for monitoring in game accelerations and impacts (Gabbett, 2013).

2.4.1.1 Speed Zones

The speed zones were set via analysis of the published literature, initial data collection and fitness testing results. Published literature provided a basis for the identification of thresholds. However due to the observational nature of studies within this thesis the speed thresholds were selected to give as clear a representation of the speeds of the populations studied. As such wider categories in comparison to some studies (namely Gabbett, 2010b) were selected so as to best capture and display the differences amongst the levels. The literature considered included articles on male and female field hockey (Lythe and Kilding, 2011 and Gabbett, 2010b), soccer (Di Salvo, Gregson, Atkinson, Tordoff and Drust, 2009; Di Salvo, Baron, Gonzalez-Haro, Gormasz, Pigozzi and Bachl, 2010; Bradley, Di Mascio, Peart, Olsen and Sheldon, 2010 and Carling, Le Gall and Dupont, 2012), rugby league (Abt and Lovell, 2009) and Australian rules football (Brewer, Dawson, Heasman, Stewart and Cormack, 2010; Coutts, Quinn, Hocking, Castagna and Rampinini, 2010 and Wisbey, Montgomery, Pyne and Rattray, 2010).

The definition of low speed running is relatively well agreed with most studies reporting similar thresholds for walking, jogging and slow speed running. The thresholds in Australian rules are reported to be < 8 $km \cdot hr^{-1}$ for walking and jogging (Wisbey, Montgomery, Pyne and Rattray, 2010) and < 14 $km \cdot hr^{-1}$ for low intensity activity (Coutts, Quinn, Hocking, Castagna and Rampinini, 2010). In soccer walking has been suggested to be between 0.7 and 7.1 $km \cdot hr^{-1}$ and walking and jogging 7.2 – 14.3 $km \cdot hr^{-1}$ (Carling, Le Gall and Dupont, 2012). Field hockey values were given as 0 – 6 $km \cdot hr^{-1}$ for walking, 6.1 – 11 $km \cdot hr^{-1}$ jogging and 11.1 – 14 $km \cdot hr^{-1}$ for slow speed running (Lythe and Kilding, 2011) which is similar to soccer (Di Salvo, Gregson, Atkinson, Tordoff and Drust, 2009).

However high intensity thresholds - which are extremely important thresholds due to the increased physical demands of high speed running - are less well defined with a wide range of values being used. Not only are the thresholds not defined the method with which they are set is also up for discussion. Some studies have utilised video analysis software to set speed thresholds with subjective determinations of each zone (Di Salvo, Gregson, Atkinson, Tordoff and Drust, 2009; Di Salvo, Baron, Gonzalez-

Haro, Gormasz, Pigozzi and Bachl, 2010; Bradley, Di Mascio, Peart, Olsen and Sheldon, 2010). However other studies have used the second ventilatory threshold (VT_2) from a treadmill test to report the point at which exercise becomes high intensity in nature (Abt and Lovell, 2009). The differences in these values can be up to 5 $km \cdot hr^{-1}$ different (15 $km \cdot hr^{-1}$ versus 19.8 $km \cdot hr^{-1}$, Abt and Lovell, 2009 versus Carling, Le Gall and Dupont, 2012, respectively). Both methods have their merits and the use of either is largely down to your requirement for individualisation and the logistics of either method. The use of VT_2 allows for more accurate quantification of cardiovascular load during competition and as such may allow for better monitoring of the training load. However, the determinants of game outcomes are not whether you can achieve a percentage of your maximum HR or stay above your own determined intensity - you just need to be faster than the opponent and so absolute speed is more relevant.

It is suggested by Abt and Lovell (2009) that using speed thresholds higher than 15 $km \cdot hr^{-1}$ will under estimate the amount of high intensity running completed. To determine this 10 elite soccer players completed a ramp treadmill test which consisted of 1 $km \cdot hr^{-1}$ increments every 1 minute starting at 10 $km \cdot hr^{-1}$. VT_2 was used to show when high intensity activity commenced. This type of testing reports steady state responses however this is rare during team sport competition or training (Dupont, Millet, Guinhouya and Berthoin, 2005). Furthermore, during ramp exercise the HR and VO_2 response is delayed from the muscle metabolic response [transit time for blood borne factors to drive HR and ventilation (V_e) is about 20 - 40 secs (Whipp, Ward, Lamarra, Davis and Wasserman, 1982 and Whipp, 2007)]. This phenomenon – termed phase 1 responses or cardiodynamic phase of O_2 uptake kinetics - means that HR or speeds derived from steady state measurements do not directly transfer to non-steady state situations as most activities in team sports don't last as long 20 – 40 seconds.

Further to this, it is unlikely that an effort of 2 – 20 seconds at 15 km·hr^{-1} in competition will have the same physiological impact as a 1 minute stage in the incremental testing. Prior activity in most instances will be completed at walking and jogging speeds less than 10 km·hr^{-1} (greater than 80 - 90 % of game time is completed at these speeds; see Chapter 1.2.5.2) and not the 4 minutes at increasing speeds as in the incremental test. This may explain why the high speed threshold is lower than many other thresholds set in the literature and why it is suggested that other thresholds underestimate high intensity running. It should be noted here that the authors do suggest that their threshold be called "physical performance speed threshold" which may be more appropriate than high-intensity threshold.

Additionally, individual speed thresholds have been used alongside independent thresholds such as the ones used in the majority of the literature Lovell and Abt (2013). This study reports large differences in the percentage of time at high intensity which is a logical finding. However whether you are using the thresholds as a marker of intensity or speed will determine whether it is appropriate. For instance, intensity zones like those produced by Abt and Lovell (2009) will report high intensity at what may actually be low speeds [(running at 15 km·hr^{-1} is ~ 50 % of the maximum speeds in international hockey players as in Lythe and Kilding (2011)]. In a sport where the ability to reach high speeds is a discriminating factor and that is the area which requires most consideration it is not the intensity or the cardiovascular load that is of the highest importance. In this example having standard thresholds will mean comparisons are easier to see – i.e. did player A make the highest speed zone or how much time did the team spend in the highest speed zone? Given the inaccuracies in GPS data it may also be appropriate to have more zones to capture the data in more detail rather than very specific cut offs which may be more susceptible to the errors.

For these studies the mens speed zones were predominantly taken from the study by Lythe and Kilding (2011). The zones presented by these authors were slightly adapted for low speed running to include slightly more data - increased range from 11.1 – 14 km·hr^{-1} in Lythe and Kildings study to 10 – 15 km·hr^{-1} in this study. Subsequently moderate speed running was slightly reduced in this study - 14.1 – 19 km·hr^{-1} to 15 – 19 km·hr^{-1}. From the literature available the maximum speeds achieved in competition by male players are 31.5 km·hr^{-1} (Lythe and Kilding, 2011) and the speeds reported in treadmill testing are > 20 km·hr^{-1} (MacLeod and Sunderland, 2012). Both of these are captured within the highest two zones selected. Furthermore the inclusion of six thresholds allows for a more graded quantification of effort rather than low, moderate and high speed which has been used previously (Coutts and Duffield, 2010). Other methods of setting individual thresholds such as those used by Abt and Lovell (2009) where a treadmill test was used to identify the speed at which LT/LTP occurred where inappropriate for this large a sample group. Additionally this type of individualised threshold over complicates the determination of differences between groups of athletes. Setting standardised thresholds allows for clear separation – for example athletes which don't reach the 23 km·hr^{-1} zone are easily seen to be slower.

Due to the physical differences in male and female athletes a separate set of speed zones were identified for each gender. Two studies were used to identify the female speed thresholds. Gabbett's (2010b) study in female field hockey players was utilised for the basis of these speed thresholds. As he uses $m{\cdot}s^{-1}$ rather than $km{\cdot}hr^{-1}$ the threshold data was converted into kilometres per hour (1 m·s^{-1} = 3.6 km·hr^{-1}). Further to this Jennings and colleagues (2012a and 2012b) study was used to further identify intensities for these athletes. Due to the rightward weighting of Gabbetts thresholds – sprinting higher than male players in Lythe and Kildings – it was decided to reduce these. Figure 2.2 and 2.3 show the percentage time and percentage distance covered at each of the speed thresholds for all international players studied. These data sets both show very similar patterns of distribution – greatest majority of exercise completed at low speeds and decreasing amount of exercise with increasing intensity of effort.

As previously been mentioned these zones were set considering speed and the importance of speed rather than the physiological load of running at these speeds. However using speed as the determining factor may lead to the logical question – why not separate the zones in 1 km·hr^{-1} increments? However this would be inappropriate due to the error within the current GPS currently available described in Chapter 1.3.2. These studies have shown error of between 11 and 33 % at speeds between 1 to 8 m·s^{-1} [3.6 to 28·8 km.hr^{-1} (Varley and Aughey, 2012)]. As such this error is likely to mean efforts being recorded in the wrong zone – especially at the higher speeds. It is felt that wider zones - as used in the other literature (Lythe and Kilding, 2011; Gabbett, 2010b; Di Salvo, Baron, Gonzalez-Haro, Gormasz, Pigozzi and Bachl, 2010; Bradley, Di Mascio, Peart, Olsen and Sheldon, 2010 and Carling, Le Gall and Dupont, 2012) - allow for this error and mean efforts are still recorded in the correct zone. Further to this it whether zones are separated by 3 or 4 $km \cdot hr^{-1}$ is arbitrary and it was decided that using zones as close to the other field hockey literature as possible would be most appropriate.

Additionally all zones were set as whole numbers instead of using decimal places (i.e. 19 – 23 $km \cdot hr^{-1}$ and not 19.1 – 23 $km \cdot hr^{-1}$). This is converse to other studies (Di Salvo, Baron, Tschan, Calderon Montero, Bachl and Pigozzi, 2007 and Lythe and Kilding, 2011). The reason for this was the potential for missed data when using decimal places such as those used in these studies. For instance and athlete could run at 19.05 $km \cdot hr^{-1}$ and this would be missed with in the analysis. Although this is unlikely – especially because the units used were 5 Hz – it was deemed more thorough to have the end of one threshold as the start of the other. This means that in some cases an effort which is exactly 19 $km \cdot hr^{-1}$ will be collected in both zones.

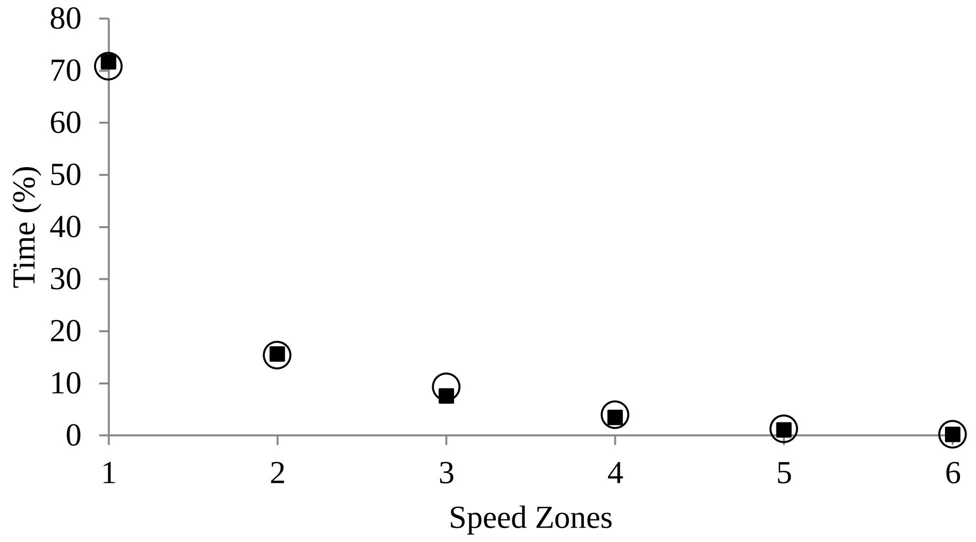

Figure 2.2. Percentage time spent in speed zones for male (squares) and female (diamonds) players in the international teams studied.

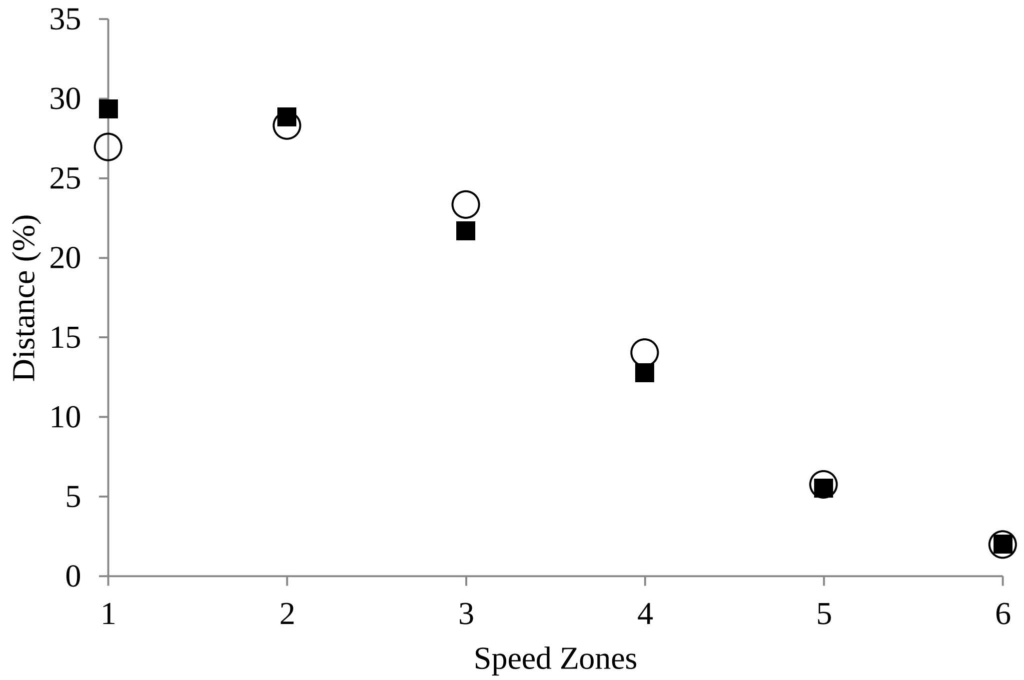

Figure 2.3. Percentage distance covered at each of the speed zones for male (squares) and female (diamonds) players in the international teams studied.

Speed Thresholds ($km \cdot hr^{-1}$)		Description
Male	Female	
0 – 6	0 – 6	Standing/Walking
6 – 11	6 – 10	Jogging
11 – 15	10 – 14	Low Speed Running
15 – 19	14 – 18	Moderate Speed Running
19 – 23	18 – 21	High Speed Running
> 23	> 21	Sprinting

Table 2.5.Selected speed thresholds for male and female observations and their associated descriptions.

2.4.1.2 Acceleration Zones

All acceleration thresholds were set to provide an overview for all accelerations and decelerations within small arbitrary zones. This was due to limited research in this area at the time of selection. Gabbett (2010b) reported a threshold of high accelerations of 0.5 $m \cdot s^{-2}$ lasting for 2 or more seconds. This acceleration threshold was below that which was selected for this study it also had a longer time threshold. The rationale for reducing the time required in an acceleration or deceleration was due to the nature of the game - stooped posture and large amounts of lunging movements – which may be missed if the threshold was 2 or more seconds.

Other thresholds used include an 2.78 $m \cdot s^{-2}$ which has been used in rugby league (Gabbett, 2012) and Australian rules football (Aughey, 2010). However these were mainly used to quantify collisions and not running based accelerations or decelerations. A studied based on professional soccer players used more arbitrary zones derived from match play data to describe low (1 – 2 $m \cdot s^{-2}$), moderate (2 – 3 $m \cdot s^{-2}$) and high acceleration (> 3 $m \cdot s^{-2}$) zones (Akenhead, Hayes, Thompson and French, 2013). This study didn't utilise any higher thresholds as they reported that these occurred from standing starts which don't occur often in soccer. They did report that thresholds up to 4 $m \cdot s^{-2}$ are valid and reliable but accelerations over 4 $m \cdot s^{-2}$ are less accurate (Akenhead, French, Thompson and Hayes, 2013). The use of the thresholds in Akenhead and colleagues study (2013) meant they were able to show a reduction in activity from first to second half at three different intensities. As such these thresholds provide more information than the one threshold reported by Aughey (2010) and Gabbett (2012). Using this data the thresholds selected for accelerations and decelerations are shown below (Table 2.6). These were selected for their ability to differentiate the rate of change so comparison can be made across games, training and in different levels.

Acceleration Zones ($m \cdot s^{-2}$)	Description
0 – 1	Small Rate of Change of Speed
> 1	Moderate Rate of Change of Speed
> 2	Large Rate of Change of Speed
> 3	Very Large Rate of Change of Speed
> 4	Sudden Extreme Rate of Change of Speed

Table 2.6. Selected acceleration zone thresholds and their associated descriptions.

2.4.1.3 Player Load Algorithm

Player Load is an arbitrary parameter which calculates the instantaneous rate of change of acceleration. The formula developed by Catapult Innovation is shown below (reproduced from Boyd, Ball and Aughey, 2011):

$$\text{Player load} = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$

where

a_y = Forward accelerometer

a_x = Sideways accelerometer

a_z = Vertical accelerometer

This parameter has been developed to identify the total accelerations and declarations of the body and thus be able to derive the physical activity and the energy expenditure of the individuals during competition. Accelerometers have been used to quantify human movement in other non-sporting settings and have been shown to accurately quantify movement (Kavanagh and Menz, 2008) and energy expenditure (Montoye, Washburn, Servais, Webster and Nagle, 1982 and Croutr, Clowers and Bassett, 2006). These systems are developed for general populations but the same relationship between muscular activity and energy expenditure exists in team sports. For sports predominantly involving running, player load will show a direct correlation to this distance covered. However for sports which involve tackles and changes of direction Player Load provides additional information. Recently it has been shown to be able to detect changes in physical activity of team sports players (Boyd, Ball and Aughey, 2011) and be able to display differences between levels and positions in Netball (Cormack, Smith, Mooney, Young and O'Brien, 2014). In addition to Player Load, Catapult MinimaxX devices and Logan Plus/Sprint software can report Player Load Slow which is the accumulated Player Load accelerations below 2 $m \cdot s^{-2}$. This parameter is utilised to show non-running based accelerations such as lunges, changes of direction and impacts which don't result in a high speed movement.

2.4.1.4 Satellite Accuracy

The accuracy of GPS recordings are reliant on the number of satellites which are available for the receiver. This is dependent on the orbits of the satellites and which of those are able to view the receiver at any one time. The minimum number of satellites is 4, however more satellites increases the accuracy of recordings (Witte and Wilson, 2004). Any observations which dropped below 4 were removed from the analysis. The average number of satellites for all studies was ~ 9 meaning that the accuracy of recording can be accepted.

Further to satellite number the horizontal dilution of precision (HDOP) of recordings is an important parameter for GPS accuracy. HDOP is the horizontal error of a GPS derived distance due to signal reception and movement of the satellites orbit. If there are obstructions making the satellites signal erroneous these may affect the ability to define an objects position. It is suggested that a HDOP of 1.0 will provide accurate data (Witte and Wilson, 2004 and 2005). Any values which differed from 1 by more than 0.5 were removed from the analysis. All observations were completed outside away from all overhead and all HDOP values recorded were within the accepted parameters thus no data was removed.

2.4.1.5 Logan Plus/Sprint Software

Logan Plus was the initial software package for all Catapult MinimaxX GPS devices. This software was developed by Catapult Innovations for the downloading and analysis of GPS data. This has been followed by Sprint Software which is the software package currently available. The majority of analysis was completed using

Sprint Software however study 1 (see Chapter 3) was completed using Logan Plus software. Both of these packages allow for downloading of data, selection of threshold zones and filters as well as reporting of results. Additionally, Mapbuilder is a supplementary software package which allows the creation of pitches using the longitude and latitude of GPS recordings alongside regulation dimensions and Chapters.

2.4.2 SECA Weighing Scales

Body weight was measured using a calibrated scale (Seca 899, Vogel & Halke, Hamburg) with participants wearing undergarments.

2.4.3 Multi-stage Fitness Test

Maximal oxygen consumption (VO_{2max}) was predicted from a multistage fitness test (Australian Sports Commission 20 m shuttle-run test) completed via MP3 playback on an indoor track before the testing period. This test has previously been shown to be a good indicator of aerobic capacity (Leger *et al*, 1988). On the other hand it has been suggested to be limited in its application – these limitations are discussed in Chapter 8.2 of this thesis. However it has been shown to be valid for team sports (St Clair Gibson, Broomhead, Lambert and Hawley, 1998 and Aziz, Chia and Teh, 2005) and is used by the majority of other studies on field hockey players so offers a good measurement for comparison (see Table 1.1 and 1.2).

2.5 Analysis

2.5.1 Data Editing

All downloading and reporting of data was carried out immediately post-game or training by the same observer. Any anomalies in the data resulted in that data set being removed from all analyses. The process for selecting competitions periods and training drills was previously reported in Chapter 2.3.1 and 2.3.2.

2.5.2 Calculation of Normalised Data

As this thesis was conducted across a large number of teams who all had different training schedules raw data was normalised for comparison purposes. Data was reported relative to the 70 minute playing period that is available for field hockey competition (referred to as 'Drill (per 70 min)' [(70/drill duration)*variable]). This method is similar to the normalisation of data relative to game time which is used in the literature (Brewer, Dawson, Heasman, Stewart and Cormack, 2010). This study looked to investigate the difference in physical activity of 41 players playing elite and sub-elite Australian rules football matches. To be able to compare across games of differing lengths all variables were reported per minute of game time. This is a valid method of normalising data as it makes absolute values from different occasions more comparable. However this method doesn't remove the differences in game time - i.e. elite games were said to have 98 mins of playing time whereas sub-elite games had 109 mins of playing time. This is a large difference and logically will reduce the distance per minute of sub-elite competition. Reporting the data as the standard 100 mins of playing time would show 125 $m\cdot min^{-1}$ versus 123 $m\cdot min^{-1}$ rather than the reported 128 and 117 $m\cdot min^{-1}$ (elite and sub-elite respectively). It can be seen from these values that Brewer and colleagues have an appropriate method for comparing values between levels but that normalising to regulation time provides additional information in comparison to relative distance alone.

Furthermore normalising to match duration further standardises the relative data for all variables and allows for better understanding of the differences between competition and training. For instance a player may produce 20 accelerations over 2 $m \cdot s^{-2}$ in a game which lasts 75 mins whilst during SSGs they produce 6 acceleration in 15 mins. This would give relative accelerations of 0.2 accelerations in competition and 0.4 accelerations in SSGs which is pretty meaningless. However by normalising to match time (70 mins) this difference becomes 14 versus 28. This makes the comparison more meaningful and allows for an identification of the demand in comparison to 'standard' competition. For comparison across a number of teams, competitions and training drills this means everything can be compared on a similar standing. To the authors knowledge this method has not been used before but offers a valid method for comparison as it accurately represents the demand of the activity using an arbitrary number.

2.5.3 Statistical Analysis

All data was downloaded and reported from Logan Plus and Sprint Software (discussed in Chapter 2.4.2) and then inputted into Microsoft Excel for organisation. Hereafter all formal statistical analyses were completed using Minitab 16 Statistical Software package. OriginLab graphing software was used for data figures. The statistical analyses used for this doctoral study will be reported in more detail in each Chapter. Statistical significance was taken as $P \leq 0.05$ and all data are reported as mean and 95 % confidence interval (95 % CI) unless otherwise stated. Further to this, all data was analysed and reported in a physically possible format (i.e. 2.1 sprint efforts would be reported as 2 efforts as 0.1 efforts is not a physically possible output).

3. Validation of Full Game Analysis Procedures

3.1 Introduction

Time–motion analysis studies using video analysis GPS have provided valuable data on the physical demands of a variety of team sports (Boyd, Ball and Aughey, 2011; Cunniffe, Proctor, Baker and Davies, 2009 and Harley, Lovell, Barnes and Portas, 2011). As previously mentioned, the advent of GPS for team sports has provided sports practitioners with more detailed information than previously obtained through video analysis. An athlete’s distance covered in high- and low-speed movements, time spent at these speeds, their high-acceleration movements, and exercise-to-rest ratios can all be collected during competition and training. Thresholds are set using a number of different criteria such as speeds from treadmill tests (Abt and Lovell, 2009) or from video analysis systems such as ProZone or Amisco (Di Salvo, Baron, Gonzalez-Haro, Gormasz, Pigozzi and Bachl, 2010; Bradley, Di Mascio, Peart, Olsen and Sheldon, 2010 and Carling, Le Gall and Dupont, 2012). There is little agreement within the literature for these thresholds however it has been suggested that using zones is appropriate if used consistently within the specific population and not for comparison to other groups (Cummins, Orr, O’Connor and West, 2013). This type of information can be used in the planning and monitoring of training and to set appropriate training prescriptions to elicit the response sought by coaches in each training session or phase of training (Kelly and Coutts, 2007).

Gabbett (2010b) provided data from a study that used GPS to elucidate the difference in intensity of competition and SSGs to better understand how training can be used to increase performance. Large differences in a range of measured parameters were shown between elite-level competition and training, with training at a lower intensity than competition. This phenomenon is only visible through time–motion analysis, and, as the author alludes to, there can be discrepancies in reporting data from time motion analysis studies. While this statement relates to the "description of locomotor activities," it is evident that the processes used to categorize these activities may also create discrepancies. This will be important when coaches use the information generated to dictate appropriate training intensities to replicate competitive performance.

Gabbett's study, and others in the literature, describe field hockey as an intermittent high intensity sport (Johnston *et al*, 2004; Spencer *et al*, 2004; Spencer *et al* 2005; Lythe and Kilding, 2011 and Jennings *et al*, 2012a). Further to this, the values that these studies report suggest that field hockey competition elicits an exercise intensity greater than soccer (Aughey, 2011). However this is a questionable construct for a number of reasons. Firstly, soccer is played on a larger pitch with the same amount of players, arguably similar tactics and the same overall goal. Logically, the greater relative pitch area (per player) would increase the accumulated effort and subsequent intensity of competition in soccer. Secondly, the reported aerobic capacities of field hockey players, shown in 1.2.3.1 are less than those published in the literature from soccer players. This would suggest soccer players are better conditioned and therefore have a greater ability to play at high intensities. Lastly, the awkward crouched posture of field hockey players increases energy expenditure (Reilly and Seaton, 1990 and Wdowski and Gittoes, 2013) which, if the current values are correct, would require more 'effort' to reach the same intensities. Thus a greater training stimulus and better overall aerobic capacity would be expected - which is not the case.

The conclusions derived from these comparisons – soccer versus field hockey – may seem worthless as athletes in different sports are not expected to be the same to be the same and there is no logical reason as to why you would want to train them to be the same. However it is pertinent information to highlight a potential flaw in the current use of time motion analysis in field hockey. For instance, if it is found that the reported intensity of field hockey is skewed and artificially increased, the results of studies like Gabbett's would lead to incorrect conclusions. Furthermore, if the competition information provided by time motion analysis is incorrect the basis of our 'scientifically-derived' field hockey training is also flawed and we may be providing inappropriate training stimuli to athletes. To answer these questions a more in-depth time motion analysis of field hockey is required starting with the analysis procedures used. The current practice for GPS analysis has essentially been derived from soccer. The procedures used follow methods derived from time–motion analysis (using notational observations or video analysis). These methods were developed specifically for the technology being used and are still appropriate for soccer, where players are on the pitch for the full game or do not re-enter the game after substitution (i.e. the time on pitch is that player's full game).

However field hockey is different from soccer in one significant way – players are able to re-enter the game on numerous occasions meaning players get off-field 'rest' periods and then return to the pitch. This can affect player pacing strategies and potentially skew the physical performance measures reported by time motion analysis. As such the mimicry of soccer analysis procedures is a potential cause of the greater relative intensities previously referred to. For example, the soccer-derived procedures report every period that a field hockey player is on the pitch and remove periods off the field. As the time on pitch is less the relative distance (distance per minute) will be affected i.e. running 2500 m in 20 minutes of a 35 minute half will give you a relative distance of 125 $m \cdot min^{-1}$ or 71.5 $m \cdot min^{-1}$ depending on the analysis period.

This initial investigation will compare the impact of data-analysis procedures derived from soccer with sport specific analysis procedures in an attempt to obtain the most appropriate method of quantifying field hockey activity for subsequent studies involved in this doctoral thesis. Comparing data analysis from the available playing time during a FG with that restricted to TOP will establish whether physical-performance measures are influenced by the pacing strategies that are used by field hockey players. It is hypothesised that FG analysis will give more realistic physical performances results and become a field hockey specific analysis procedure which can be used throughout this doctoral study.

3. 2 Methods

3.2.1 Subjects

Sixteen elite male field hockey players (mean ± SD age 25 ± 4 yrs, body mass 70.9 ± 6.6 kg, and maximal oxygen consumption 61.0 ± 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$) participated in the study. Athletes were all members of the Scottish national hockey team. They had completed a 3-month special preparatory program consisting of strength and power gym-based exercise, interval running, and speed training in addition to their hockey-based pitch sessions before the competition phase of their season (International Four Nations Tournament and EuroHockey Nations Trophy). Consequently, all participants were free from injury at the time of the study. GPS analysis was completed as part of the normal squad performance monitoring. All participants observed provided informed consent.

3.2.2 Design

In the current study, the physiological demands of elite men's field hockey competition were investigated, and these demands were analysed by 2 separate analysis procedures (see 2.3.1.1). The University of Glasgow ethics committee approved all procedures.

3.2.3 Equipment

The Catapult MinimaxX 5 Hz GPS system was used for all recordings (Catapult Innovations, Melbourne, Australia). All protocols are fully described in Chapter 2.

3.2.4 Environmental Conditions

Games were played in 2 different countries: Scotland and Ukraine. Three games were played in a temperate climate in June (~ 14 °C). The other 5 games were played in a warm climate in August (~ 19 °C). All games were played on water-based Astroturf away from overhead obstructions. Each tournament was played on the same pitch, so only 2 pitches were used for testing. Satellite signal strength (12.3 ±

1.0 and 10.3 ± 1.2, Scotland and Ukraine, respectively) and horizontal dilution of position were strong (1.3 ± 0.4 and 1.0 ± 0.4, Scotland and Ukraine, respectively). Analysis was conducted on the same data set for comparison of methods removing the error of GPS rate.

3.2.5 GPS Analyses

Seventy-three (n = 73) game analyses were collected from this group over 8 games. All opposition teams were from Europe and were ranked 2nd to 32nd in the world at the time of testing. Data were downloaded, analysed, and reported using Logan Plus v4.4.0 analysis software.

3.2.6 Statistical Analyses

All data were normally distributed using an Anderson-Darling normality test. Bland-Altman plots (Tukey mean difference test) were used to illustrate the difference between the 2 methods of analysis on the same data set and not as normally used (to measure 2 different methods measuring the same variable) (Bland and Altman, 1986). Data were plotted as FG minus TOP using the following equation:

$$S(x,y) = \{[(S1 + S2)/2],(S1 – S2)\}$$

Where S (x, y) = x- and y-axis points of difference of the two methods

S1 = FG

S2 = TOP.

Limits of agreement were set at 1.96 × SD of the difference between the 2 methods.

One-way ANOVA and Tukey confidence interval tests were performed and one sample t-tests were used for post hoc analysis of continuous data (e.g., distance, relative distance, and Player Load) or Poisson rate/Mann-Whitney tests were used for post hoc analysis of other variables (e.g., number of efforts in speed or acceleration zones). Differences were calculated from 95 % confidence intervals of difference (FG – TOP). Effect sizes were calculated using Cohens *d* test [ES = (Δ Mean)/Pooled SD] using the methodology presented by Cohen (1988), and magnitudes reported by Batterham and Hopkins (2006) and Hopkins (2009). Magnitudes were: trivial = < 0.2, small 0.2 – 0.6, moderate = 0.6 – 1.2, large = 1.2 to 2, very large = 2.0 – 4.0 and extremely large > 4.The physical parameters distance covered, relative distance, and Player Load were analysed for correlation to estimated VO_{2max} using regression analysis. Statistical significance was taken as $P \leq 0.05$, and all data are reported as mean and 95 % confidence intervals.

3.3 Results

3.3.1 Time-Dependent Measurements of GPS Data

Obviously, training intensity and volume will be dictated by the time taken to complete an activity or the relative duration spent in an intensity domain during that activity. The mean duration of competitive match play during the analyses described here was 74 minutes (74 – 76 min), but individual players were on the pitch for only 48 minutes (46 – 51 min), or 65 % (59 – 71 %) of available game time (see Figure 3.4.).

The differences in the two GPS analysis procedures are illustrated in Figure 3.2 and 3.4. Figure 3.4 demonstrates that measurements of distance are unaffected by the analysis procedure employed, but there are differences when assessing important time-related measurements. Traditional TOP analysis procedures resulted in a higher relative distance than in analysis of GPS data using procedures that account for all available game time (124 $m \cdot min^{-1}$ [120 – 128] vs. 78 $m \cdot min^{-1}$ [76 – 80], $P \leq 0.0001$). Table 3.4 further demonstrates that the exercise-to-rest ratio is higher with TOP analysis (0.55 [0.50 – 0.62] vs. 0.24 [0.22 – 0.25], $P \leq 0.0001$).

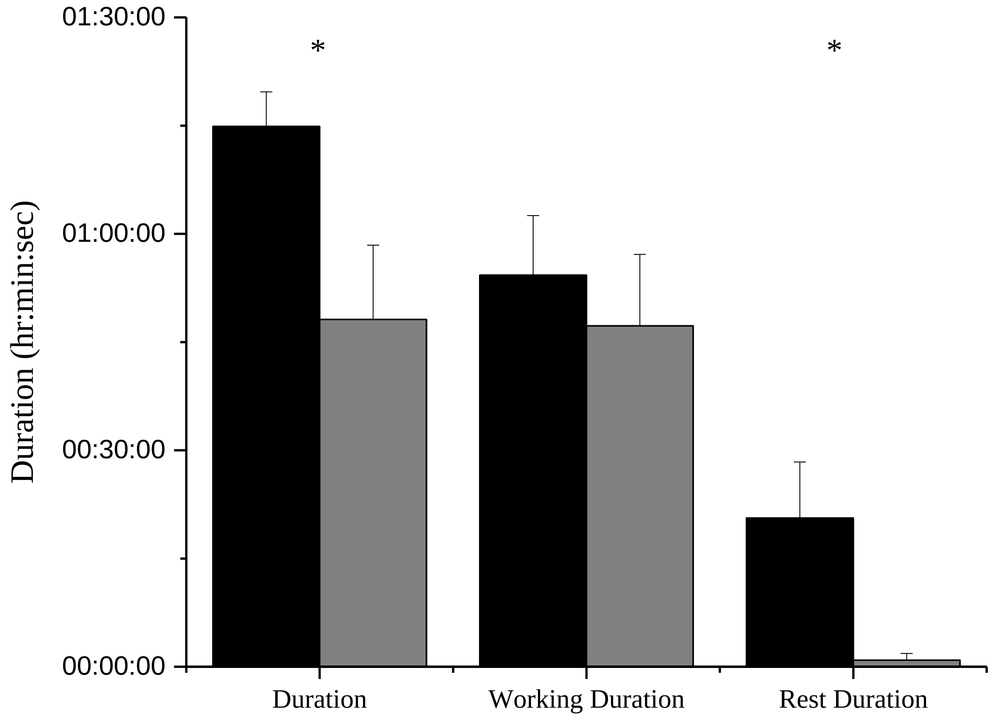

Figure 3.1. Differences in total analysis duration, exercise duration and rest duration as measured by Full Game (dark columns) and Time on Pitch (grey columns) analysis. *$P \leq 0.001$

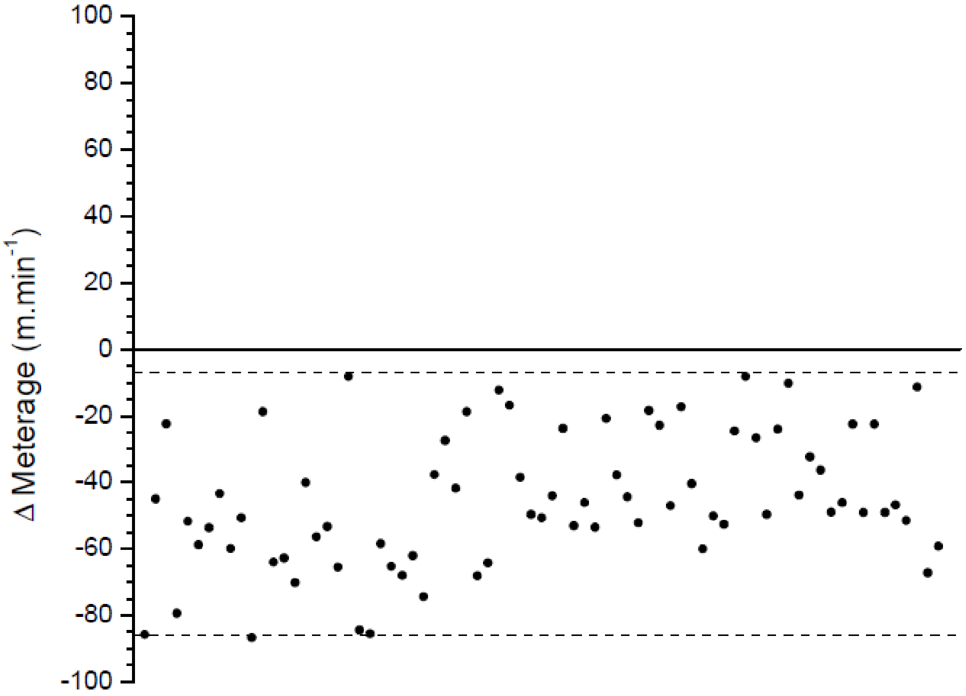

Figure 3.2. The influence of data analysis procedures on GPS measurements from elite male hockey players during competition illustrated by Bland-Altman plots where shows a comparison of distance covered per minute of time (relative distance) reported by time on pitch (TOP) and full game (FG) analysis procedures. Limits of agreement set at 1.96 x SD.

Figure 3.1 further illustrates the impact of the GPS analysis procedures on the relative proportion of time that the players spend in relative intensity domains during the analysis period. At all speeds – except 0 – 6 km·hr^{-1} - the proportion of time spent was higher by the traditional TOP procedure, as seen by the ES ($P \leq 0.001$).

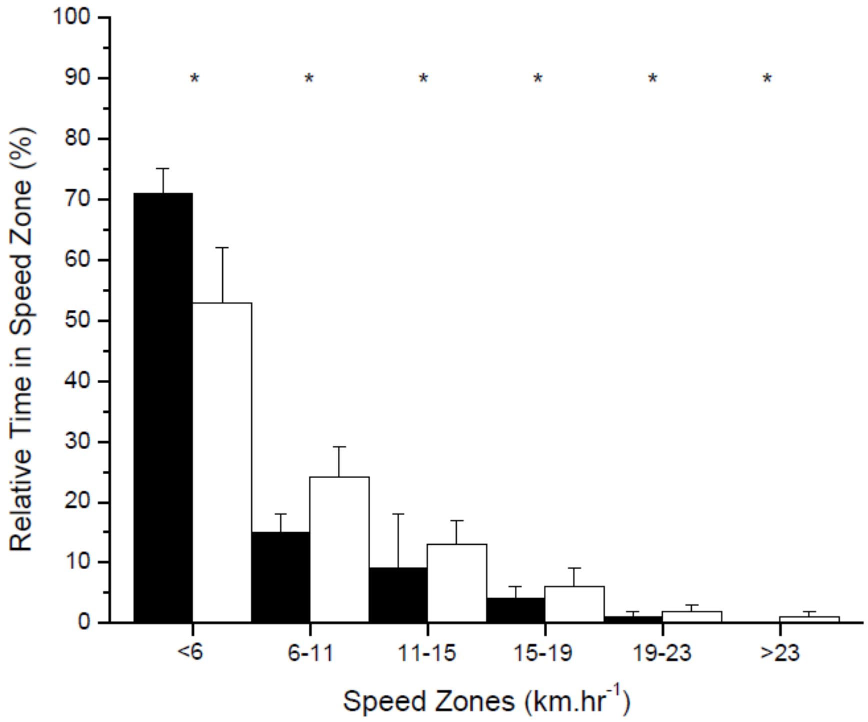

Figure 3.3. The influence of data analysis procedures on GPS measurements from elite male hockey players during competition illustrated by a bar chart showing how the percentage of time spent in each speed zone is changed by time on pitch (TOP) and full game (FG) analysis procedures. *$P \leq 0.001$.

3.3.2 Distance Measurements of GPS Data

The procedures applied to analysis of GPS data appear to have little impact on measurements that derive the distance covered by an athlete during competitive game play. Table 3.1 demonstrates no difference in distance related measurements from the GPS analysis procedures, with players covering 5824 m (95 % CI; 5677 – 5972 m) using FG analysis procedures versus 5819 (5661 – 5976 m) using TOP analysis procedures ($P > 0.05$). Similarly, there was no difference in maximum speed (7.58 [7.47 – 7.67] $m \cdot s^{-1}$ vs. 7.58 [7.47 – 7.67] $m \cdot s^{-1}$, $P > 0.05$) or the commercial-software-derived parameter of Player Load (645 [622 – 668] AU vs. 631 [606 – 656] AU, $P > 0.05$).

	Method of GPS Analysis				
	FG	TOP	Δ (95% CI)	Cohens *d* Effect Size	
Total Distance (m)	5824 (5677 to 5972)	5819 (5661 to 5976)	-219 to 208	0.01	Trivial
Relative Distance ($m \cdot min^{-1}$)	78 (76 to 80)	124 (120 to 128)*	41 to 50	-3.30	Very Large
Player Load Acc (AU)	645 (622 to 668)	631 (606 to 656)	-48 to 20	0.14	Trivial
Efforts >15 $km \cdot hr^{-1}$	70 (66 to 73)	70 (67 to 74)	-4 to 6	-0.03	Trivial
Efforts >19 $km \cdot hr^{-1}$	28 (27 to 30)	28 (27 to 30)	-2 to 2	0.00	Trivial
Efforts >23 $km \cdot hr^{-1}$	7 (7 to 8)	7 (7 to 8)	-1 to 1	0.00	Trivial
Acceleration Efforts >2 $m \cdot s^{-2}$	16 (14 to 18)	18 (16 to 20)	-1 to 5	-0.17	Trivial
Max Speed ($km \cdot hr^{-1}$)	27.2 (26.9 to 27.6)	27.2 (26.9 to 27.6)	-0.5 to 0.5	0.02	Trivial
Exercise-to-Rest Ratio	0.24 (0.22 to 0.25)	0.55 (0.50 to 0.62)*	0.26 to 0.38	-1.61	Large

Table 3.1. Activity profile produced by time on pitch (TOP) and full game (FG) analysis procedures. *$P \leq 0.001$

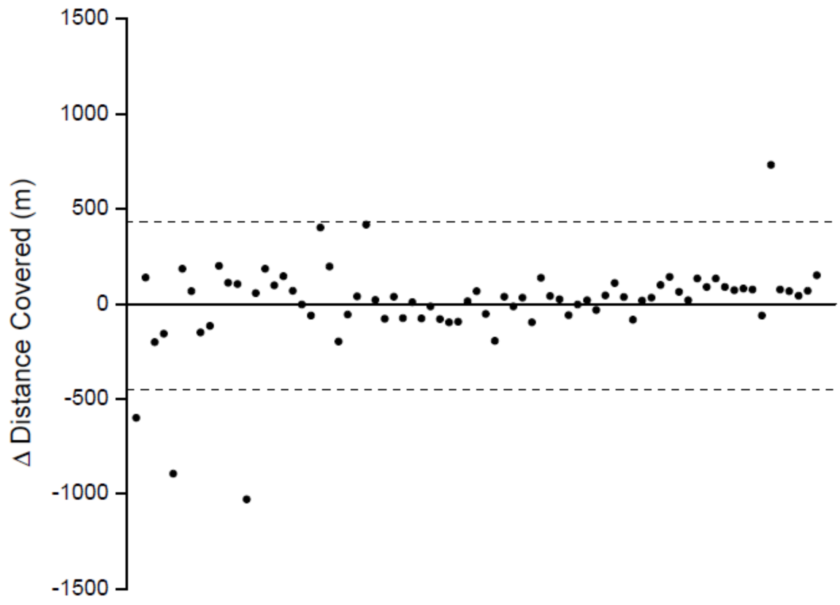

Figure 3.4. The influence of data analysis procedures on GPS measurements from elite male hockey players during competition illustrated by Bland-Altman plots where shows a comparison of absolute distance covered reported by time on pitch (TOP) and full game (FG) analysis procedures. Limits of agreement set at 1.97 x SD.

The number of efforts or distance covered in standardized relative intensity domains was also unaffected by the analysis procedures used in this study, with Table 3.5 demonstrating no difference in efforts or distance covered during walking (0 – 6km·hr^{-1}), jogging (6 - 11 km·hr^{-1}), low-speed running (11 – 15 km·hr^{-1}), moderate-speed running (15 – 19 km·hr^{-1}), high-speed running (19 – 23 km·hr^{-1}) and sprinting (> 23 km·hr^{-1}).

The number of efforts in standardized acceleration domains was also unaffected by the analysis procedures used in this study, with Figure 3.2 showing no difference in efforts during accelerations over 1 m·s^{-2}, 2 m·s^{-2}, 3 m·s^{-2} and 4 m·s^{-2} (83 vs. 76, 18 vs. 16, 4 vs. 4 and 1 vs. 1 respectively; $P > 0.05$) .

During competitive game play, there was no significant correlation between distance covered (either relative or absolute) or Player Load and predicted VO_{2max} from the multistage fitness test (see Figure 3.6; R^2 values 22.2 %, 33.7 %, and 27.5 %; $P > 0.05$).

	Distance (%)			Time (%)		
	Δ(95% CI)	Cohens *d* Effect Size		Δ(95% CI)	Cohens *d* Effect Size	
0 – 6 $km·hr^{-1}$	-3 to 2	0.07	Trivial	-21 to -16*	2.58	Very Large
6 – 11 $km·hr^{-1}$	-1 to 1	-0.02	Trivial	8 to 10*	-2.24	Very Large
11-15 $km·hr^{-1}$	-2 to 1	0.00	Trivial	2 to 7*	-0.59	Small
15-19 $km·hr^{-1}$	-2 to 2	0.00	Trivial	2 to 3*	-1.14	Moderate
19-23 $km·hr^{-1}$	-0.3 to 1	0.10	Trivial	1 to 1*	-1.26	Large
>23 $km·hr^{-1}$	-0.3 to 0.3	0.01	Trivial	0 to 1*	-0.90	Moderate

Table 3.2 Difference between Full Game (FG) and Time on Pitch (TOP) analysis procedures (95% CI) and Cohens *d* Effect Size between relative distance covered and time spent in different speed zones.
$^*P \leq 0.001$

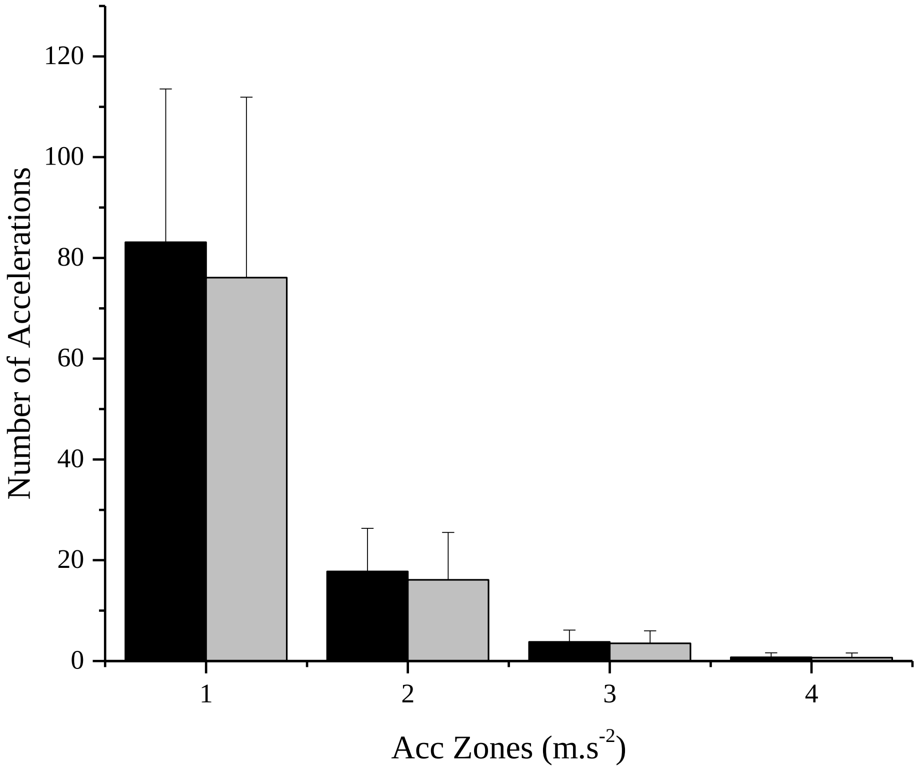

Figure 3.5. Acceleration efforts as measured by Full Game analysis (dark columns) and Time on Pitch analysis (grey columns). *$P \leq 0.05$

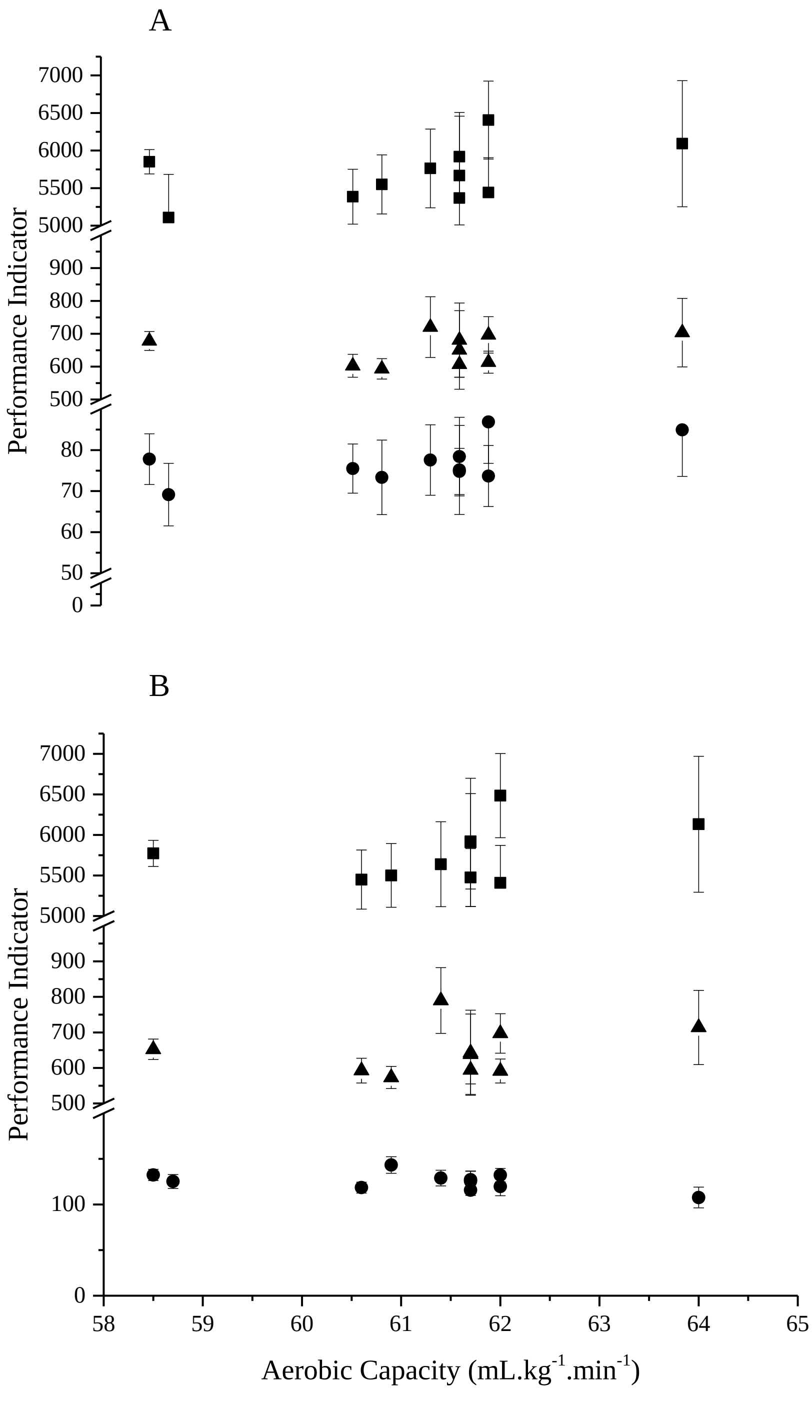

Figure 3.6. Predicted aerobic capacity as measured by MSFT and physical performance measures as reported by A) Full Game analysis and B) Time on Pitch analysis procedures. Closed squares represent the average distance covered by individuals (m), closed triangles represent the Player Load of individuals (AU) and closed circles represent the average relative distance covered by individuals during competition (m· min^{-1}).

3. 4 Discussion

The data presented here show that using different GPS analysis procedures can significantly influence commonly used measurements of physical performance and exercise-to-rest ratios. In general, it is accepted that distance covered during a game will be directly related to the intermittent physical capacity of the sport (Reilly, 2003; Krustrup, Mohr, Amstrup, Rysgaard, Johansen, Steensberg, Pedersen and Bangsbo, 2003; Krustrup, Mohr, Ellingsgard and Bangsbo, 2005; Bradley, Mohr, Bendiksen, Randers, Flindt, Barnes, Hood, Gomez, Andersen, Di Mascio, Bangsbo and Krustrup, 2011 and Bradley, Bendiksen, Dellal, Mohr, Wilkie, Datson, Orntoft, Zebis, Gomez-Diaz, Bangsbo and Krustrup, 2014) and, as such, hockey players with higher aerobic capacity are likely to cover greater distances during the time they are on the pitch. In support of this assertion, Lythe and Kilding (2011) demonstrated that elite hockey players with a mean peak oxygen uptake of 65 $mL \cdot kg^{-1} \cdot min^{-1}$ covered around 6800 m during competitive game play (compared with 5800 min this study where the players are predicted to have a lower mean aerobic capacity). However, in the current study the distance covered (both relative and absolute) and Player Load did not correlate with predicted VO_{2max}. This may be due to using the MSFT or relatively small participant numbers. Nevertheless, since the main aim of this study was to compare effects of the analysis procedures this finding will have little impact.

Field hockey is an intermittent sport characterized by short periods of very high intensity interspersed with low-intensity activity and periods of inactivity (both on the pitch and on the bench during unlimited substitutions). Thus, the energy demands of hockey can be further analysed by breaking down movements on the pitch into different intensity (speed) zones (Gabbett, 2010b and Lythe and Kilding, 2011). As with total distance covered, the distances travelled in different intensity zones were not significantly affected by the data analysis procedures used in this study. Thus, FG analysis provides valid information in this respect to understand the physiological demands of the game.

Additionally, the unique nature of field hockey – stance and equipment – increases the mechanical cost of game play (Reilly and Seaton, 1990). The requirement to bend and lunge to contact the stick and ball and the random nature of game play means players are required to make a large number of eccentric actions and changes of direction (Lythe and Kilding, 2011). These movements could be argued to be of greater importance than distance covered and relative distance for the prescription of training due to the muscular damage associated with eccentric actions (Proske and Morgan, 2001). The ability to quantify these parameters accurately is an important consideration for all TMA procedures. As such the ability for FG analysis to produce the same results as TOP for acceleration and deceleration data was an important consideration for this investigation. The number of accelerative efforts in a variety of zones were similar for both analysis procedures in this study adding further support for the application of FG analysis for field hockey.

The data-analysis procedures described here do, however, produce significant differences when considering distances travelled relative to TOP. This is self-evident in relation to the significantly different absolute exercise and rest durations and subsequent exercise-to-rest ratios. By including periods off the pitch higher recovery periods are evident and suggest a lower relative accumulation of effort during game play. Furthermore, the proportion of time spent in each of the intensity zones was significantly reduced by inclusion of all available game time in the analysis procedure. These differences are further emphasized when considering the average distance covered during each minute of the analysis period (“relative distance”). The nature of the analysis procedure employed will therefore have a significant impact on the inferences that can be made on player performance or the physiological demands of competition that have to be addressed in training (Gabbett, 2010b).

Classic time-motion analyses of team sports have employed TOP analysis because the video footage is generally restricted to the playing surface, so it is unsurprising that the TOP procedure has been adopted in subsequent GPS analysis to allow direct comparison with the existing data despite data being available from beyond the playing surface. From this analysis procedure, field hockey usually ranks high in terms of relative distance, with values as high as 140 $m \cdot min^{-1}$; it was 124 $m \cdot min^{-1}$ in the current study (Lythe and Kilding, 2011; Jennings, Cormack, Coutts and Aughey, 2012 and Macutkiewicz and Sunderland, 2011). This is higher than is generally reported in other team sports; for example, in soccer relative distance is generally reported as 100 to 120 $m \cdot min^{-1}$ (Bangsbo, Mohr and Krustrup, 2006). As mentioned in the introduction to this Chapter, these higher values are recorded despite the fact that a hockey player’s aerobic capacity is generally lower than in an equivalent level of soccer and that the game is played on a smaller pitch than in soccer and does not seem to be influenced by the impact of the hockey “stance” on speed over the ground.

The data from studies that use TOP analysis have led to the suggestion that hockey training is not intense enough to reflect the physiological demands of competition (Gabbett, 2010b). However, the FG analysis procedure described here measures relative distance at around 80 $m \cdot min^{-1}$ and may limit the impact of the previous data due to the inherent pacing strategies employed by the players during competitive play (where they exercise at a higher intensity for their allotted rotation before resting and then returning to play). This artefact of the analysis procedure is further emphasized if data are expressed in relation to the playing position rather than the individual player (e.g., Jennings *et al*, 2012b report average distances of nearly 9800 m during international competition).

If rest values are removed from analysis by restricting data to just TOP, a skewed impression of the true physiological demands will be obtained. It may be suggested that TOP data provides an understanding of exactly what the players are required to do when they enter the field of play. However this is relevant for one period of play and is not indicative of what the player must completed across a whole game. As a consequence, training based on such analysis will exceed the true demands of competition, making the emphasis specifically aimed at the intensity of short blocks of time and not the volume and intensity of the game as a whole. This intensity focus may be good for helping to drive conditioning work but may increase the risk of injury and overtraining if used inappropriately. In essence, FG analysis will give an indication of appropriate training volume even if the appropriate training intensity is difficult to predict from the data currently available.

Additionally, it is often reported that training drills – specifically SSGs – cannot meet the demands of competition (Gabbett, 2010b and Gabbett and Mulvey, 2008). The reason for this is attributed to the training drill itself and not the competition information. However if competition data is reported as the highest potential intensity (i.e. highest distance achieved in one period of the game) versus the mean distance in the SSGs practices then two different variables are being considered, namely peak distance versus mean distance. As such it is logical that differences would be seen. If these players don't have the skill level or tactical ability to achieve the high intensities similar to those reported by TOP then SSGs become counterproductive and unable to elicit both physiological and/or technical/tactical adaptations (Hill-Haas, Dawson, Impellizzeri and Coutts, 2011). Conversely FG analysis allows for mean distance of the whole game time to be compared to mean drill distance across all SSGs within that session meaning players are not aiming for excessive thresholds which may alter and negatively affect skills and tactics. This is likely to provide exercise intensities which are more appropriate for sports such as field hockey whilst still allowing for manipulations to stimulate improvements in physiological ability as well as technical/tactical skills.

Furthermore Gabbett's (2010b) study failed to report the size of pitches used for the comparison to competition. As such the difference between high speed running during SSGs and competition may not only be due to the differences in competition analysis but also an artefact of the pitch size used. It has been shown that smaller pitch sizes reduce the ability to achieve and accumulate high speed running in soccer (Casamichana and Castellano, 2010). Gabbett (2010b) does suggest that altering drill design may better simulate competition demands however this has subsequently not been studied within field hockey SSGs. Additionally the impact of other drills on the physical demands of training have not been reported meaning that the ability of training to simulate competition is unknown.

The timing of this type of testing is also very important – Gabbett (2010b) carried out his testing during the preparatory phase of training where it would be expected that volume would be increased and intensity reduced (Bompa and Haff, 1999 and Gamble, 2006). However it is unknown whether this is the case as this was not reported. Investigating the similarities and differences between FG analysis and training drills during other times of the season may be important to make better conclusions regarding competition versus training demands and validate the use of FG analysis. Testing during the tapering phase – where volume is reduced and intensity maintained or slightly reduced (Bompa and Haff, 1999 and Gamble, 2006) – will allow for comparison of training drills and competition - using FG analysis - in scenarios where both activities are expected to be reduced. Using training drills during the taper will allow for investigation when the lowest volumes are seen [reduction in volume has been shown to be between 50 – 90 % during the taper (Bompa and Haff, 1999)] and similar intensities to competition expected [between 90 and 100 % of pre-taper intensity (Bompa and Haff, 1999)].

Furthermore, this skewed impression of game intensity is likely to reflect pacing strategies used in field hockey game play and so may also affect other team sports even when the game is subject to restricted substitutions. While time–motion analysis is not ideal for assessing pacing strategies during competitive game play, it does appear that data from FG analysis may allow some insight into potential pacing strategies where TOP does not. For example, it could be argued that use of tactical substitutions in soccer is relatively commonplace in the last 20 to 30 minutes of game play, so the total TOP for the players being substituted will be reduced. If the players knew that the intention was to remove them from play, their pacing strategy would be based on a shorter playing period. Consequently, the relative distance recorded during the TOP would be greater than that recorded for a player expecting to play the whole game. It may also be the case that the decision to replace a player was based on a rehabilitation strategy from a previous injury, and using relative distance recorded during the TOP analysis might suggest a greater level of preparedness than is actually the case (increasing the risk of recurrent re-injury).

3.5 Conclusion

The data presented here emphasize the importance of adapting GPS analysis procedures to the specific circumstances of the game or an individual player's activity within that game. It is unequivocal that hockey is an intermittent high-intensity sport characterized by fast passages of play. However, the speed of the ball movement does not necessitate a higher-intensity physiological demand on the players during the game, and it is likely that traditional time–motion analysis procedures will overestimate these demands.

FG analysis has been shown here to report similar results to current procedures (TOP) for all time independent parameters - such as distance covered, Player Load and the number of efforts in both speed zones and acceleration zones - which are currently used to measure the overall volume of exercise in team sports. However time dependent factors - such as relative distance and time spent in standardised speed zones – which are used to describe the intensity of team sport activity are reduced when using FG analysis. Rather than being an 'incorrect' result this should be viewed as a more in-depth view of team sport competition especially those that allow rolling substitutions such as field hockey. Analysis of GPS data in relation to the full playing time may allow appreciation of pacing strategies used during game play and alter our impression of the training intensity and volume required to elicit an appropriate physiological adaptation or training response.

3.6 Future Direction

This investigation highlights the necessity to use sport specific analysis procedure and is the rationale behind the use of FG analysis throughout the subsequent studies. However, these findings pose other questions. Namely, what is the true physical activity, intensity and subsequent physiological cost of competitive field hockey games and training sessions? Furthermore what are the current training practices and how appropriate are they in comparison to the 'new' competitive standards? These two questions must be answered to properly audit the current situation in Scotland and allow for appropriate interventions to be developed and implemented.

4. Analysis of International Competition and Training in Male and Female Field Hockey

4.1 Introduction

The previous Chapters have shown that there are a small number of studies that report the physiological demands of elite field hockey but all to date utilise FG analysis procedures. They demonstrate field hockey to be an, intermittent, high intensity sport and report relative intensities greater than that of soccer (Johnston *et al*, 2004; Spencer *et al*, 2004a and 2004b; Spencer *et al*, 2005; Lythe and Kilding, 2011 and Jennings *et al*, 2012a and 2012b). This has been argued to be an inappropriate finding due to the intricacies of field hockey such as rolling substitutions and interchanging positions. The initial investigation into GPS analysis procedures supported this theory and identified that the current time motion analysis (TMA) data on field hockey misrepresent the demands of field hockey due to the use of TOP analysis which overestimates time dependant parameters. Furthermore previously literature - specifically Gabbett (2010b) - has reported differences between SSGs and competition. However we have suggested duration differences, pitch sizes during SSGs, timing of testing and FG analysis procedures bias this investigation in favour of competition activity. This posed the question what is the current physical demands of competition and training using FG analysis competition and for all drills completed during training (not just SSGs).

Understanding the physiological demands of competition is vital for appropriate training prescription and planning. Therefore without accurate, sport specific results, training prescription has the potential to be detrimental to the athlete and potentially cause an insufficient training stimulus or overtraining and injury. The effect of inappropriate TMA procedures – as reported in study 1 (Chapter 3) requires competition activity to be reassessed prior to an investigation into the relevance of the training stimulus.

Previous studies have analysed competition and training demands to assess the training stimulus of athletes in a variety of sports (Brewer, Dawson, Heasman, Stewart and Cormack, 2010; Casamichana, Castellano and Castagna, 2012; Gabbett, Jenkins and Abernethy, 2012; Gabbett and Mulvey, 2008 and Montgomery, Pyne and Minahan, 2010). In all of these studies, training is reported to be performed at a lower relative intensity than in competition. Similar results, have been shown in sub-elite male field hockey (Johnston *et al*, 2004) and more recently during the preparatory phase of the season in elite female field hockey using GPS analysis (Gabbett, 2010b). These data have drawn the conclusion that training prescription has been inadequate across the majority of team sports. More significantly it was shown that SSGs were insufficient at providing physical activity of a high enough intensity for a conditioning stimulus even in the preparation phase of the season.

However, such a conclusion may be unwarranted because of the inflated intensity of competition due to TOP analysis and the 'stop-start' nature of training sessions which reduces the relative intensity over all. Moreover, during training the session may not focus entirely on conditioning and consequently the nature of the exercise components will influence the observed training intensity. Reviewing all components during the tapering phase of the season will allow for comparison of volumes and intensities less than Gabbett (2010b) with FG analysis procedures. As such it would be expected that similar results to those of Gabbetts (2010b) study would be found. Furthermore attempting to assess all exercise and rest periods during drills will provide more accurate exercise-to-rest ratios for comparison to competition.

The aim of this study is, therefore, to assess the physical activity demands of elite field hockey during competition and training with data expressed relative to the available 'active' time (*i.e.* only omitting breaks between playing periods in competition and breaks between specific training drills [*e.g.* the transition between running drills and small-sided games where players might stop to put on shin guards or retrieve sticks]).

4.2 Methods

4.2.1 Subjects

Sixteen elite male field hockey players (Mean ± SD; age 25 ± 4 yrs, body mass 70.9 ± 6.6 kg and predicted maximal oxygen uptake 61.0 ± 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ [mean± SD]) and seventeen elite female players (age 25 ± 3 yrs, body mass 64.0 ± 5.8 kg and predicted maximal oxygen uptake 52.9 ± 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ [mean ± SD]) participated in the study. Athletes were all members of the male and female Scottish National Hockey teams. Players had completed a 3-month special preparatory programme consisting of strength and power gym based exercises, interval running and speed training in addition to their hockey based pitch sessions prior to the competition phase of their season observed (Male International Four Nations Tournament and EuroHockey Nations Trophy and Female Four Nations Tournament and International friendlies). All participants were free from injury at the time of the study. GPS and inertial sensor analysis was completed as part of the normal squad performance monitoring. All participants provided consent for observations.

4.2.2 Design

In the present study, the physiological demands of elite male and female field hockey were investigated using GPS and inertial sensor technology during competition and training. The data is presented as absolute values to allow comparison with the previous literature but also relative to the 70 minute playing period (referred to as 'Drill (*per* 70 min)' [(70/drill duration)*variable] described in Chapter 2.5.2). The University of Glasgow ethics committee approved all procedures.

4.2.3 Equipment

The Catapult MinimaxX 5 Hz GPS system was used for all recordings (MinimaxX, Catapult Innovations, Melbourne, Australia). All protocols described in methodology Chapter (Chapter 2).

4.2.4 Environmental Conditions

Games were played in three different countries: Scotland (SCO), Ukraine (UKR) and Ireland (IRE). Games in SCO and IRE were played in a temperate climate (~ 14 °C) and the other games were played in a warmer climate in UKR (~ 19 °C). All games were played on water based Astroturf and away from overhead obstructions. Only three pitches were used for testing. Satellite signal strength (range 10.3 ± 1.2 to 12.3 ± 1.0) and horizontal dilution of position were strong (range 1.0 ± 0.4 to 1.3 ± 0.4).

4.2.5 GPS Analyses

Data was downloaded, analysed and reported using Logan Plus v4.4.0 analysis software as has been previously described (Chapter 2).

4.2.5.1 Competition Analyses

A total of seventy-five male and forty-one female elite level competition analyses were completed. Each player was observed at least once (some players analysed in all games) in eight competitive games against seven teams ranked between 2 and 32 in the FIH World Rankings 2011 (male) and five competitive games against 3 teams ranked between 11 and 29 in the FIH World Rankings 2011 (female).

4.2.5.2 Training Analyses

Thirty-seven training analyses from four training sessions with male players and thirty-one training analyses in the female group were observed prior to competition. Training data were classified using the criteria described in Chapter 2.

The specific aim of the drills being monitored was determined by the head coach in the final phase of preparation for competition (so the main focus tended to be technical/tactical development and peaking for competition for both teams). In the male group one category, the running drills, was used for conditioning and aimed to maintain fitness levels achieved in the previous months. No specific conditioning was carried out in the female group. Rest periods within each drill were retained but transitions between drills were omitted (to replicate the competition analysis where only the half time rest period was omitted).

4.2.6 Statistical Analyses

One-way ANOVA and Tukey confidence interval tests were performed and one sample t-tests were used for post hoc analysis of continuous data (e.g. distance, relative distance, Player Load, percentage distance and percentage time). Mann-Whitney and Poisson rate tests were used for post-hoc analysis of all other variables (e.g. absolute, relative and normalised number of efforts in speed or acceleration zones) Differences were calculated from 95 % confidence intervals of difference (FG – TOP). Effect sizes were calculated using Cohens *d* test [ES = (Δ Mean)/Pooled SD] using the methodology presented by Cohen (1988), and magnitudes reported by Batterham and Hopkins (2006) and Hopkins (2009). Magnitudes were: trivial = < 0.2, small 0.2 – 0.6, moderate = 0.6 – 1.2, large = 1.2 to 2, very large = 2.0 – 4.0 and extremely large > 4. Statistical significance was taken as $P \leq 0.05$ and all data are reported as mean and 95 % CI unless otherwise stated.

4.3 Results

4.3.1 Male Competition and Training

4.3.1.1 Competition and Training Duration and Average Maximum Velocities

Table 4.1 shows that full training sessions had a longer duration than competition at 109 (104 to 114) min vs. 75 (74 to 76) min; $P \leq 0.001$. However, individual component drills for the sessions were all shorter in duration than competition (5 (5 to 5) min, 13 (12 to 14) min, 13 (13 to 14) min, 19 (16 to 22) min; running drills, SSGs, full pitch practices and tactical technical drills respectively; $P \leq 0.001$).

Time omitted from analysis (for transition between drills in training and the half-time rest period in competition) was similar at 18 (15 to 20) min vs. 20 (19 to 22) min; however, this represented a lower proportion of the full training duration than in competition at 17 (14 to 18) % vs. 27 (20 to 29) %; $P \leq 0.001$.

Exercise time was greater for the full training session compared to competition at 91 (87 to 96) min vs. 54 (53 to 56) min; $P \leq 0.001$. All component drills were shorter (4 (4 to 5) min, 11 (10 to 12) min, 11 (10 to 11) min, 15 (12 to 17) min; running drills, SSGs, full pitch practices and tactical technical drills respectively; $P \leq 0.001$).

	Duration (min)	Rest Time (min)	Exercise Time (min)	E:R Ratio
Competition	75 (74 to 76)	20 (19 to 22)	54 (53 to 56)	0.24 (0.22 to 0.25)
Running	5 (5 to 5) [a,d]	1 (0 to 1) [a,d]	4 (4 to 5)[a,d]	0.12 (0.11 to 0.13)[a]
SSGs	13 (12 to 14)[a]	2 (2 to 2)[a]	11 (10 to 12)[a]	0.17 (0.16 to 0.18)[a]
Full Pitch Practice	13 (13 to 14)[a]	3 (2 to 3)[a]	11 (10 to 11)[a]	0.20 (0.18 to 0.23)[a]
Tactical/Technical	19 (16 to 22)[a]	4 (3 to 6)[a]	15 (12 to 17)[a]	0.01 (0.01 to 0.02) [a,d]
Full Training Session (mean)	109 (104 to 114)[b]	18 (15 to 20)	91 (87 to 96)[b]	0.14 (0.12 to 0.15)[a]

Table 4.1 Duration, rest time, exercise time and exercise-to-rest ratio during elite male training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

The exercise-to-rest ratio was lower for the full training session and all component drills in comparison to competition (0.12 (0.11 to 0.13), 0.17 (0.16 to 0.18), 0.20 (0.18 to 0.23), 0.01 (0.01 to 0.02) and 0.14 (0.12 to 0.15) vs. 0.24 (0.22 to 0.25); running drills, SSGs, full pitch practices, tactical technical drills and full training session vs. competition respectively; $P \leq 0.001$).

Table 4.3 shows running drills produced the highest average maximum velocities (29.3 (28.7 to 30.0) km·hr^{-1}; $P \leq 0.001$). SSGs, full pitch practices and tactical/technical drills all produced lower average maximum velocities compared to competition (22.4 (22.0 to 22.8) km·hr^{-1}, 23.4 (22.2 to 24.6) km·hr^{-1}, 12.6 (11.1 to 14.0) km·hr^{-1} vs. 26.6 (26.3 to 26.8) km·hr^{-1} respectively; $P \leq 0.001$).

4.3.1.2 Absolute Data

Table 4.2 shows that absolute distance covered during running, SSGs, full pitch and tactical/technical drills were all lower in training than competition (see Table 4.2 for values; $P \leq 0.001$). The absolute distance covered during full training sessions was greater than competition (see Table 4.2 for values; $P \leq 0.001$).

	Absolute (m)	Relative ($m \cdot min^{-1}$)	Drill (*per* 70mins)
Competition	5868 (5718 to 6018)	78 (76 to 81)	5405 (5337 to 5617)
Running	426 (414 to 438) [a]	84 (82 to 87)	5964 (5796 to 6132) [b]
SSGs	967 (889 to 1046) [a]	74 (71 to 77)	5207 (4787 to 5632)
Full Pitch Practice	1016 (940 to 1092) [a]	78 (71 to 85)	5471 (5062 to 5880)
Tactical/Technical	493 (372 to 615) [a]	28 (23 to 33) [a,d]	1816 (1371 to 2266) [a]
Full Training Session (mean)	7318 (6875 to 7761) [b]	67 (65 to 69) [c]	4699 (4575 to 4961) [a]

Table 4.2 Distance covered by elite male players during training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average distance over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

Similarly, Player Load was lower for all component drills (see Table 4.3 for values; $P \leq 0.001$) but greater during full training (see Table 4.3 for values; $P \leq 0.001$) compared to competition. Absolute number of efforts over 15, 19 and 23 $km \cdot hr^{-1}$ were lower for all component drills (see Table 4.3 for values; $P \leq 0.001$). Efforts over 15 $km \cdot hr^{-1}$ were greater full training compared to competition (see Table 4.3 for values; $P \leq 0.001$). Efforts over 19 and 23 $km \cdot hr^{-1}$ were similar for full training and competition (see Table 4.3 for values; $P > 0.05$).

	Player Load	Efforts >15 $km \cdot hr^{-1}$	Efforts >19 $km \cdot hr^{-1}$	Efforts >23 $km \cdot hr^{-1}$	Max Speed ($km \cdot hr^{-1}$)
Competition	631 (602 to 661)	70 (67 to 73)	28 (27 to 30)	7 (7 to 8)	27.3 (27.0 to 27.7)
Running	51 (48 to 54)[a]	5 (4 to 6)[a]	6 (5 to 6)[a]	6 (5 to 6)[a]	29.3 (28.7 to 30.0)[b]
SSGs	108 (99 to 117)[a]	12 (11 to 13)[a]	5 (4 to 5)[a]	1 (1 to 1)[a]	22.4 (22.0 to 22.8)[a]
Full Pitch Practice	106 (98 to 113)[a]	10 (9 to 11)[a]	4 (3 to 5)[a]	1 (1 to 1)[a]	23.4 (22.1 to 24.6)[a]
Tactical/Technical	58 (44 to 71)[a]	1 (0 to 2)[a,d]	0 (0 to 1) [a,d]	0 [a,d]	12.6 (11 to 14) [a,d]
Full Training Session (mean)	816 (773 to 858)[b]	81 (74 to 88)[b]	32 (28 to 36)	8 (6 to 9)	26.8 (26.0 to 27.5)

Table 4.3. Player load (accumulated accelerations), efforts over 15, 19 and 23 $km \cdot hr^{-1}$ and maximum velocities of elite male players during training and competition. Data are mean and 95 % confidence intervals. The mean data for a full training session is the average over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

Table 4.4 shows that sprint and high intensity running distance (above approximately 6.4 $m \cdot s^{-1}$ and 5.3 $m \cdot s^{-1}$ respectively) was lower in full pitch practice and tactical/technical drills compared to competition (see Table 4.4 for values; $P \leq 0.001$). Running drills produced greater sprint distance than competition but lower high intensity running distance (see Table 4.4 for values; $P \leq 0.001$). SSGs produced similar sprint distance than competition but lower high intensity running distance (see Table 4.4 for values; $P \leq 0.001$).

Table 4.5 shows that running, SSGs, full pitch and tactical/technical drills all produced less acceleration efforts than competition (see Table 4.5 for values; $P \leq 0.001$). However the mean full training session data shows more accelerations than competition (see Table 4.5 for values; $P \leq 0.001$).

4.3.1.3 Relative Data

Table 4.2 also shows that relative distance covered to be similar for running, SSGs and full pitch drills and competition (see Table 4.2 for values). The relative distance covered during full training sessions was lower than in competition (see Table 4.2 for values; $P = 0.008$). Tactical/technical drills had the lowest relative distance compared to all other areas (see Table 4.2 for values; $P \leq 0.001$).

The relative time spent sprinting or high intensity running was greater in running practices than competition (see Table 4.4 for values; $P \leq 0.001$); not different between competition and full pitch practices or SSGs (see Table 4.4 for values), lower in tactical/technical drills than competition (see Table 4.4 for values; $P \leq$ 0.001).

		Absolute (m)	Relative ($m \cdot min^{-1}$)	Drill (*per* 70mins)
Competition	S	114 (102 to 126)	2 (1 to 2)	105 (94 to 116)
	HI	457 (444 to 470)	6 (6 to 6)	421 (409 to 433)
Running	S	146 (139 to 153)[b]	29 (28 to 31)[b]	2044 (1951 to 2140)[b]
	HI	135 (123 to 147)[a]	27 (25 to 29)[b]	1890 (1722 to 2058)[b]
SSGs	S	107 (87 to 126)	8 (7 to 9)[b]	576 (470 to 679)[b]
	HI	250 (173 to 326)[a]	19 (14 to 23)[b]	146 (931 to 1755)[b]
Full Pitch Practice	S	76 (60 to 93)[a]	6 (5 to 7)[b]	409 (321 to 498)[b]
	HI	163 (144 to 183)[a]	13 (11 to 13)[b]	877 (775 to 985)[b]
Tactical/Technical	S	19 (13 to 26)[a]	1 (1 to 1)[a]	70 (48 to 96)[a]
	HI	34 (25 to 43)[a]	2 (2 to 2)[a]	125 (94 to 159)[a]
Full Training Session (mean)	S	116 (97 to 134)	1 (1 to 1)	108 (91 to 124)
	HI	448 (384 to 512)	4 (4 to 5)	417 (358 to 477)

Table 4.4. Distance covered and relative time spent sprinting/high intensity running during elite male training and competition. Data are mean and 95 % confidence intervals; *S* is sprinting and *HI* high intensity running. Mean data for a full training session is the average distance covered over each session (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq$ 0.001; [b]data significantly greater than competition, $P \leq$ 0.001.

4.3.1.4 Data Normalised to Match Duration [Drill (per 70 min)]

Table 4.2 shows that normalised distance covered during SSGs and full pitch practices are all similar to competition (see Table 4.2 for values). Full training session and tactical/technical drills produced lower normalised distance covered than competition (see Table 4.2 for values; $P \leq$ 0.001). Running drills produced higher normalised distance covered than competition (see Table 4.2 for values; $P \leq$ 0.001).

Table 4.4 once more shows normalised sprint and high intensity running distance is greater in running drills, SSGs and full pitch practices compared to competition (see Table 4.4 for values; $P \leq$ 0.001). Tactical/technical drills are lower than competition for normalised sprint and high intensity running distance (see Table 4.4 for values; *P*

$\leq$ 0.001) whereas full training session values are similar to competition (see Table 4.4 for values).

Table 4.5 shows that normalised to competition time, running drills and SSGs produce a greater number of accelerations and decelerations than in competition (see Table 4.5 for values; $P \leq 0.001$). Normalised mean full training session data shows a greater number of accelerations than in competition (see Table 4.5 for values; $P = 0.004$). Tactical/technical drills had the lowest normalised number of accelerations (see Table 4.5 for values; $P \leq 0.001$). The number of absolute and normalised decelerations were similar in full training as competition ($P > 0.05$). Absolute decelerations in tactical/technical drills were similar to competition ($P > 0.05$) but greater when normalised for competition time ($P \leq 0.001$).

	Absolute Acc (number)	Absolute Dec (number)	Normalised Acc (*per* 70 min)	Normalised Dec (*per* 70 min)
Competition	20 (17 to 23)	8 (8 to 9)	19 (16 to 22)	8 (8 to 8)
Running	10 (7 to 15) [b]	19 (10 to 27) [d]	140 (98 to 210) [d]	266 (140 to 378) [d]
SSGs	6 (6 to 8) [b]	34 (30 to 39) [d]	32 (32 to 43) [d]	183 (161 to 210) [d]
Full Pitch Practice	3 (2 to 4) [b]	19 (17 to 22) [d]	16 (11 to 21)	102 (92 to 119) [d]
Tactical/technical	2 (1 to 4) [b]	8 (3 to 12)	7 (4 to 15) [b]	30 (16 to 65) [d]
Full Training Session (mean)	37 (32 to 42) [d]	9 (8 to 9)	24 (21 to 28) [c]	6 (5 to 6)

Table 4.5. Accelerations and decelerations performed during elite male training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average distance over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$; [d]data significantly greater than competition, $P \leq 0.05$.

4.3.1.5 Effect Sizes

The data presented in previous Chapters is corroborated by the data in Table 4.6 and Table 4.7. Table 4.6 displays the difference between the two means of training and competition percentage distance covered and time in each of the speed zones. The percentage distance covered in the lowest speed zone is the only speed zone to be greater in training than competition. This difference has a large effect size. All other zones are greater in competition. 6 – 11 km·hr^{-1}, 15 – 19 km·hr^{-1} and 19 – 23 km·hr^{-1} all report moderate effect sizes. Distance covered in the highest speed zone has a small effect size. However slow speed running has a large effect size suggesting.

The percentage time spent in each of the speed zones is also shown in Table 4.6. These data show a small effect size in favour of training for the lowest speed zone. Small and trivial effect sizes are shown between 19 – 23 km·hr^{-1} and greater than 23 km·hr^{-1}. In the other speed zones – 6 – 11 km·hr^{-1}, 11 – 15 km·hr^{-1} and 15 – 19 km·hr^{-1} moderate effect sizes are reported with more time spent in these zones during competition compared to training.

	Distance (%)		Time (%)	
0-6 km·hr^{-1}	-1.58	Large	-0.49	Small
6-11 km·hr^{-1}	0.77	Moderate	1.19	Moderate
11-15 km·hr^{-1}	1.42	Large	0.64	Moderate
15-19 km·hr^{-1}	0.96	Moderate	1.14	Moderate
19-23 km·hr^{-1}	0.63	Moderate	0.38	Small
> 23 km·hr^{-1}	0.27	Small	0.09	Trivial

Table 4.6. Percentage distance and time in specified speed zones during elite male competition and training (competition minus training). Data are Cohens *d* Effect sizes and magnitudes. The effect size describes the difference between the mean competition distance and time and the mean full training session distance and time (the sum of running, SSGs, full pitch practice and tactical/technical drills. Magnitude descriptor reported in Chapter 2.5.3.

Table 4.7 displays the difference in absolute, relative and normalised [Drill (*per* 70mins)] mean HSR and SPR during competition, training and each of the training drills. The effect sizes from the absolute HSR data show very large differences between competition and three drills - namely running, full pitch practices and technical/tactical drills. This very large difference is only carried over to SPR in technical/tactical drills. Moderate differences in absolute SPR are seen in running and full pitch practices. Trivial effect sizes between competition and full training are seen in absolute HSR and between competition and SSGs and full training for SPR.

Relative HSR and SPR effect sizes show negative extremely large differences between running drills and competition. Further to this very large differences are seen between competition and three drills - full pitch practices, SSGs and technical/tactical drills. Large differences are also seen between competition and full training. Competition relative SPR shows moderate differences compared technical/tactical drills and competition as well as large differences to SSGs. Very large and extremely large differences are seen in SSGs and respectively.

Lastly normalised HSR and SPR effect sizes show extremely large differences between competition and running. Additionally very large differences compared to full pitch practices for both HSR and SPR. Trivial, moderate and large differences in HSR are seen for full training, SSGs and tactical/technical respectively. Competition normalised SPR show trivial, small, large and very large differences in comparison to full training, tactical/technical, SSGs and full pitch practices respectively.

	Absolute HSR		Absolute SPR		Relative HSR		Relative SPR		Drill (*per* 70mins) HSR		Drill (*per* 70mins) SPR	
Running	2.98	Very Large	-0.71	Moderate	-9.91	Extremely Large	-24.70	Extremely Large	-9.90	Extremely Large	-25.35	Extremely Large
SSGs	1.81	Large	0.12	Trivial	-3.27	Very Large	-1.70	Large	0.99	Moderate	-1.90	Large
Full Pitch	2.70	Very Large	0.80	Moderate	-2.88	Very Large	-2.47	Very Large	-2.68	Very Large	-2.68	Very Large
Tactical/Technical	3.88	Very Large	2.00	Very Large	1.79	Very Large	0.77	Moderate	1.89	Large	0.38	Small
Full Training	0.08	Trivial	-0.04	Trivial	1.00	Large	1.19	Moderate	0.03	Trivial	-0.05	Trivial

Table 4.7. A comparison of absolute, relative and Drill (per 70mins) high speed running (HSR) and sprint running (SPR) distance in competition, full training and specified drills in elite male field hockey players. Data are Cohens *d* Effect sizes and magnitudes. The effect size describes the difference between the mean competition distance and time and the mean distance during running drills, small sided games (SSGs), full pitch practices, tactical/technical and full training session distance. Magnitude descriptor reported in Chapter 2.5.3.

4.3.2 Female Competition and Training

4.3.2.1 Competition and Training Duration and Average Maximum Velocities

Tab1e 4.8 shows that full training sessions had a longer duration than competition at 86 (81 to 92) min vs. 75 (74 to 75) min; $P \leq 0.001$. However, individual component drills for the sessions were all shorter in duration than competition (8 (6 to 9) min, 37 (31 to 43) min, 14 (13 to 14) min, 18 (14 to 22) min; running drills, SSGs, full pitch practices and tactical technical drills respectively; $P \leq 0.001$).

Time omitted from analysis (for transition between drills in training and the half-time rest period in competition) was similar at 19 (17 to 21) min vs. 18 (16 to 20) min; however, this represented a lower proportion of the full training duration than in competition at 22.1 (20.1 to 22.8) % vs. 24.0 (21.6 to 26.7) %; $P \leq 0.001$.

Exercise time was greater for the full training session compared to competition at 67 (63 to 73) min vs. 56 (54 to 59) min; $P \leq 0.001$. All component drills were shorter (7 (5 to 8) min, 28 (24 to 33) min, 12 (11 to 12) min, 14 (11 to 18) min; running drills, SSGs, full pitch practices and tactical technical drills respectively; $P \leq 0.001$).

	Duration (min)	Rest Time (min)	Exercise Time (min)	E:R Ratio
Competition	75 (74 to 75)	18 (16 to 20)	56 (54 to 59)	0.21 (0.19 to 0.22)
Running	8 (6 to 9)[a,d]	1 (1 to 1)[a,d]	7 (5 to 8)[a,d]	0.07 (0.05 to 0.08)[a]
SSGs	37 (31 to 43)[a]	9 (7 to 11)[a]	28 (24 to 33)[a]	0.12 (0.1 to 0.15)[a]
Full Pitch Practice	14 (13 to 14)[a]	2 (2 to 2)[a]	12 (11 to 12)[a]	0.07 (0.03 to 0.11)[a]
Tactical/Technical	18 (14 to 22)[a]	4 (3 to 5)[a]	14 (11 to 18) [a]	0.07 (0.05 to 0.08)[a]
Full Training Session (mean)	86 (81 to 92)[d]	19 (17 to 21)	67 (63 to 73)[b]	0.15 (0.11 to 0.18)[a]

Table 4.8. Duration, rest time, exercise time and exercise-to-rest ratio during elite female training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

The exercise-to-rest ratio was lower for the full training session and all component drills in comparison to competition (0.07 (0.05 to 0.08), 0.12 (0.10 to 0.15), 0.07 (0.03 to 0.11), 0.07 (0.05 to 0.08) and 0.15 (0.11 to 0.18) vs. 0.21 (0.19 to 0.22); running drills, SSGs, full pitch practices, tactical technical drills and full training session vs. competition respectively; $P \leq 0.001$).

Table 4.8 shows competition produced the highest average maximum velocities (23.8 (23.3 to 24.3) km·hr^{-1}; $P \leq 0.001$). Running drills, SSGs, full pitch practices, tactical/technical drills and full training session all produced lower average maximum velocities compared to competition (17.3 (14.9 to 19.7) km·hr^{-1}, 20.6 (20.0 to 21.1) km·hr^{-1}, 20.9 (19.6 to 22.2) km·hr^{-1}, 17.7 (16.3 to 19.1) km·hr^{-1} and 21.0 (20.2 to 21.8) km·hr^{-1} respectively; $P \leq 0.001$).

4.3.2.2 Absolute Data

Table 4.7 shows that absolute distance covered during running, SSGs, full pitch and tactical/technical drills were all lower in training than competition (see Table 4.7 for values; $P \leq 0.001$). The absolute distance covered during full training sessions was also lower than competition (see Table 4.7 for values; $P \leq 0.001$).

Similarly, Player Load was lower for all component drills (see Table 4.10 for values; $P \leq 0.001$) and during full training (see Table 4.10 for values; $P \leq 0.034$) compared to competition. Absolute number of efforts over 14, 18 and 21 km·hr^{-1} were lower for all component drills (see Table 4.10 for values; $P \leq 0.001$) but similar for competition and full training (see Table 4.10 for values; $P > 0.05$).

	Absolute (m)	Relative (m·min^{-1})	Drill (*per* 70mins)
Competition	5625 (5417 to 5833)	75 (73 to 78)	6992 (6872 to 7111)
Running	470 (361 to 579)[a,d]	60 (51 to 70)[a]	5321 (4596 to 6047)[a]
SSGs	2054 (1667 to 2441)[a]	53 (50 to 55)[a]	4846 (4660 to 5031)[a]
Full Pitch Practice	1166 (1073 to 1260)[a]	86 (81 to 91)[b]	6960 (6623 to 7298)
Tactical/Technical	786 (641 to 930)[a]	49 (43 to 55)[a]	4120 (3700 to 4539)[a,d]
Full Training Session (mean)	4825 (4433 to 5217)[a]	56 (53 to 60)[a]	5024 (4794 to 5255)[a]

Table 4.9. Distance covered by elite female players during training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average distance over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

Table 4.9 shows that sprint and high intensity running distance (above approximately 5.8 m·s^{-1} and 5.0 m·s^{-1} respectively) and maximum velocities were lower in all component drills and full training compared to competition (see Table 4.10 for values; $P \leq 0.001$).

Table 4.12 shows that running, SSGs, full pitch and tactical/technical drills all produced less acceleration efforts than competition (see Table 4.12 for values; $P \leq 0.001$). Mean full training session data shows similar accelerations as competition (see Table 4.12 for values; $P > 0.05$).

	Player Load	Efforts >14 km·hr^{-1}	Efforts >18 km·hr^{-1}	Efforts >21 km·hr^{-1}	Max Speed (km·hr^{-1})
Competition	665 (629 to 700)	70 (65 to 76)	22 (19 to 25)	6 (5 to 8)	23.8 (23.3 to 24.3)
Running	61 947 to 75)[a]	3 (2 to 3)[a,d]	2 (1 to 2)[a,d]	1 (0 to 1)[a]	17.3 (14.9 to 19.7)[a]
SSGs	253 (200 to 307)[a]	46 (32 to 59)[a]	13 (10 to 17)[a]	2 (1 to 2)[a]	20.6 (20.0 to 21.1)[a]
Full Pitch Practice	151 (133 to 168)[a]	14 (12 to 16)[a]	4 (3 to 5)[a]	1 (0 to 2)[a]	20.9 (19.6 to 22.2)[a]
Tactical/Technical	85 (70 to 100)[a]	6 (4 to 7)[a]	2 (1 to 2)[a,d]	0 (0 to 0)[a,d]	17.7 (16.3 to 19.1)[a]
Full Training Session (mean)	591 (535 to 646)[c]	83 (69 to 96)	25 (21 to 28)	4 (3 to 5)[a]	21.0 (20.2 to 21.8)[a]

Table 4.10. Player load (accumulated accelerations), efforts over 14, 18 and 21 km·hr^{-1} and maximum velocities of elite female players during training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$: [d]data significantly less than all other comparisons, $P \leq 0.001$.

		Absolute (m)	Relative ($m \cdot min^{-1}$)	Drill (*per* 70mins)
Competition	S	331 (292 to 370)	4 (4 to 5)	309 (273 to 345)
	HI	767 (716 to 817)	10 (10 to 11)	716 (668 to 763)
Running	S	26 (13 to 39)[a]	3 (2 to 5)[a]	228 (114 to 341)[a]
	HI	73 (42 to 105)[a]	9 (5 to 13)[a]	639 (368 to 919)[a]
SSGs	S	15 (9 to 22)[a]	0 (0 to 1)[a]	28 (17 to 42)[a]
	HI	43 (30 to 57)[a]	1 (1 to 2)[a]	81 (57 to 108)[a]
Full Pitch Practice	S	13 (3 to 22)[a]	1 (0 to 2)[a]	65 (15 to 110)[a]
	HI	71 (48 to 95)[a]	5 (3 to 7)[a]	355 (240 to 475)[a]
Tactical/Technical	S	25 (13 to 37)[a]	1 (1 to 2)[a]	97 (51 to 144)[a]
	HI	44 (27 to 62)[a]	2 (2 to 3)[a]	171 (105 to 241)[a]
Full Training Session	S	129 (87 to 172)[a]	2 (1 to 2)[a]	105 (71 to 140)[a]
(mean)	HI	284 (213 to 356)[a]	3 (2 to 4)[a]	231 (173 to 290)[a]

Table 4.11. Distance covered and relative time spent sprinting/high intensity running during elite female training and competition. Data are mean and 95% confidence intervals; *S* is sprinting and *HI* high intensity running. Mean data for a full training session is the average distance covered over each session (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$.

4.3.2.3 Relative Data

Table 4.9 also shows that relative distance covered to be lower for running, SSGs and tactical/technical drills and mean full training session compared to competition (see Table 4.9 for values). The relative distance covered during full pitch practices was greater than in competition (see Table 4.9 for values; $P \leq 0.001$).

The relative time spent sprinting or high intensity running was lower in all component drills and mean full training compared to competition (see Table 4.9 for values; $P \leq 0.001$).

4.3.2.4 Data Normalised to Match Duration [Drill (per 70 min)]

Table 4.11 yet again shows that normalised distance covered during running drills, SSGs, tactical/technical drills and mean full training session were all less than competition (see Table 4.11 for values; $P \leq 0.001$). Only full pitch practices were similar to competition (see Table 4.11 for values; $P > 0.05$).

Table 4.11 once more shows normalised sprint and high intensity running distance were lower in all component drills and mean full training compared to competition (see Table 4.11 for values; $P \leq 0.001$).

Table 4.12 shows that normalising the number of accelerations (> 2 $m \cdot s^{-2}$ for more than 1 second) makes full pitch practices, tactical/technical and full training session similar to competition (see Table 4.12 for values; $P > 0.05$). Normalised SSGs shows a greater number of accelerations than in competition (see Table 4.12 for values; $P \leq 0.001$). Running drills had the lowest normalised number of accelerations (see Table 4.12 for values; $P \leq 0.001$). Similarly both absolute and normalised decelerations were shown to be less for running drills (see Table 4.12 for values; $P \leq 0.001$) but greater for full pitch practices (see Table 4.12 for values; $P \leq 0.001$). Interestingly, normalised SSGs were greater than competition (see Table 4.12 for values; $P \leq 0.001$) but absolute values were not ($P \geq 0.001$).

	Absolute Acc (number)	Absolute Dec (number)	Normalised Acc (*per* 70 min)	Normalised Dec (*per* 70 min)
Competition	18 (14 to 22)	23 (19 to 27)	23 (18 to 26)	17 (13 to 21)
Running	0 (0 to 1)[a]	1 (1 to 2) [a]	2 (0 to 5)[a,d]	1 (1 to 2) [a]
SSGs	10 (8 to 13)[a]	24 (19 to 29)	31 (24 to 36)[b]	45 (43 to 47) [d]
Full Pitch Practice	3 (2 to 5)[a]	9 (7 to 12) [d]	18 (8 to 29)	45 (35 to 56) [d]
Tactical/technical	4 (2 to 5)[a]	4 (2 to 6)	21 (12 to 29)	15 (11 to 19)
Full Training Session (mean)	23 (17 to 27)	23 (18 to 27)	18 (8 to 29)	19 (15 to 21)

Table 4.12. Accelerations and declarations performed during elite female training and competition. Data are mean and 95% confidence intervals. The mean data for a full training session is the average distance over the four sessions (the sum of running, SSGs, full pitch practice and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity). [a]Data significantly less than competition, $P \leq 0.001$; [b]data significantly greater than competition, $P \leq 0.001$; [c]data significantly less than competition, $P \leq 0.05$; [d]data significantly greater than competition, $P \leq 0.05$.

4.3.2.5 Effect Sizes

Similar to the male data the effect size information has been used to show the difference between means and support the previously reported data. Table 4.13 displays the difference between the two means of training and competition percentage distance covered and time in each of the speed zones. The percentage distance covered in 0 – 6 km·hr^{-1} and 6 – 10 km·hr^{-1} speed zones are the only speed zones to be greater in training than competition. This difference were large and trivial respectively. All other zones are greater in competition. Small effect sizes were seen from 10 - 14 km·hr^{-1} and large differences in 14 – 18 km·hr^{-1} and 18 – 21 km·hr^{-1} all report moderate effect sizes. Distance covered in the highest speed zone had a moderate effect size.

The percentage time spent in each of the speed zones is also shown in Table 4.13. These data show a very large effect size in favour of training for the lowest speed zone. Small and trivial effect sizes are shown between 18 – 21 km·hr^{-1} and greater than 21 km·hr^{-1}. In the other speed zones – 6 – 10 km·hr^{-1}, 10 – 14 km·hr^{-1} and 14 – 18 km·hr^{-1} moderate effect sizes are reported with more time spent in these zones during competition compared to training.

	Distance (%)		Time (%)	
0-6 km·hr^{-1}	-0.79	Large	-2.14	Very Large
6-10 km·hr^{-1}	-0.19	Trivial	0.82	Moderate
10-14 km·hr^{-1}	0.24	Small	0.64	Moderate
14-18 km·hr^{-1}	1.38	Large	1.14	Moderate
18-21 km·hr^{-1}	1.28	Large	0.38	Small
>21 km·hr^{-1}	0.82	Moderate	0.09	Trivial

Table 4.13. Percentage distance and time in specified speed zones during elite male training and competition. Data are Cohens *d* Effect sizes and magnitudes. The effect size describes the difference between the mean competition distance and time and the mean full training session distance and time (the sum of running, SSGs, full pitch practice and tactical/technical drills. Magnitude descriptor reported in Chapter 2.5.3.

Table 4.13 displays the difference in absolute, relative and normalised [Drill (*per* 70mins)] mean HSR and SPR during competition, training and each of the training drills. The effect sizes from the absolute HSR and SPR data show extremely large differences between competition and training and all training.

Relative HSR and SPR effect sizes show moderate differences between running drills and competition. Further to this very large differences are seen between full pitch practices and SSGs. Extremely large differences were shown between competition and both technical/tactical drills and full training. Similarly relative SPR shows moderate differences in running drills and SSGs. Large differences were seen in full pitch practices and very large differences are seen in technical/tactical drills and full training.

Lastly normalised HSR effect sizes show extremely large differences between competition and training as well as all other drills. Additionally large differences were shown in SPR during running, full pitch practices and technical/tactical drills.

Trivial effect sizes were shown for full training. Normalised SPR shows extremely large differences in SSGs to competition.

	Absolute HSR		Absolute SPR		Relative HSR		Relative SPR		Drill (*per* 70mins) HSR		Drill (*per* 70mins) SPR	
Running	13.65	Extremely Large	7.61	Extremely Large	0.63	Moderate	0.67	Moderate	5.27	Extremely Large	2.02	Large
SSGs	14.41	Extremely Large	8.04	Extremely Large	9.89	Very Large	5.57	Moderate	10.96	Extremely Large	14.38	Extremely Large
Full Pitch	13.81	Extremely Large	8.05	Extremely Large	4.81	Very Large	3.43	Large	9.13	Extremely Large	-3.91	Large
Tactical/Technical	14.26	Extremely Large	7.67	Extremely Large	7.41	Extremely Large	3.25	Very Large	8.68	Extremely Large	-2.59	Large
Full Training	8.25	Extremely Large	4.08	Extremely Large	6.99	Extremely Large	2.41	Very Large	9.57	Extremely Large	-0.24	Small

Table 4.14. A comparison of absolute, relative and Drill (per 70mins) high speed running (HSR) and sprint running (SPR) distance in competition, full training and specified drills in elite male field hockey players. Data are Cohens *d* Effect sizes and magnitudes. The effect size describes the difference between the mean competition distance and time and the mean distance during running drills, small sided games (SSGs), full pitch practices, tactical/technical and full training session distance. Magnitude descriptor reported in Chapter 2.5.3.

4.4 Discussion

The use of time motion analysis in team sports facilitates the quantification of activity in both competition and training. The aim of the current study was to compare the physical demand of training and competition in elite field hockey to consider whether current exercise prescription was able to elicit appropriate physical activities similar to the requirements of competition. It was expected that due to the use of FG analysis and reporting training data from the tapering phase of the season that this would bias the results showing a similar difference to Gabbett (2010b) who used TOP analysis and training during the preparatory phase of the season. However the results showed less of a difference between competition and training than was expected. Further to this the relative and normalised data revealed that current training drills have the ability to overload activity demands in comparison to competition if used for different time periods.

4.4.1 Competition Data

The competition data displayed here provides a picture of the physical demands of elite male and female field hockey in two Northern Hemisphere teams. This data suggests that Scottish international players are similar to other elite players in some aspects of physical condition but are unable to complete the same amount of physical activity during competition irrespective of the analysis procedure used.

The data available for time motion analysis in male elite field hockey during competition and training are relatively sparse (especially for studies using GPS and inertial sensor technology). However, the average distance covered during match play by an individual player is about 900 m lower here (in absolute terms) than previously reported by Lythe and Kilding (2011). While the players in the current study have similar aerobic capacities to elite level field hockey players in other studies (Aziz, Chia, Teh, 2000 and Jennings, Cormack, Coutts and Aughey, 2012b), their predicted maximal oxygen uptake from a multi-stage fitness test was 3 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ less than in Lythe and Kilding (2011). As both studies utilised the same MSFT the difference is less likely to be due to the limitations of this test and more likely due to differences in aerobic capacity. This 3 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ would predict that, at constant running pace over 70 minutes, the total distance covered by the players described here should be lower by around 850 m (Paliczka, Nichols and Boreham, 1987). Thus the difference observed will substantially reflect player conditioning rather than extrinsic factors such as opposition effects, tactics, etc.

In support of this hypothesis, the female data reported distances which are similar to those reported in the literature on elite female field hockey players (5625 vs. 5541 m, this study vs. Macutkiewcz and Sunderland, 2011, respectively) and aerobic capacities among the highest in the literature. Additionally the distances covered were found to be less than Gabbett (2010b) by approximately 1 km (*c.f.* 6.6 km reported by Gabbett) with aerobic capacities also lower in this group (52.9 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ vs. 53.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). Further to this the players in this study had mean maximum velocities of 23.8 $km{\cdot}hr^{-1}$ which is lower than the sprint threshold in Gabbett's study (7 $m{\cdot}s^{-1}$ equivalent to 25 $km{\cdot}hr^{-1}$).

As has been previously described, the absolute distance covered by players is unaffected by the analysis procedure used. However, the relative distance covered ($m{\cdot}min^{-1}$) by an individual player during competition is substantially lower when using FG analysis. The effect of this can be seen when comparing the relative distance. 78 $m \cdot min^{-1}$ and 75 $m \cdot min^{-1}$ (male and female respectively) with the values reported by Aughey (2011) (c.f. ~ 125 $m \cdot min^{-1}$ for international female forward). Interestingly national standard (sub-elite) midfielders and defenders were shown to have relative distances similar to those report in this cohort (~ 80 $m \cdot min^{-1}$). This finding is likely due to the differences in utilisation of substitution strategies between levels which will mean players playing longer in sub-elite games reducing the impact of TOP.

Normalising the data allows for comparison across all data relative to the competition period. This has been done previously in the literature albeit with a different methodology. The study by Lythe and Kilding (2011) reported "$Position_{70}$" data – summative value of distance covered by all players in that position during the 70 minute game. This method has its flaws as it is the accumulation of activity by all players who play in this position including starting players and substitutions. In sports where rolling substitutions are allowed, players are given extra off-field recovery and as such have been shown to have increased activity in the immediate period after the game (Waldron, Higton, Daniels and Twist, 2013). It also reduces temporal fatigue and allows for better maintenance of activity throughout the game (Spencer *et al*, 2004b). As such accumulating the activity of players in the same position fails to show their individual differences and positively skews the positional data making it look like these positions require activity well above that achieved by individuals. This normalisation gave mean distances of 8160 ± 428 m which is far higher than the normalised distance in this investigation (5405 (5337 to 5617) m).

Even given the differences in normalisation it is clearly evident that the players in this study had lower physical activity levels.

The physical activity of both male and female players in this study falls someway short of the other elite players in the published literature. This is likely due to a decreased aerobic capacity in male players but less so in the female group - their aerobic capacity is within a similar range to MacLeod and colleagues *(*2007) ~ 52.9 $mL\cdot kg^{-1}\cdot min^{-1}$ and absolute distance covered in competition was similar to Macutkiewcz and Sunderland (2011).

There is potential for the results to be impacted upon by the effects of contextual variables such as opposition, the game being home or away and if the team are winning or losing (Castellano, Blanco-Villasenor and Alvarez, 2011 and Bradley and Noakes, 2013). Data from male competition was in the European Division B competition which involves promotion and relegation whereas the female data is from international friendlies. Both of which will be affected in some way by contextual variables but it is more likely that the male players will have been under increased pressure due to the importance of the games. Interestingly, match importance has been shown to have no affected on high intensity running distance in soccer (Bradley and Noakes, 2013). Furthermore, the amount of ball possession has no effect on total activity but can increase high speed running by up to 31 % in teams who have lots of possession in elite soccer (Bradley, Lagos-Penas, Rey and Gomez Diaz, 2013). Although this data is fairly comprehensive [over 800 athletes studied in Bradley, Lagos-Penas, Rey and Gomez Diaz (2013)] it has not been studied in field hockey. As such all data was reported as averages to reduce the potential effects of context, tactics and opposition on the data used for comparison.

4.4.2 Training Data

In conditioning for athletic performance the principle of progressive overload requires consideration of the specific exercises and total activity undertaken in a periodised training programme (Bompa and Haff, 1999). Specificity of training will mean that certain exercises may focus on specific movement patterns, energy systems or speed of movement and provide an overload to adapt and exceed the physiological demands of the sporting activity (Fry, Morton and Keast, 1992 and Gamble, 2006). The result showed that training in the female group lacked high speed running and the male group training sessions were limited to short distances with very little intensity. This was expected when the data was taken from tapering sessions. However absolute, relative and normalised data showed that the current training regimens for field hockey can provide an appropriate stimulus for adaptation if viewed appropriately in comparison to FG analysis and with inclusion of rest time within drills retained (similar to FG competition analysis).

Comparisons of training load with the demands of competition have been reported in a number of team sports (Brewer, Dawson, Heasman, Stewart and Cormack, 2010, Casamichana, Castellano and Castagna, 2012, Gabbett, Jenkins and Abernethy, 2012, Gabbett and Mulvey, 2008 and Montogomery, Pyne and Minahan, 2010). The only study in field hockey compared SSGs in training to competition in female players (Gabbett, 2010b) where it was concluded that SSGs were played at a lower intensity than in competition (but that they contained similar movement patterns). This comparison was based on time spent in low-intensity, moderate or high-intensity activities (determined by speed) during small-sided games. However, by their nature SSGs limit the distance available for players to accelerate to high speed and will limit their ability to accumulate significant time at higher speeds – similar to results from both male and female players in this study. Furthermore, if small-sided games are being compared to relative times and distances during competition where 'rest periods' on the bench have been removed then any difference may be over-estimated.

The rationale for including bench periods in the data reported here is that it reflects a sport specific activity. These periods are analogous to the rest period between exercise sets in the gym and are relevant to calculation of exercise-rest ratio and influence overall competition intensity. For direct comparison with training data, the recovery periods allowed within specific drills have been included but the short periods of time between drills omitted (e.g. when the players stopped to retrieve sticks and put on shin guards not used during running drills). The data omitted were not sport specific and represented a significantly lower proportion of the training time compared to the half-time rest period during competition.

Specificity of training will dictate what exercises are chosen to provide an adaptive stimulus to improve performance, to maintain condition or even taper towards a specific competition (Hewson and Hopkins, 1996 and Baechle and Earle, 2000). Therefore, it is essential to consider all aspects of the session when assessing the training demands in comparison to competition. This means including drills which may not produce high intensity activity or focus on a physiological adaptation such as tactical/technical drills. All drills are completed at different intensities by different teams with some drills having greater physiological demand than others nevertheless all of them will have an impact on the overall volume of the session and the total sessions exercise-to-rest ratio.

The present study monitored training demands during final preparation for an international tournament and consequently the focus of the exercises was not to provide an adaptive stimulus. Nevertheless, the mean data accumulated for the full training session shows that total distance covered and high speed running distance was not different from competition in the male group investigated. The relative distance is significantly lower than competition but can be explained, in part, by the longer duration of training and the impact of specific very low intensity technical/tactical activities incorporated with this data. Traditionally, a high-intensity, low volume taper has been suggested for activities with an endurance component (Shepley, MacDougall, Cipriano, Sutton, Tarnopolsky, Coates, 1992) and analysis of the individual components within these training sessions allow consideration as to whether players accumulate appropriate high-intensity from different components despite reduced durations to limit total volume. 'Normalising' these component drills to the 70 minute match duration has been used to indicate relative intensity; these data demonstrate that running drills, SSGs and limited duration full pitch matches provide a relative training intensity in excess of that observed during competition.

Distance covered at high speed during small-sided games was not significantly different from competition in the data presented here and suggests similar intensity (but reduced volume) to midfielders and strikers when 'normalised' to match duration in Gabbett (2010b) and average distance covered at high speed per position in Lythe and Kilding (2011). The use of team averages to compare competition and SSGs is likely to be more relevant given the lack of position specific movement in the SSGs. If position specific differences are relevant to the data presented here, then the team average will be reduced by inclusion of defensive player data. Furthermore, despite the large volume of low intensity activity during technical/tactical training the male group studied accumulate the same volume of high speed running over the whole training session (due largely to the contribution of specific high intensity running). These data suggest that field hockey training session can provide an adequate stimulus to maintain condition appropriate to the demands of field hockey.

In support of this hypothesis the results from the female population show SSGs to produce a similar training stimulus – low to moderate speeds with significant numbers of absolute and normalised accelerative movements. Distance covered at high speed and sprint speed is reduced in the female population and this may be a physiological characteristics as has been previously mentioned (unable to meet Gabbett’s sprint threshold). It may also be that the drills selected were not designed for high speed activity – male training involved running drills which were focused on conditioning players and were high intensity in nature, the female running drills on the other hand were low intensity, steady state drills. Although these data highlight the low intensity (as described by high speed/sprint exercise) of female training it supports the importance of drill design and not the inability for training to meet competition demands.

Gabbett (2010b) suggests that altering the conditions, design or drill complexity for SSGs is necessary to provide an appropriate training stimulus for field hockey. The intensity of small-sided game play is easily manipulated by changing conditions within the game; for example the dimensions of the pitch, the player numbers, inclusion of goal-keepers or playing possession games with limited ball contacts before passing (Rampinini, Impellizzeri, Castagna, Abt, Chamari, Sassi and Marcora, 2007; Dellal, Lago-Penas, Wong, and Chamari, 2011; Koklu, Ersoz, Alemdaroglu, Asci and Ozkan, 2012 and Kennett, Kempton, & Coutts, 2012). The data presented here illustrates playing area sizes and exercise durations that can provide an appropriate training stimulus to maintain conditioning. Increasing the volume of high intensity activity within a training session should make it possible to apply progressive overload and thereby enhance performance. However, independent of any desired manipulation, the intensity of SSGs will also be limited by the physical and technical capacity of the players involved. It is undeniable that the a wider range of physical and technical abilities will be observed in national level teams than in an international team. It can be speculated that including sub-elite field hockey players in small-sided games will cause the exercise 'to break down' more often than with exclusively international players and this effect contributes to the reduced intensity observed previously (Gabbett, 2010b). In addition to this it can be hypothesised that the reduced game time that sub-elite players are likely to obtain during national competition will limit their impact on the measured intensity of game play. The resultant increase in game time for the elite players will lead to the observed increase in distance covered during competition and provides the stimulus for the higher predicted maximal oxygen uptake.

Although the players in this study are international players and thus classed as ‘elite’ they are amateur athletes and obtain the major part of their physical condition from national level competition and training. Jennings and colleagues (2012a) demonstrated that international players perform more high-speed running than their national level counterparts and this observation may be important in this context. This skill factor may also be evident in the competition data presented here. Although absolute predicted aerobic capacity and total distance covered in competition is lower than some previous studies (Aziz *et al*, 2000; Gabbett, 2010b and Jennings *et al*, 2012b) these data show the players covering a greater distance at high speed and producing more high intensity accelerations supporting the notion that high intensity activity differentiates international competition (Jennings *et al*, 2012a). Moreover, these data demonstrate that international players are able to replicate the intensity of competition in small-sided games or use alternative drills to increase volume to ensure an appropriate training stimulus. To reiterate, the training data presented here should be considered in relation to their collection during the tapering phase of preparation for international games.

4.5 Conclusion

The data presented here provides evidence that, although similar to other elite players in some aspects of physical condition, both male and female players from the Scottish international teams are unable to complete the same amount of physical activity. In comparison to other literature male players have poorer aerobic capacities than their international counterparts and cover less overall distance in a match. Female players cover less distance in competition which is likely due to poor speed capabilities rather than aerobic capacity. These nuances may be an artefact of the training that they are subjected to – female players lacked high speed running in the training sessions observed and male players spent a large proportion of time completing tactical/technical drills which were limited to short distances with very little intensity – which were insufficient to stimulate anaerobic and aerobic adaptation respectively.

However, by viewing the drills with absolute, relative and normalised data the evidence presented shows that the current training regimens for field hockey can provide an appropriate stimulus for adaptation. For instance, running drills were shown to be effective at accumulating high speed running when viewed using the normalised data which may have been missed if viewed solely as absolute values due to the lack of time spent completing these drills. The progressive overload required to improve performance (Baechle and Earle, 2000) can be provided in a sports specific manner by using a range of exercise drills. The selection of these drills and their importance within the session can affect the eventual training stimulus and subsequent adaptation.

Furthermore in prescribing appropriate stimuli during a periodised programme it will be necessary to consider how player interactions during small-sided games can influence training intensity. If technical ability limits accumulation of the prescribed high intensity activity during small-sided games then it is necessary to fall back on running drills. It is important to remember that the value of small-sided games will extend beyond physical preparation and they remain an important component to facilitate physical and technical development. It is also important to recognise the contribution that competitive match play makes to physical conditioning.

4.6 Future Direction

The findings here highlight the importance of training drills and their ability to affect the physical condition of players. In addition to this the results show the value of competition as a training stimulus. However players within the Scottish international squads spend three quarters of their season within the sub-elite environment. From this information it would be expected that competition and not training will provide the main conditioning stimulus for these players. The ability of sub-elite competition to stimulate the same aerobic and anaerobic energy producing systems and elicit the same speed profiles as elite field hockey is unknown. Considering this type of comparison will require FG analysis due to the likelihood of players having different exercise and rest times (rotations will not follow exactly the same timings across such a wide group of teams and players). In attempt to consider the impact of sub-elite hockey on physical activity competition at a sub-elite level needs to be observed.

5. Comparison of Elite and Sub-Elite Field Hockey Competition

5.1 Introduction

In the previous Chapter it was shown that both male and female elite players in the Scottish national team were unable to match the physical demands during competition of elite teams published in the literature. The difference between standards within the same level of a sport has been shown before (Mohr, Krustrup and Bangsbo, 2003). This study showed, in a group of professional soccer players, that the ranking of the respective teams (top-class and moderate-class) had an impact on a player’s ability to perform high intensity running. This is a logical finding as every league or tournament has top ranked teams fighting to win titles and bottom ranked teams who struggle to compete. The Scottish team sit in the middle of the world rankings with ambitions of competing with the top ranked nations.

The ranking phenomenon is more apparent when comparing elite to sub-elite players. This has been reported in a number of studies on different sports (Sirotic, Coutts, Knowles and Catterick, 2009; Brewer, 2010 and Scanlan, Dascombe and Reaburn, 2011) and within field hockey competition (Jennings *et al*, 2012a). A common theme amongst these studies is a greater amount of high speed running during elite level competition. Jennings and colleagues (2012a) showed elite players in one of the highest ranked teams in male field hockey had 10.1 % better aerobic capacity than sub-elite players, 13.9 % more distance covered and 42 % more high speed running during matches.

It has been suggested in the previous Chapter the elite players in Scotland spend three quarters of their season in the sub-elite environment. Further to this, it is expected that the main conditioning stimulus they are subjected to comes in the form of competition (assuming that training is of a lower intensity as reported in the previous Chapter and in the majority of literature presented). As such the players get the majority of their conditioning from sub-elite competition. Further to this, it is a common concern that players will drop their standards to suit the sub-elite level - and/or utilise different energy systems - and as a result become de-conditioned for elite level competition. This is of great concern for international teams who are already lowly ranked and have players who are poorer conditioned than the elite level in their sport – like the Scottish players in the previous Chapter.

This investigation aims to gather information on the physical activity demands of sub-elite competition in comparison to those reported in the previous Chapter. It is expected that the physical activity of players during sub-elite field hockey will be lower, especially for high speed exercise, than found in the elite level. However due to the lower condition of the elite players studied it is expected that the differences will not be as marked as those shown by Jennings and colleagues (2012a).

5. 2 Methods

5.2.1 Subjects

Sixteen elite male field hockey players (age range: 25 ± 4 yrs), seventeen elite female players (age range: 25 ± 3 yrs), one-hundred and thirty one (n = 103) sub-elite male players (age range: 25 ± 4 yrs), and one hundred and eight (n = 108) female field hockey players sub-elite female players (age range: 26 ± 7 yrs), participated in the study. Elite players were all members of the male and female Scottish National Hockey teams. Sub-elite players were all members of teams in the top domestic competition in Scotland. All participants provided consent for observations – any participants layer under 18 had to provide parental consent to be included in the observations.

5.2.2 Design

In the present study, the physiological demands of elite and sub-elite male and female field hockey were investigated using GPS and inertial sensor technology during competition. National League data was collected on a team-by-team basis (up to 15 players observed from one team in a single game) in 10 games over the course of the season. The author conducted all observations - using the same GPS units throughout the investigation - following the protocols previously outlined (Chapter 3.2). The data is presented in raw format to allow comparison with the previous literature but also relative to the 70 minute playing period (referred to as 'Drill (*per* 70 min)' [(70/drill duration)*variable] described in Chapter 2). The University of Glasgow ethics committee approved all procedures.

5.2.3 Equipment

The Catapult MinimaxX 5 Hz GPS system was used for all recordings (MinimaxX, Catapult Innovations, Melbourne, Australia). All protocols are described in the methodology Chapter (Chapter 2).

5.2.4 Environmental Conditions

Games were played in three different countries: Scotland (SCO), Ukraine (UKR) and Ireland (IRE). Games in SCO and IRE games were played in a temperate climate (~ 14 °C) and the other games were played in a warmer climate in UKR (~ 19 °C). All games were played on water based Astroturf and away from overhead obstructions. A total of 12 pitches were used for testing. Satellite signal strength (range 9.5 ± 1.5 to 12.3 ± 1.0) and horizontal dilution of position were strong (range 1.0 ± 0.4 to 1.3 ± 0.4).

5.2.5 GPS Analyses

Data was downloaded, analysed and reported using Logan Plus v4.4.0 analysis software as has been previously described (Chapter 2).

5.2.5.1 Competition Analyses

A total of seventy-three male and forty-one female elite level competition analyses were completed. Each player was observed at least once (some players analysed in all games) in eight competitive games against seven teams ranked between 2 and 32 in the FIH World Rankings 2011 (male) and five competitive games against 3 teams ranked between 11 and 29 in the FIH World Rankings 2011 (female). A total of one-hundred and thirty-one male and one-hundred and eight female sub-elite competition analyses were completed during nine male and nine female games in the Scottish National League. Each player was observed once.

5.2.6 Statistical Analyses

One-way ANOVA and Tukey confidence interval tests were performed and one sample t-tests were used for post hoc analysis of continuous data e.g. distance, relative distance, Player Load, percentage distance and percentage time). Mann-Whitney and Poisson rate tests were used for post-hoc analysis of other variables (e.g. number of efforts in speed or acceleration zones). Differences were calculated from 95% confidence intervals of difference (FG – TOP). Effect sizes were calculated using Cohens *d* test [ES = (Δ Mean)/Pooled SD] using the methodology presented by Cohen (1988), and magnitudes reported by Batterham and Hopkins (2006) and Hopkins (2009). Magnitudes were: trivial = < 0.2, small 0.2 – 0.6, moderate = 0.6 – 1.2, large = 1.2 to 2, very large = 2.0 – 4.0 and extremely large > 4. Statistical significance was taken as $P \leq 0.05$ and all data are reported as mean and 95 % CI unless otherwise stated.

5.3 Results

5.3.1 Male Elite and Sub-Elite Competition

The total duration of elite and sub-elite competition is similar (see Table 5.1; $P > 0.969$). Rest time was greater in elite competition (20 (19 to 22) min vs. 14 (12 to 17) min; elite versus sub-elite respectively; $P \leq 0.001$) resulting in less exercise time (54 (53 to 56) min vs. 60 (58 to 63) min; elite versus sub-elite respectively; $P \leq 0.001$) and exercise-to-rest ratio (0.24 (0.22 to 0.25) vs. 0.27 (0.25 to 0.30); elite versus sub-elite respectively; $P \leq 0.015$).

	Duration (min)	Rest Time (min)	Exercise Time (min)	E:R Ratio
Elite	75 (74 to 76)	20 (19 to 22)[a]	54 (53 to 56)	0.24 (0.22 to 0.25)
Sub-Elite	75 (74 to 76)	14 (12 to 17)	60 (58 to 63)[a]	0.27 (0.25 to 0.30)[b]

Table 5.1. Duration, rest time, exercise time and exercise-to-rest ratio during elite and sub-elite male competition. Data are mean and 95% confidence intervals. [a]Data significantly greater than other level of competition, $P \leq 0.001$ [b]Data significantly greater than other level of competition, $P \leq 0.05$

Absolute data shows sub-elite competition produces greater total distance (5868 (5718 to 6018) m vs. 6575 (6265 to 6886) m; elite versus sub-elite respectively; $P \leq 0.001$). However Player Load, efforts over 15, 18 and 23 km·hr^{-1}, absolute accelerations are similar ($P = 0.367$, $P = 0.525$, $P = 0.530$, $P = 0.056$; 15, 18 and 23 km.hr^{-1}, absolute accelerations respectively). Mean maximum velocities were higher in elite level competition [27.3 (27.0 to 27.7) km·hr^{-1} vs. 26.2 (25.9 to 26.5) km·hr^{-1}; elite versus sub-elite respectively; $P \leq 0.001$].

Table 5.2 shows the relative distance (distance per minute) for elite and sub-elite competition. Sub-elite competition had greater relative distance [78 (76 to 81) m·min^{-1} vs. 88 (84 to 92) m·min^{-1}; elite versus sub-elite respectively; $P \leq 0.001$]. Similarly, normalised distance was greater in sub-elite competition [5405 (5337 to 5617) m vs. 6132 (5852 to 6413) m; elite versus sub-elite respectively; $P \leq 0.001$].

	Elite	Sub-Elite	Cohens *d*	Effect Size
Absolute Distance (m)	5868 (5718 to 6018)	6575 (6265 to 6886)[a]	-0.52	Small
Relative Distance ($m \cdot min^{-1}$)	78 (76 to 81)	88 (84 to 92)[a]	-0.02	Trivial
Drill (*per* 70mins)	5405 (5337 to 5617)	6132 (5852 to 6413)[a]	-0.58	Small
Player Load	631 (602 to 661)	649 (615 to 683)	-0.49	Small
Efforts >15 $km \cdot hr^{-1}$	70 (67 to 73)	73 (69 to 77)	-0.06	Trivial
Efforts >19 $km \cdot hr^{-1}$	28 (27 to 30)	27 (25 to 29)	0.07	Trivial
Efforts >23 $km \cdot hr^{-1}$	7 (7 to 8)	7 (6 to 8)	0.10	Trivial
Max Speed ($km \cdot hr^{-1}$)	27.3 (27.0 to 27.7)[a]	26.2 (25.9 to 26.5)	0.66	Moderate

Table 5.2. Absolute distance, relative distance and normalised distance [Drill (*per 70 mins*)], Player Load (Accumulated accelerations), efforts over 15, 19 and 23 $km \cdot hr^{-1}$ and maximum speed during elite and sub-elite male competition. Data are mean and 95 % confidence intervals and Cohens *d* Effect Size of difference. [a]Data significantly greater than other level of competition, $P \leq 0.001$

Figure 5.1 displays the percentage distance covered in different speed thresholds. Sub-elite players cover more distance walking [27 (25 to 29) % vs. 30 (28 to 31) %; elite versus sub-elite respectively; $P \leq 0.05$]. Jogging, low and moderate speed running were similar at both levels [28 (27 to 29) % vs. 28 (28 to 29) %; 23 (22 to 25) vs. 23 (22 to 24) %, 14 (13 to 15) % vs. 13 (12 to 14) %; elite versus sub-elite jogging, low and moderate speed running respectively; $P = 0.165$, $P = 0.110$, $P = 0.115$]. However, the percentage distance covered high speed running and sprinting was higher in elite competition [6 (5 to 6) % vs. 5 (5 to 5) % and 2 (2 to 2) % vs. 2 (1 to 2) %; $P = 0.046$ and $P = 0.039$; elite versus sub-elite high speed running and sprinting respectively].

	Absolute (number)	Drill (*per* 70mins)
Elite	20 (17 to 23)	19 (16 to 22)
Sub-Elite	25 (22 to 28)	23 (20 to 27)

Table 5.3. Absolute and normalised [Drill (*per 70 mins*)] acceleration efforts during elite and sub-elite male competition. Data are mean and 95% confidence intervals. [a]Data significantly greater than other level of competition, $P \leq 0.001$

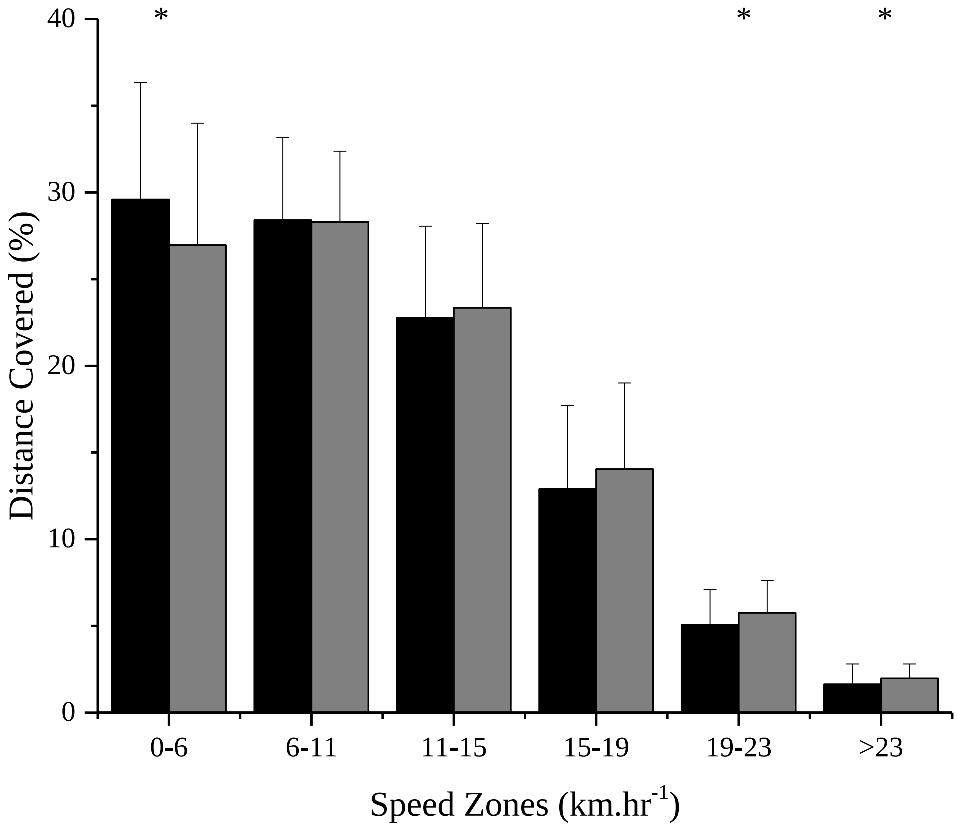

Figure 5.1. Percentage distance covered in specified speed zones during elite (grey columns) and sub-elite (dark columns) male competition. Data are mean ± SD. *Data significantly greater than other level of competition, $P \leq 0.05$

5.3.2 Female Elite and Sub-Elite Competition

Table 5.4 shows the total duration was greater in elite level competition [75 (74 to 75) min vs. 73 (72 to 73) mins; $P > 0.05$]. Similarly rest time was greater in elite competition [18 (16 to 20) min vs. 13 (10 to 16) min; elite versus sub-elite respectively; $P \leq 0.001$] resulting in similar exercise time [56 (54 to 59) min vs. 60

(57 to 62) min; elite versus sub-elite respectively; $P > 0.05$] and exercise-to-rest ratio [0.21 (0.19 to 0.22) vs. 0.23 (0.21 to 0.25); elite versus sub-elite respectively; $P > 0.05$].

	Duration (min)	Rest Time (min)	Exercise Time (min)	E:R Ratio
Elite	75 (74 to 75)[a]	18 (16 to 20)[a]	56 (54 to 59)	0.21 (0.19 to 0.22)
Sub-Elite	73 (72 to 73)	13 (10 to 16)	60 (57 to 62)	0.23 (0.21 to 0.25)

Table 5.4. Duration, rest time, exercise time and exercise-to-rest ratio during elite and sub-elite female competition. Data are mean and 95% confidence intervals. [a]Data significantly greater than other level of competition, $P \leq 0.001$

Absolute data shows total distance were similar for both levels (see Table 5.5; $P > 0.05$). Similarly Player Load, and efforts over 14 $km \cdot hr^{-1}$ (see Table 5.6; $P > 0.05$). Efforts over 18 and 21 $km \cdot hr^{-1}$ were greater in elite level competition [22 (19 to 25) vs. 17 (16 to 19) and 6 (5 to 8) vs. 4 (3 to 5); elite versus sub-elite respectively; $P \leq 0.001$]. Additionally mean maximum velocities were higher in elite level competition [23.8 (23.3 to 24.3) $km \cdot hr^{-1}$ vs. 22.8 (22.4 to 23.2) $km \cdot hr^{-1}$; elite versus sub-elite respectively; $P \leq 0.001$].

	Elite	Sub-Elite	Cohens *d*	Effect Size
Absolute Distance (m)	5625 (5417 to 5833)	5931 (5600 to 6261)	-0.23	Small
Relative Distance ($m \cdot min^{-1}$)	75 (73 to 78)	82 (77 to 86)	0.32	Small
Drill (*per* 70mins)	6992 (6872 to 7111)[a]	5724 (5410 to 6039)	1.60	Large
Player Load	665 (629 to 700)	609 (570 to 647)	-0.37	Small
Efforts >15 $km \cdot hr^{-1}$	70 (65 to 76)	64 (59 to 69)	0.13	Trivial
Efforts >19 $km \cdot hr^{-1}$	22 (19 to 25)[a]	17 (16 to 19	0.43	Small
Efforts >23 $km \cdot hr^{-1}$	6 (5 to 8)[a]	4 (3 to 5)	0.28	Small
Max Speed ($km \cdot hr^{-1}$)	23.8 (23.3 to 24.3)[a]	22.8 (22.4 to 23.2)	1.63	Large

Table 5.5. Absolute distance, relative distance and normalised distance [Drill (*per 70 mins*)], Player Load (Accumulated accelerations), efforts over 15, 19 and 23 $km \cdot hr^{-1}$ and maximum speed during elite and sub-elite female competition. Data are mean and 95% confidence intervals and Cohens *d* Effect Size of difference. [a]Data significantly greater than other level of competition, $P \leq 0.001$

Table 5.5 shows the relative distance for elite and sub-elite competition which were similar for both levels ($P > 0.05$). However, normalised distance was greater in elite competition [6992 (6872 to 7111) m vs. 5724 (5410 to 6039) m; elite versus sub-elite respectively; $P \leq 0.001$].

Figure 5.2 displays the percentage distance covered in different speed thresholds. Sub-elite players cover more distance walking [30 (29 to 31) % vs. 34 (33 to 35) %; elite versus sub-elite respectively; $P \leq 0.001$]. Jogging and low speed running were similar at both levels [28 (24 to 32) % vs. 28 (26 to 30) % and 26 (25 to 27) vs. 26 (25 to 26) %; elite versus sub-elite jogging and low speed running respectively; $P > 0.05$]. However, the percentage distance covered moderate speed running, high speed running and sprinting was higher in elite competition [14 (13 to 15) % vs. 12 (11 to 12); 4 (4 to 5) % vs. 3 (3 to 3) % and 2 (1 to 2) % vs. 1 (1 to 1) %; elite versus sub-elite high speed running and sprinting respectively; $P \leq 0.001$].

	Absolute (number)	Drill (*per* 70mins)
Elite	18 (14 to 22)	23 (18 to 26)
Sub-Elite	17 (15 to 20)	17 (14 to 19)

Table 5.6. Absolute and normalised [Drill (*per 70 mins*)] acceleration efforts during elite and sub-elite female competition. Data are mean and 95% confidence intervals. [a]Data significantly greater than other level of competition, $P \leq 0.001$

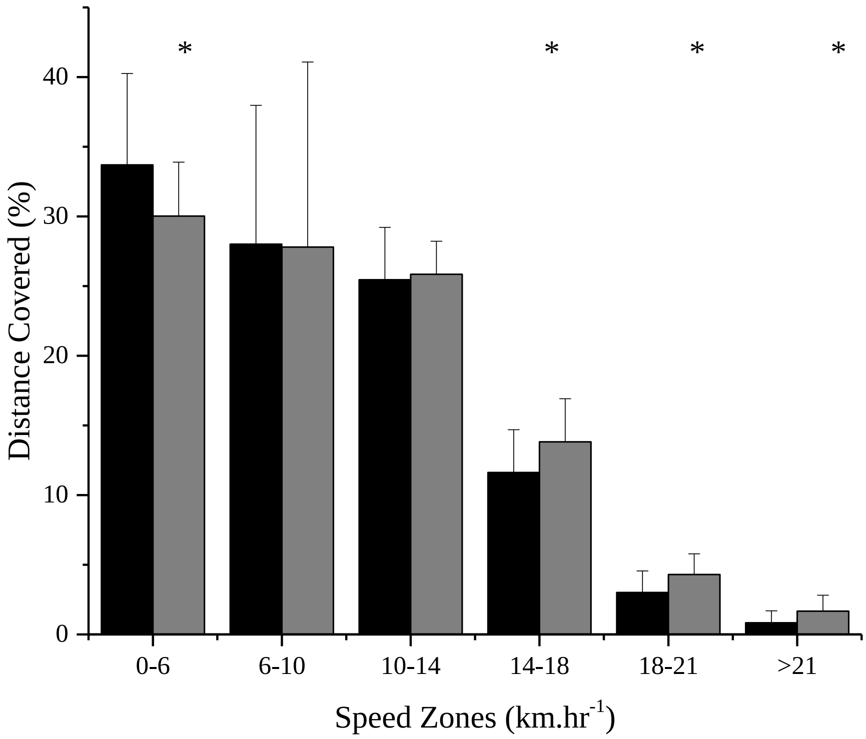

Figure 5.2. Percentage distance covered in specified speed zones during elite (grey columns) and sub-elite (dark columns) female competition. Data are mean ± SD. [*]Data significantly greater than other level of competition, $P \leq 0.05$

5.4 Discussion

The findings from this study show that the overall physical activity as described by the total distance covered during international games is different for both genders - male elite players covered a lower distance than their sub-elite counterparts whereas female elite players covered more. This finding in elite male players is different from the one reported by Jennings and colleagues (2012a) which showed that elite players covered 13.9 % more distance during competition. Two possible reasons for this difference are the increased exercise duration of sub-elite players versus elite players in our study – it is a logical assumption that greater playing time results in greater distance covered – and the better overall condition of the Australian players as shown by greater distance covered (9776 ±720 m and 8589 ±623 m for elite and sub-elite matches, respectively). In agreement with Jennings and colleagues are the findings of female players in this study. Elite female players covered ~ 18 % more distance (when normalised for 70 minute playing period). However the absolute distances were similar due to equal exercise times for both levels. This finding highlights the importance of exercise time on overall volume of exercise. Unfortunately Jennings and colleagues don't report overall exercise time at each level but it might be assumed by our findings that this was similar for both levels.

The in-season period in sub-elite competition is long for most team sports. This has been shown to have a negative impact on the physical condition of the athletes involved. Gabbett (2005) showed that maximal aerobic power and muscular power were both reduced towards the end of the competitive season due to the increased volume of games and reduced training time. It has been suggested that this phenomenon can be curtailed by the use of sport specific practices and strength and conditioning programmes (Silvestre *et al*, 2006 and Aughey, 2011). However sub-elite teams seldom have access to appropriate periodised strength and conditioning programmes due to a lack of funding at this level meaning that deconditioning is a real issue for this population. A further issue for elite players is the timing of their international competition which usually follows the end of the sub-elite season. If players are subjected to low intensity physical activity during games and are potentially deconditioned off the back of a long season they are far from the physical condition required to play elite competition.

Field hockey has been consistently described as a high intensity intermittent sport in the literature (Johnston *et al*, 2004; Spencer *et al*, 2004 and 2004b; Spencer *et al*, 2005; Lythe and Kilding, 2011 and Jennings *et al*, 2012a and 2012b). To allow for repeated bursts of high intensity activity low intensity recovery periods are required. If playing for the whole period, 95 % of these recovery periods have been shown to be active in nature (Spencer *et al*, 2004b). Thus increasing your distance covered at low speeds and total distance covered for the match. The elite competition reported in this study had longer periods of absolute rest on the bench - male six minutes and female five minutes more rest - than players in sub-elite competition (NB. only male rest time was statistically significant). If sub-elite players spend the majority of their time during this 'rest' period moving at between 6 and 10 $km \cdot hr^{-1}$ (82 % of active recovery at walking and jogging speeds in Spencer *et al's* study) an extra 500 – 1000 m will be covered which is similar to the difference in normalised distance shown in the female elite and sub-elite groups. Although this may not be as important compared to additional high intensity exercise it would still result in an increased energy expenditure of and subsequently increased glycogen usage (Greiwe and Kohrt, 2000 and de Silva, Fernandes and Fernandez, 2008).

The utilisation of the unlimited substitution rule in field hockey and its impact on physical outputs of players has been studied previously (Jennings *et al*, 2012b and Lythe and Kilding, 2013). In these two studies contradictory findings have been shown: Jennings reported that high numbers of rotations increased high intensity efforts throughout a game whereas Lythe and Kilding reported no change to physical outputs but more interactions in the game. However it is apparent that rest periods allow for phosphocreatine (PCr) resynthesis (Reilly, 1997) and as such it is logical to suggest that increased rest periods off the field will allow for increased recovery and more high intensity efforts. Players are provided this luxury when playing elite level competition however due to poorer use of the rolling substitution rule – limited number of interchanges and increased time on pitch - sub-elite players must get their rest whilst on the field. This causes a greater reliance on aerobic mechanisms (Tomlin and Wenger, 2001) and more low and moderate speed exercise.

Although total distance has been shown to be a discriminating factor between elite and sub-elite team sport players (Sirotic, Coutts, Knowles and Catterick, 2009; Brewer, 2010 and Scanlan, Dascombe and Reaburn, 2011) the difference in high speed exercise has been reported as the main differentiating variable (Jennings *et al*, 2012a). It is not dissimilar in this group where both male and female elite players covered more distance high speed running and sprinting. As has been described, this is likely due to the increased rest time given to elite players. However the ability for sub-elite players to meet the thresholds set may be the overriding issue - sub-elite male players had maximum velocities of 26.2 km·hr^{-1} and female players 22.8 km·hr^{-1}. Compared to the elite players in this group they were both significantly less which is further amplified by the fact that the elite players are far slower than other players in the literature (Gabbett, 2010b and Lythe and Kilding, 2011).

The differences in elite and sub-elite field hockey are fairly well understood, elite players have been shown to have greater aerobic capacities, greater total distance covered and more high speed running (Sirotic, Coutts, Knowles and Catterick, 2009; Brewer, 2010; Scanlan, Dascombe and Reaburn, 2011 and Jennings *et al*, 2012a). This has been shown to be largely true in this study – especially within the female population. However greater exercise time resulting in greater distance by sub-elite males questions at least one of these assumptions. On the other hand, high speed running and maximum velocities are lower in both sub-elite genders and highlight this as one area separating the levels.

Additionally the impact of the other players and teams within the sub-elite environment may have an influential effect on the results presented. For example it has been shown in soccer that the total distance covered and distances at running speeds from 0 to 21.1 km·hr^{-1} in competition are affected by the level of the opposition (Castellano, Blanco-Villasenor and Alvarez, 2011). This study comprised of video analysis – by Amisco software which has been shown to be a valid and reliable measure of total distance (Randers, Mujika, Hewitt, Santisteban, Bischoff, Solano, Zubillaga, Peltola, Krustrup and Mohr, 2010) – during Spanish La Liga games with 434 games reviewed. The results reported that higher amounts of activity were completed against the top ranked teams compared to the middle and lower ranked teams. The sample size and consistency of results reported illustrates that this is a definite consideration for any time motion analysis study. As such it may be a limiting factor for this study and one which needs to be assessed to allow for more appropriate conclusions to be made regarding the conditioning stimulus of sub-elite competition. Furthermore, it poses the question of the regularity of the conditioning stimulus if the league in which you play has a wide range of playing standards.

5.5 Conclusion

The differences between levels (top elite, elite and sub-elite) are conclusive but the reason for these differences is less well defined. This study displays the differences in physical activity between two levels (and other literature) and the ability of elite players to produce more high speed efforts. Further to this, the results highlight the impact of duration and rest time on physical activity demands, namely total distance covered, of players at both levels. Greater rest times allow the opportunity to pace for shorter periods producing more high speed work and less walking on the field. However tactical and technical differences and contextual effects are not considered.

Interestingly, the elite$_{SE}$ players are conditioned to maintain activity throughout a match which is converse to what they do during international competition. This begs the questions – does club competition negatively affect physiological condition and do the energy systems of these players become conditioned to switch to aerobic energy production and worsen their ability to use anaerobic mechanisms? For instance it is known that endurance exercise training improves fat oxidation and aerobic energy production (Horowitz and Klein, 2000). As such if elite$_{SE}$ players are playing longer periods during competition will they begin to produce adaptations which will lend themselves more to aerobic exercise. This will largely be determined by the level of competition and the standard of opposition as this has been shown to effect the intensity of game play (Castellano, Blanco-Villaseñor, and Alvarez, 2011).

5.6 Future Direction

The lack of consideration for tactical/technical and contextual variables in this study is highlighted by the physical activity (distance covered) of elite players being less than that of sub-elite players and more similar to other elite teams in the published literature (Lythe and Kilding, 2011). Furthermore, the effects of duration on the physical activity of female player's questions the impact of rolling substitutions and pacing strategies implemented at each level. If elite players gain the majority of their conditioning in the sub-elite environment differences due to opposition, tactics, and pacing strategies may produce inappropriate adaptations. As such the effects of opposition on physical demands in competition and training must be reviewed as well as the different pacing strategies employed at each level.

6. Opposition and Ranking Effects on Physical Activity of Competition and Training

6.1 Introduction

The physical outputs of players in elite and sub-elite field hockey have been reported in the previous Chapters. However tactics, technical ability and contextual variables were not considered. The results displayed have shown that there is a difference in physical outputs of elite players and sub-elite players and that elite players may be inappropriately conditioned in the sub-elite environment.

Player conditioning in team sports is complicated because of the need to develop or maintain athletic ability along with technical/tactical skills and the concomitant demands of competition over a long playing season. To enable appropriate exercise prescription it is necessary to understand the factors that influence physical demands in competition and the training load that results from specific drills. The aim of the present study was, therefore, to describe the direct effects of opposition and team ranking on the physical demands of field hockey competition and to establish whether team ranking (and by inference skill and physical capacity) has an influence on the exercise intensity achieved during training.

Recent studies suggest that circumstances, such as the quality of opposition and match status, can influence competitive performance (Taylor, Mellalieu, James and Shearer, 2008; Lago, 2009 and Sampaio, Lago, Casais and Leite, 2010). Potential relationships have been identified that link the perceived quality of opposition and possession strategies in soccer (Lago, 2009), the course of a tennis match (O'Donoghue, 2009), volleyball performance (Marcelino, Mesquita and Sampaio, 2010) and the number and outcome of game actions in netball (O'Donoghue, Mayes, Edwards and Garland, 2008). However, a consistent influence has not been demonstrated, largely due to differences in analysis procedures. Indeed, the opposition is not usually considered directly and rather teams are categorized as 'successful' or 'unsuccessful' through their ranking at a particular competition (Grant, Williams and Hocking, 1999) or by symmetric division of their end-of-season league classification (Marcelino, Mesquita, Castro and Sampaio, 2008; O'Donoghue *et al*, 2008 and Taylor *et al*, 2008).

Furthermore, the available literature has tended to examine such effects only in competition and generally disregarded the effects of physical or technical ability on performance during training. Such effects could be important in the planning of training prescription because individuals or small groups might influence the team's ability to achieve the intended intensity for team sport specific exercises. The aim of the present study was, therefore, to assess the direct effects of opposition and team ranking on the physical demands in field hockey competition and then to establish whether team ranking influences exercise intensity during training.

6.2 Methods

6.2.1 Subjects

One hundred and eight (n = 108) female field hockey players (age 16 - 39 yrs) participated in the study. Athletes were all members of the Scottish National League One Hockey teams. All participants had completed a pre-season training programme, were in the competitive phase of their season and were in good physical condition and free from injury at the time of the study. All participants provided consent for observations – any participants player under 18 had to provide parental consent to be included in the observations.

6.2.2 Design

In the present observational study, the physiological demands of field hockey were investigated using GPS and inertial sensor technology during competition and training over a competitive national league season. The data is presented in raw format to allow some comparison with the previous literature but is also expressed relative to the notional 70 minute playing period in field hockey competition (referred to as 'Drill (per 70 min)' [(70/drill duration)*variable]). The University of Glasgow ethics committee approved all procedures.

6.2.2.1 Opposition Effects on Competition

One team in the first division of the Scottish National field hockey league who had placed in the middle of the table the previous season (2011 - 12) was selected to study the effect of opposition ranking on the physical demands of competition in the subsequent season (i.e. establishing how the mid ranked team's movement patterns were influenced by the opposing team ranking so that the data presented are for that team played against all available opposition in rank order). A total of 16 female field hockey players (age range 19 - 35 yrs) were studied over eight separate games against all other teams in their league (resulting in seventy-eight player analyses as some did not play every match). Common markers of game play intensity for individual players (e.g. distance covered, relative distance, Player Load, efforts in speed zones, percentage time in speed zones and distance covered in speed zones) were compared in competitive matches. League position after completion of eight matches in the season studied determined team rankings. The league has a significant element of competition with the National championship, entry to European club hockey competition and relegation at stake.

A critical component of this study was the team rank allocated during the first part of the season. The mid-placed team was chosen on the basis of their league position obtained in the previous season and at the time of ranking (after completion of eight matches) the pre-selected team was placed 5th from 9 teams in the league. At the end of the competitive season (on completion of sixteen matches) the mid-placed team chosen at the start of the season finished in 5th place. In the subsequent season, the same team finished the league competition in sixth from ten teams and demonstrates that over three separate competitions and through the season studied that this team chosen was a valid choice for a mid-ranking team.

6.2.2.2 Ranking Effects on Competition

10 teams in the first division of the Scottish National field hockey league were selected to study the effect of league ranking on the physical demands of competition. One hundred and eight (n = 108) female field hockey players (age 16 - 39 yrs) were studied during one half of the season 2011 - 12. All analysis including team ranking occurred after the end of the season. Markers of game play intensity (e.g. distance covered, relative distance, Player Load, efforts in speed zones, percentage time in speed zones and distance covered in speed zones) were compared in competitive matches (i.e. to determine whether team movement patterns were independent of the opposing team). League position after completion of eight matches in the season studied determined

team rankings. The first and second teams ranked at this stage subsequently finished the season in the same positions when ranked (and were either winners or runners up in the preceding and subsequent competitions). The two lowest ranked teams finished the season as ranked after eight matches and both teams were promoted to this competition in the preceding competition and relegated for the next. This demonstrates that over three separate competitions and through the season studied that the teams chosen were a valid choice for a top and lowest ranking teams.

The league has a significant element of competition with the National championship, entry to European club hockey competition and relegation at stake. The ranking was performed after eight matches because of the league structure where there is a mid-winter break and the teams play each other twice (once before and once after the break).

6.2.2.3 Ranking Effects on Training

Forty eight small-sided games (SSG) analyses from five teams were observed (n = 48) during training sessions in season 2011 - 12. Due to the observational nature of this study coaches were not advised on what drills to carry out and as such no other teams observed completed SSGs practices during the training sessions observed. All analysis including team ranking occurred after the end of the season. SSGs where conducted with pitch dimensions between 27.5 x 22.9 m and 27.5 x 45.7 m. Rest periods within each drill were retained (to replicate the competition analysis where only the half time rest period was omitted). Markers of game play intensity (e.g. distance covered, relative distance, Player Load, efforts in speed zones, percentage time in speed zones and distance covered in speed zones) were compared in SSGs to determine whether movement patterns were dependent on the team ranking.

6.2.3 Equipment

The Catapult MinimaxX 5 Hz GPS system was used for all recordings (MinimaxX, Catapult Innovations, Melbourne, Australia). GPS Analyses were completed using the methodology described in Chapter 2.

6.2.4 Environmental Conditions

Games and training were based in Scotland (SCO) with a temperate climate (~ 14 °C). All activities took place on water based Astroturf pitches and away from overhead obstructions. Satellite signal strength (11.2 ± 1.3) and horizontal dilution of position were strong (0.9 ± 0.2).

6.2.5 GPS analyses

Data was downloaded, analysed and reported using Logan Plus v4.4.0 analysis software. All downloading and reporting of data was carried out immediately post-game by the same observer. All physiological parameters (e.g. speed zones) were standardised.

6.2.6 Statistical Analyses

Spearman rank order correlation and regression analysis was completed on opposition ranking with all other parameters. Teams were ranked from 1st to 9th, but excluded data for the observed team, when assessing opposition effects on competition. In assessing team ranking effect on competition the teams were ranked 1st to 9th and included data from all teams. Finally, the teams were ranked from 1st to 9th when observing the ranking effects on training. Only teams ranked 1st, 4th, 5th, 8th and 9th were included in this analysis because the others did not use SSGs in the observed training session. Statistical significance was taken at $P \leq 0.05$ and data are reported as mean and 95 % confidence interval unless otherwise stated.

6.3 Results

6.3.1 Opposition Effects on Competition

The relationship between opposition ranking and physical performance indicators are shown in Figure 6.1. The team average distance covered by players from the mid-ranked team observed during competition ranged from 6498 (5583 to 7413) m against the top ranked team to 5949 (4726 to 7171) m against the bottom ranked team. However, the greatest team average distance was accumulated in the match against the third ranked opposition at 7719 (7194 to 8224) m. The software derived value Player Load ranged from 771 (629 to 913) AU during competition against the top ranked team to 670 (526 to 814) m against the bottom ranked team. However, greater Player Load values were measured in the match against the third ranked opposition at 883. The average relative distance covered by players from the mid-ranked team ranged from 90 (77 to 103) $m \cdot min^{-1}$ against the top ranked team to 82 (65 to 99) $m \cdot min^{-1}$ against the bottom ranked team. The largest relative distance measurements were observed in the match against the fourth ranked opposition at 103 (93 to 113) $m \cdot min^{-1}$. Spearman rank order correlation analysis demonstrates a strong relationship between team average distance and opposition ranking (Spearman's r = 0.67), relative distance (Spearman's r = 0.68) and Player Load Spearman's r = 0.67).

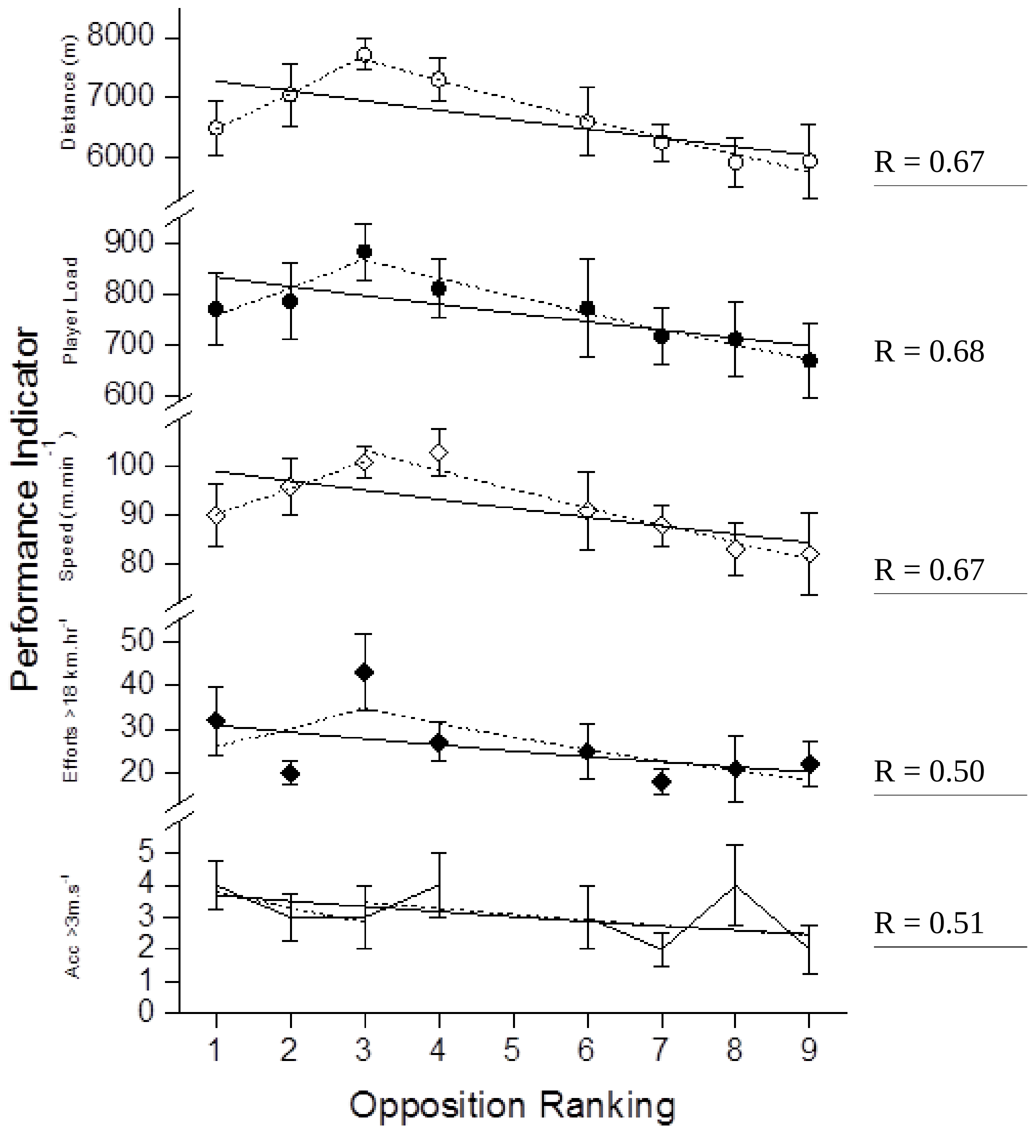

Figure 6.1. The figure illustrates the influence of opposition ranking on common performance indicators during hockey competition. Data are mean ± SD with solid lines indicating the Spearman rank order correlation analysis performed across each data set and the broken lines for subsequent multiple regression analysis. The open circles represent the team average distance covered during competition (m); the closed circles represent the team average for the software derived value for Player Load during competition (AU); the open diamonds represent the team average for the relative distance ($m \cdot min^{-1}$) covered during competition; the closed diamonds represent the team average for the number of high intensity running efforts made (in excess of 18 $km \cdot hr^{-1}$) and the open squares represent the team average for number of high intensity accelerations made (lasting more than 1 second and in excess of 3 $m \cdot s^{-2}$).

Similarly, the number of efforts greater than 18 km·hr^{-1} ranged from 32 (16 to 47) against the top ranked team to 22 (12 to 32) against the bottom ranked team (giving a Spearman's r = 0.50). The greatest number of efforts were accumulated playing against the opposition ranked third at 43 (35 to 60) . The number of accelerations over 3 m·s^{-2} during competition for players from the mid-ranked team ranged from 4 (2 to 5) against the top ranked team to 2 (1 to 4) against the bottom ranked team (Spearman's r = 0.51). These data demonstrate a simple linear relationship albeit relatively weak.

6.3.2 Ranking Effects on Competition

The relationship between team ranking and physical performance indicators during competition are shown in Figure 6.2. In contrast to opposition ranking, there is no substantial relationship between the team rank and physical performance when competition (and therefore opposition) is randomly monitored. For example, the average distance covered by each team ranged from 5177 (4289 to 6065) m in the top ranked team to 5337 (4212 to 6463) m in the lowest ranked team; with the maximum average distance being observed in the seventh ranked team at 7316 (6834 to 7798) m. The strongest relationship with team ranking was observed in the comparison with number of accelerations over 3 m·s^{-2} (Spearman's r = 0.30).

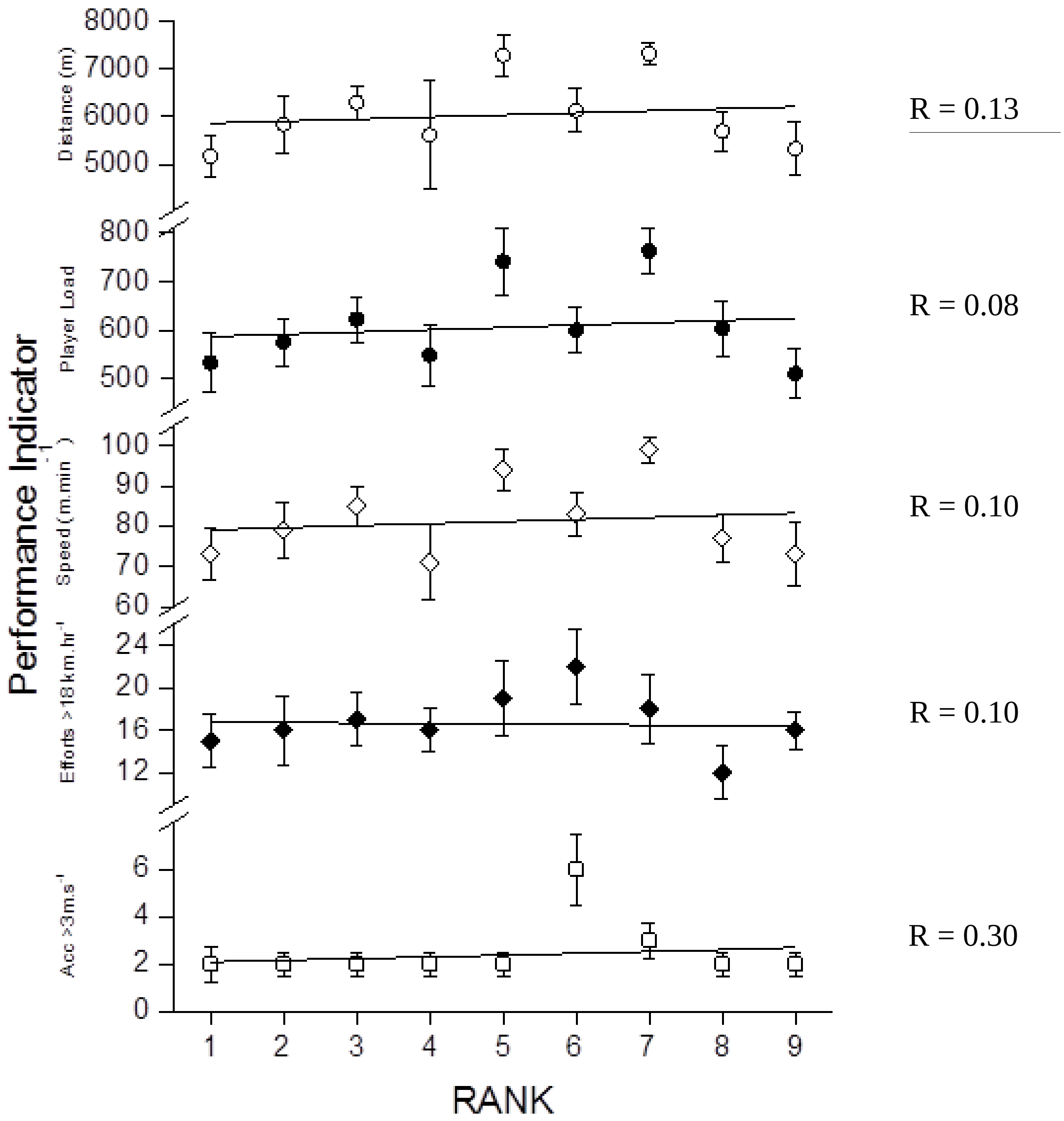

Figure 6.2. The figure illustrates the influence of team ranking on common performance indicators during hockey competition. Data are mean ± SD with solid lines indicating the Spearman rank order correlation analysis performed on each data set. The open circles represent the team average distance covered during competition (m); the closed circles represent the team average for the software derived value for Player Load during competition (AU); the open diamonds represent the team average for the relative distance ($m \cdot min^{-1}$) covered during competition; the closed diamonds represent the team average for the number of high intensity running efforts made (in excess of 18 $km \cdot hr^{-1}$) and the open squares represent the team average for number of high intensity accelerations made (lasting more than 1 second and in excess of 3 $m \cdot s^{-2}$).

6.3.3 Ranking Effects on Training

The relationship between team ranking and physical performance indicators during training are shown in Figure 6.3. The distance covered in small-sided games was highest in the top ranked team 5877 (5501 to 6252) m drill (per 70 min) and lowest in the second lowest ranked team 3551 (3163 to 3936) m drill (per 70 min); the lowest ranked team covered 3943 (2964 to 4919) m drill (per 70 min). The relationship between team ranking and distance covered for drill (per 70 min) was strong giving Spearman's r = 1.00). Similar relationships were established for the derived value of Player Load (Spearman's r = 1.00) and relative distance (Spearman's r = 0.96).

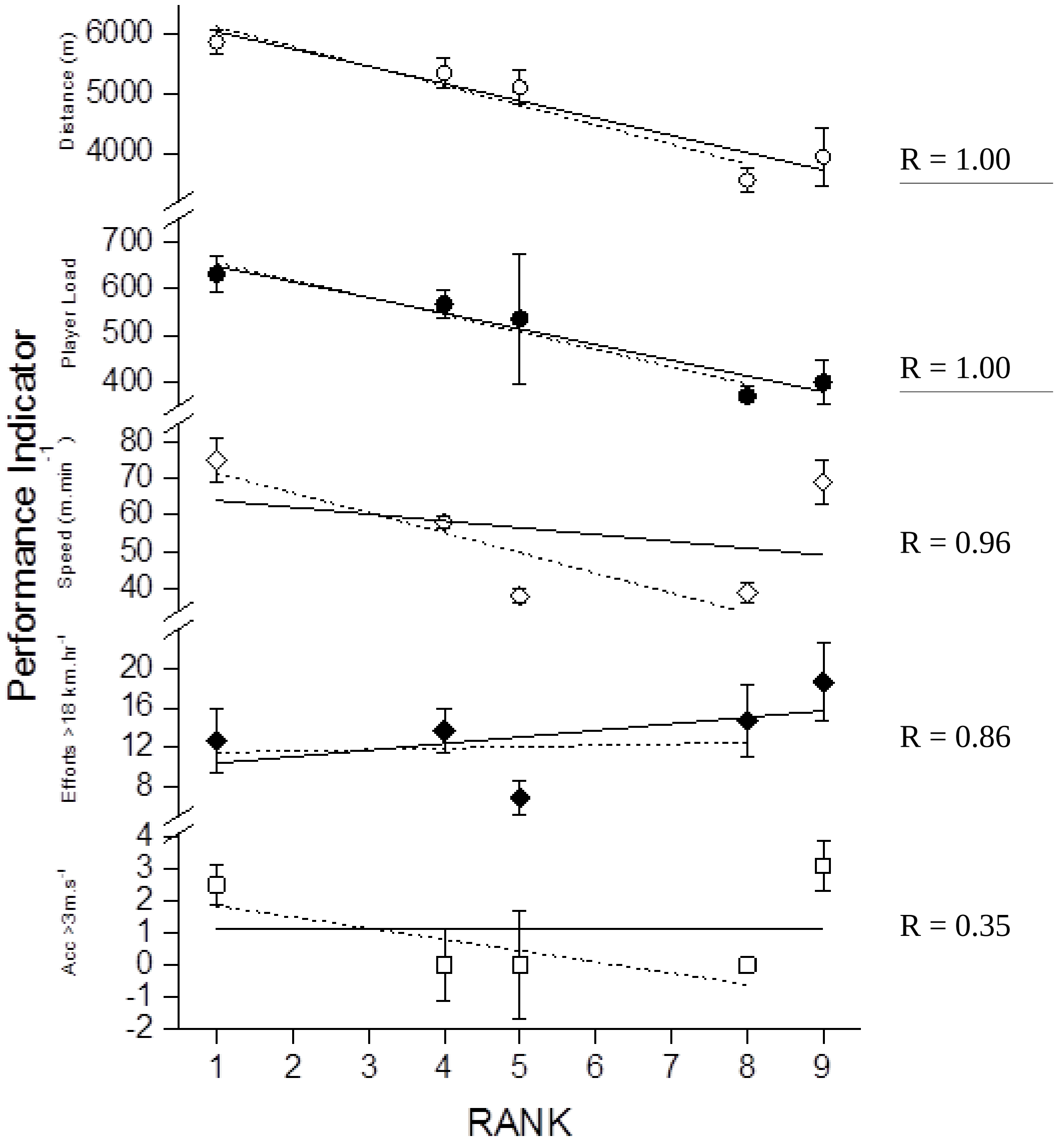

Figure 6.3. The figure illustrates the influence of opposition ranking on common performance indicators during hockey training. Data are mean ± SD (normalised to 'Drill (per 70 min)') with solid lines indicating the Spearman rank order correlation analysis performed on each data set and the broken lines for linear regression analysis omitting the 9th ranked team. The open circles represent the team average distance covered during competition (m); the closed circles represent the team average for the software derived value for Player Load during competition (AU); the open diamonds represent the team average for the relative distance ($m \cdot min^{-1}$) covered during competition; the closed diamonds represent the team average for the number of high intensity running efforts made (in excess of 18 $km \cdot hr^{-1}$) and the open squares represent the team.

The number of efforts at speeds greater than 18 $km \cdot hr^{-1}$ and the number of accelerations over 3 $m \cdot s^{-2}$ when expressed as drill (per 70 min) during the SSGs also showed strong relationships with team ranking. The number efforts over 18 $km \cdot hr^{-1}$ was highest in the lower ranked teams [19 (12 to 28) Spearman's r = 0.86] Similarly, the greatest number of accelerations were observed in the lowest ranked team [3 (0 to 3), Spearman's r = 0.35]. However, a detailed analysis of individual player movement demonstrated that the lowest ranked team performed more activity outside the prescribed playing area in their small-sided games than any of the other teams. The average player excursion outside the pitch area was 1 (1 to 2) for the top ranked team and 4 (2 to 6) for the lowest ranked team.

Since these off pitch excursions will allow the lowest ranked team to accumulate greater distances and efforts through non-specific drill activity the regression analysis was repeated with their data omitted. The relationship between the performance indicators and team ranking improved in all cases except .

6.4 Discussion

Player conditioning in team sports is complicated because of the need to develop or maintain athletic ability along with technical/tactical skills and the concomitant demands of competition over a long playing season. To enable appropriate exercise prescription it is necessary to understand the factors that influence physical demands in competition and the training load that results from specific drills. The aim of the present study was to describe the direct effects of opposition and team ranking on the physical demands of field hockey competition and to establish whether team ranking (and by inference skill and physical capacity) has an influence on the exercise intensity achieved during training. The first part of this study was, therefore, to assess the impact of opposition ranking on common performance indicators associated with TMA using GPS and inertial sensor technology. The data presented here demonstrates that the relationship between physical performance and opposition ranking is not simple. When a mid-ranked team is in competition with other teams of similar or lower rank then they choose or have to 'work' harder covering greater distances. However, when they play against the highest ranked teams their activity patterns change in that they may cover lower distances. It seems logical that this is a strategic choice to reduce physical competition and assume a defensive tactical approach to the game where there is a low chance of winning. Nevertheless, for this mid-ranked team the team average distance covered during the majority of their games is not substantially different from that reported in domestic competition by Gabbett (2010b). Interestingly, however, any relationship between opposition ranking and the number of high speed running efforts or accelerations was less apparent or lost. These data are consistent with the concept that is high intensity activities that determine match outcome or team status rather than distance accumulated over the period of match play e.g. (Jennings and colleagues, 2012a).

Technical and tactical ability are generally considered to be the main determinants for the outcome of a competition. Consequently, a significant focus of research output has been on developing the concept that performance is time and context dependent (McGarry, Anderson, Wallace, Hughes and Franks, 2002; O'Donoghue *et al*, 2008; Marcelino *et al*, 2008; Lago, 2009; O'Donoghue, 2009; Marcelino *et al*, 2010; Sampaio, Lago and Drinkwater, 2010 and Montgomery, Pyne and Minahan, 2010). These data have also addressed these contextual effects of physical performance where we also accept that fatigue is a confounding factor for outcome in the latter stages of team sport and that match status (i.e. whether the team is winning, losing or drawing) will also influence. These contextual responses in the physical demands of game play are likely to have an important impact on training status (i.e. the accumulated training impulse during that period). Furthermore, while empirical evidence supports the notion that the match context will influence performance outcomes it is often based on categorical data where teams are deemed successful or unsuccessful in specific events. However, in such circumstances the categorical data (such as progressing to the final phase of an international tournament) is unlikely to provide any information on the potential impact on a player's physical conditioning. In reality, any significant conditioning due to match play will come via domestic competition (and training) where the potential range of technical/tactical skills and physical capacity will be greater. This also provides a better opportunity to assess the direct effect of rank order on performance indicators (since the final phase of tournament play will tend to match high ranking teams against each other).

This simple observation of an opposition ranking effect has significant implications for the training load that can be acquired through match play during the competitive season in team sports. For the highest ranked team, they will always be playing against teams where they do not need to 'work' at full physical capacity and, importantly, where the opposition may adopt a defensive tactical approach. In such circumstances, any rank effect on physical performance indicators should be lost. The second component of the study investigated this and the data demonstrate that in a random observation of match play during the playing season it is not possible to discriminate team ranking by common performance indicators.

The lack of a team ranking effect will mean that any sport specific conditioning from match play during domestic competition will be limited to a greater extent in the higher ranked teams. Obviously, while their conditioning from match play will, by definition, be appropriate to their domestic competition it may be inadequate in other situations. In European field hockey, like in many other team sports, there is more than just a National championship at stake during domestic competition. For the teams studied here, finishing first or second in their league will gain entry to a European club hockey competition (with tournaments against the best ranked teams from other domestic National leagues). So, while the relative contribution of match play to physical conditioning may be subject to debate, it is irrefutable that an appropriate, periodised, training programme is mandatory for developing or maintaining physical condition. The lack of a team ranking effect in competitive match play will mean that the demands of competition are not under predictable control and are essentially reactive to opposition effects (i.e. contextually dependent on whether the lower ranked teams take a decision to compete or assume a more defensive strategy). Furthermore, the observation of a team ranking effect can also be confounded by the competitiveness of the observed game where a winning team may decide to lower their intensity when there is a high game score differential. In this competition, both the highest ranked teams displayed a very significant positive goal differential (> 80 goals) with the highest game scores achieved against the lowest ranked teams. The distribution of goal difference at the end of the competition generally followed the team rank and is consistent with the lower ranked teams displaying less technical and/or tactical skill based on game outcomes.

It would seem appropriate to assume training load prescription is under more predictable control but given the opposition effects described here it is possible that a similar effect will be observed in game-like training activity. Many previous studies have analysed competition and training load to assess how appropriate the training stimulus is for athletes in a variety of sports (Brewer, Dawson, Heasman, Stewart and Cormack, 2010; Montgomery *et al*, 2010; Casamichana, Castellano and Castagna, 2012 and Gabbett, Abernethy and Jenkins, 2012). In all of these studies, training is found to be performed at a lower relative intensity than is observed in competition. Similar data has been reported for sub-elite male field hockey (Johnston, Sproule, McMorris and Maile, 2004) and elite female field hockey with GPS analysis (Gabbett, 2010b). These data draw the obvious conclusion that training prescription is inadequate across the majority of team sports but have not considered the context in which the training is performed. The last part of this study addresses this issue directly by observing training sessions for the presence of a team ranking effect on the player's physical performance.

From the data available - not all teams played small-sided games during the observed training session - there does seem to be a significant team ranking effect observed for distance related performance indicators. This is consistent with both the other contextual observations within this study because the players within that team are acting as opposition within the small-sided games. The players are of similar ranking and have to compete physically in the small-sided games to achieve the desired outcome (e.g. to score or retain possession). In contrast to distance related indicators, high intensity activities described by the number of high speed running or accelerative efforts did not show the same ranking effect and may argue against a ranking effect. However, although it is high intensity activity that generally decides the outcome of competition or team status e.g. Jennings and colleagues (2012a), it is likely that the constraints of a small playing area will prevent the player's from using these movement patterns.

6.5 Conclusion

The presence of an opposition ranking effect has significant practical implication to exercise prescription for physical conditioning in team sports. For higher ranked teams, the physical demand of game play will be heavily influenced by the strategy employed by their opposition. In predominantly amateur sports, like field hockey, a significant proportion of training stimulus will come from match play. In situations where lesser ranked teams adopt a defensive strategy it will be necessary to provide a greater load from training. While it may seem appropriate to apply this load through game-like activity the presence of the opposition ranking effect needs to be considered. Inclusion of reserve or development squad players in such training drills to 'make up numbers' is likely to reduce the prescribed training impulse. While such activities will remain a useful tool for team sports it may be prudent to include high intensity, intermittent, running to provide an appropriate stimulus as necessary.

6.6 Future Direction

The ranking effects on both competition and training create a problematic situation for the coaches and players in the international set up. Playing domestic field hockey is a necessary part of the periodised programme for elite players due to the lack of international competition all year round. However as this study has shown it may be detrimental to the physiological adaptation of players. As such methods of intervention to improve short term physiological deficits may be required. Furthermore, it may be appropriate to look at interventions to increase the standard of the lower ranked teams to create more closely matched teams and therefore higher intensity games.

7. Pacing Strategies Utilised by Elite and Sub-Elite Field Hockey Players During Competition

7.1 Introduction

The previous Chapter examined the factors that influence the physical demands of competition and the stimulus that results from specific drills in training in an attempt to more appropriately prescribe training. This study showed that there are ranking effects on the physical activity of players in competition and training. However the previous study didn't look into the fatigue of players (specifically a reduction in physical activity), their potential pacing strategies [how an athlete distributes exercises throughout a game (Abbiss and Laursen, 2008)] or the influence of substitutions which may all have an impact on the physical activity of players and the conditioning stimulus they receive from match play.

Each of these areas has been studied in other teams sports. Fatigue during the second half of team sports is a common occurrence due to the prolonged duration of match play and the high intensity nature of competition (Mohr, Krustrup and Bangsbo, 2003; Spencer, Lawrence, Rechichi, Bishop, Dawson and Goodman, 2004; Stølen, Chamari, Castagna and Wisløff, 2005; Cunniffe, Proctor, Baker and Davies, 2009 and Di Salvo, Gregson, Atkinson, Tordoff and Drust, 2009). Previous studies in soccer have shown a decrease in low and high intensity running from 1st to 2nd half and up to a 40 % decrease in intense exercise in the last fifteen minutes of competition (Mohr, Krustrup and Bangsbo, 2003). Unsurprisingly, this decrease in intensity in the last period of a game can have a negative outcome on results.

Further to this pacing strategies have recently been studied in rugby league and have shown the effects of the initial intensity adopted by replacement players on their subsequent physical activity (Waldron, Highton, Daniels and Twist, 2013). Higher intensity activity earlier in their rotation results in reduced intensity in the last period of the game. Similarly in soccer it has been shown that pacing strategies are determined by a players activity in the first half of games and is influenced by the number of substitutions in the game (Bradley and Noakes, 2013). It was also shown that soccer players have reduced activity in the 5 minute period after high intensity activity. These findings suggest that pacing – either consciously or sub-consciously – is of paramount importance to the activity levels of players in the following period of the game and the last period of the game. As field hockey has unlimited substitutions the reduced activity seen post-high intensity activity - like reported in Bradley and Noakes study – can be negated by providing that player with adequate rest in the form of bench time. This may also help to increase the amount of high intensity exercise completed towards the end of the game. These studies, although in other team sports, highlight the importance of substitution strategies in field hockey and questions the impact on physical performance of those currently in use.

A review into the pacing strategies used within sport highlighted the differing strategies which can be adopted during sports lasting less than 30 seconds to those lasting over 4 hours (Abbiss and Laursen, 2008). It is suggested that more prolonged events (> 2 minutes) require even pacing from the beginning of exercise to the finish but suggests that positive pacing (increasing exercise intensity at the end) is potentially beneficial – such as using a sprint finish in running (Abbiss and Laursen, 2008). Field hockey is interesting in this regard as each period may be an all-out effort due to the players knowledge of the ensuing rest period or it may be considered to be prolonged due to the length of total game time. Tucker (2009) reports that pacing is regulated by the brain and that at the beginning of an exercise bout the brain forecasts the duration that can be safely completed using physiological and external information. This model of regulation is based around exercise at a constant workload which limits its application to intermittent sports such as field hockey but it does highlight the ability of the brain to subconsciously decide on exercise intensity to allow for maintenance of performance. Whether the brains of field hockey player decide it will be an all-out effort each period, evenly paced or positively paced is currently unknown. Using GPS data the pattern of a players overall activity may point to the pacing strategies utilised.

The effect of the unlimited substitution rule has not been studied in great detail in the current literature. One doctoral study looked at the effect the number of rotations has on the physical and performance outcomes of strikers (Lythe, 2008). This data showed that substitutions can positively influence sprinting distance in the 2nd half of hockey games. Spencer and colleagues (2004a) studied field hockey competition (not specifically the usage of substitutions) and reported that activity was maintained from first to second half. This is similar to Aughey's study (2013) on AFL players where it was shown that relative intensity – as measured by $m \cdot min^{-1}$ - was not reduced by a practically significant amount due to the rotations used and pacing strategies implemented.

The present study looked at the fatigue patterns, subsequent pacing strategies and physical activity of elite and sub-elite field hockey and specifically of elite players playing in the sub-elite environment. It was hypothesized that sub-elite competition would require less intense physical activity than elite competition thus requiring different pacing strategies. It was also hypothesized that the use of rolling substitutions would alter the pacing strategies of players (either consciously or sub-consciously) producing more high intensity exercise. Finally it was speculated that elite players in sub-elite competition would have different fatigue patterns and pacing strategies due to the increased roles they have within their domestic teams.

7.2 Methods

7.2.1 Subjects

Seventeen elite female players (age range: 25 ± 3 yrs) and one-hundred and eight (n = 108) sub-elite female field hockey players (age range: 26 ± 7 yrs) participated in the study. Of the sub-elite analyses, thirteen (n = 13) players were categorised as elite players playing sub-elite competition (referred to as elite$_{SE}$). Analyses were taken during competitive international and domestics matches. All participants were in good physical condition and free from injury at the time of the study. All participants provided consent for observations – any participants layer under 18 had to provide parental consent to be included in the observations.

7.2.2 Design

In the present study, the physiological demands of elite and sub-elite female field hockey were investigated using GPS analysis during competitive match play. Physical activity parameters were compared between first and second halves of games and across the playing levels. The University of Glasgow ethics committee approved all procedures.

7.2.3 Equipment

The Catapult MinimaxX 5 Hz GPS system was used for all recordings (MinimaxX, Catapult Innovations, Melbourne, Australia). GPS Analyses were completed using the methodology described in Chapter 2.

7.2.4 Environmental Conditions

Games and training were based in Scotland (SCO) with a temperate climate (~14°C). All games were played on water based Astro Turf pitches away from overhead obstructions. In total, 11 pitches were used – 10 in Scotland and 1 in Ireland. Satellite signal strength (10.3 ± 1.2 to 12.3 ± 1.0 satellites) and horizontal dilution of position were strong (1.0 ± 0.4 to 1.3 ± 0.4).

7.2.5 GPS Analyses

Forty-one elite level analyses (n = 41) were collected over five games and one hundred and eight (n = 108) sub-elite level analyses were collected over a total of nine games. Data was downloaded, analysed and reported using Sprint analysis software as described in Chapter 2. Sprint has been developed to work alongside the Catapult MinimaxX system.

7.2.6 Statistical Analyses

Initial one sample T-Tests were performed on each parameter. One-way ANOVAs and Tukey confidence interval tests were performed and used for post-hoc analysis of continuous data (*e.g.* distance, relative distance and Player Load). Differences were quantified using one sample t-tests of difference and reported as 95 % confidence intervals. Statistical significance was taken as $P \leq 0.05$ and all data are reported as mean and 95 % CI unless otherwise stated.

7.3 Results

The amount of fatigue present from first to second half during competition in elite, sub-elite and elite$_{SE}$ players can been seen as the difference between halves (1st minus 2nd) in Figure 7.1. Elite players cover almost exactly the same distance between halves (2815 vs. 2818 m, 1st and 2nd half respectively). Sub-elite and elite$_{SE}$ both have reduced distance in the 2nd half of games but neither is significantly different (2993 vs. 2895 m and 3439 vs. 3188 m, 1st and 2nd half of sub-elite and elite$_{SE}$ competition respectively, P = 0.383).

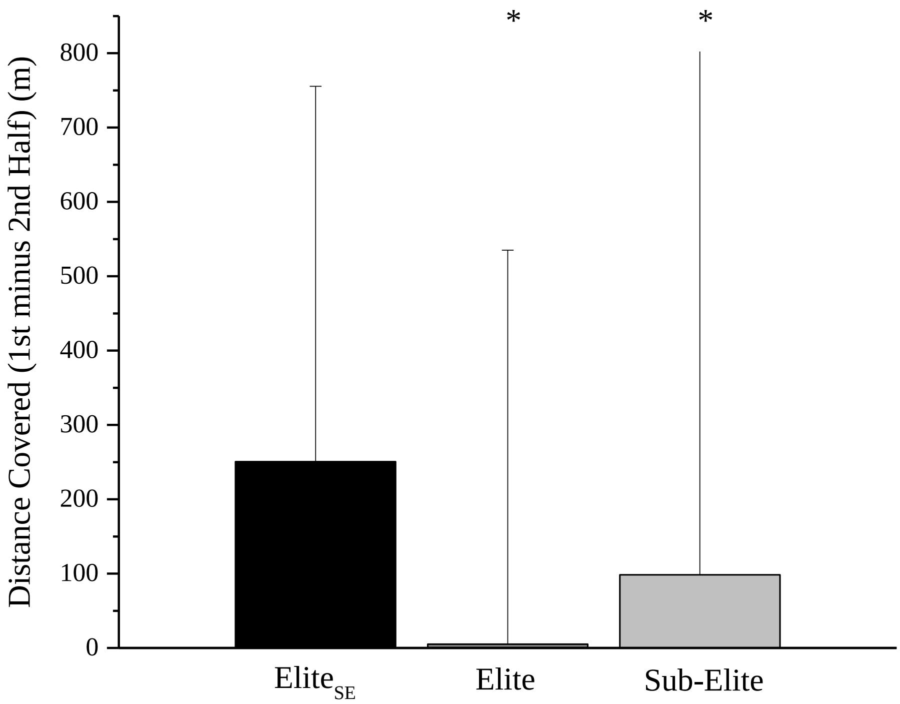

Figure 7.1. A comparison of fatigue in elite, sub-elite and elite$_{SE}$ players during competition illustrated by the difference in distance covered from first to second half. *Data significantly less than other values, $P \leq 0.05$.

However, the mean distance covered values under represent the range of values present in the data. Figure 7.2 shows the variance in distance covered in the 1st and 2nd halves of all players during elite, sub-elite and elite$_{SE}$ competition.

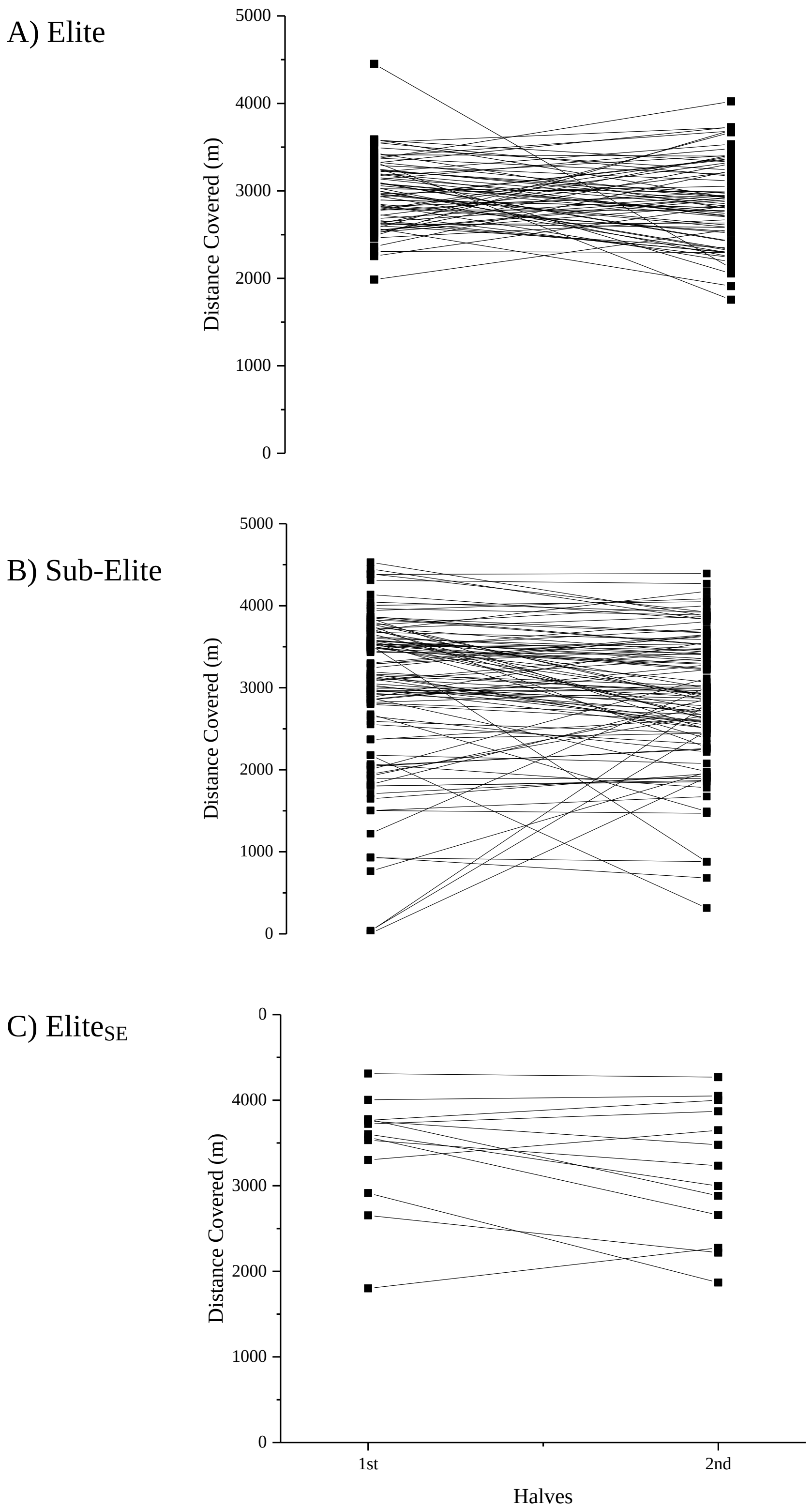

Figure 7.2. Individual differences in fatigue patterns during elite, sub-elite and elite$_{SE}$ competition. A) first and second half distance covered in elite competition B) first and second half distance covered in sub-elite competition C) first and second half distance covered in elite$_{SE}$ competition. All data reported as mean values with individual players 1st and 2nd half values highlighted by connecting lines.

Total half duration, rest time and total time exercise is shown in Table 7.1 and 7.2. Elite competition has an increased 2nd half duration compared to sub-elite and elite$_{SE}$ (P = 0.001) but has significantly more rest time in both halves (P = 0.005). However, only exercise time in the first half of elite competition is less than sub-elite and elite$_{SE}$ (P = 0.033). Additionally, total exercise time in elite$_{SE}$ competition is greater than both elite and sub-elite competition (64 min versus 45 min and 60 min, P = 0.007 and P = 0.023, elite and sub-elite respectively).

	Duration 1st (min)	Rest Time 1st (min)	Exercise Time 1st (min)
Elite	36 (36 to 37)	9 (8 to 10)*	28 (26 to 29)
Sub-Elite	36 (36 to 37)	6 (5 to 8)	30 (29 to 32)*
Elite$_{SE}$	36 (36 to 36)	4 (1 to 6)	33 (30 to 35)**

Table 7.1. First half duration, rest time and exercise time during elite, sub-elite and elite$_{SE}$ competition. * $P \leq 0.05$, greater than one level, ** $P \leq 0.05$ greater than two levels.

	Duration 2nd (min)	Rest Time 2nd (min)	Exercise Time 2nd (min)
Elite	38 (37 to 39)†	9 (8 to 11)*	28 (27 to 30)
Sub-Elite	36 (36 to 36)	6 (5 to 8)	30 (28 to 31)
Elite$_{SE}$	36 (35 to 36)	5 (2 to 8)	31 (28 to 34)

Table 7.2. Second half duration, rest time and exercise time during elite, sub-elite and elite$_{SE}$ competition. * $P \leq 0.05$, greater than one level, † $P \leq 0.001$ greater than one level ** $P \leq 0.05$ greater than two levels.

There was no difference in the percentage time in each of the standardised speed zones between halves at any of the three levels (all greater than $P > 0.05$). However there was differences between the three levels (see Figure 3). Elite players spent more time standing and walking – or on the bench - than both sub-elite and elite$_{SE}$ players in the 1st (79 vs. 71 and 63 %, P = 0.002 and P = 0.005, elite vs. sub-elite and elite$_{SE}$ respectively) and 2nd halves (81 vs. 73 and 71 %, elite vs. sub-elite and elite$_{SE}$ respectively, P = 0.011). Further to this low and moderate speed running were greater in sub-elite and elite$_{SE}$ than elite competition in the 1st (Low; 12 and 10 vs. 4 %, Moderate; 5 and 4 vs. 3 %, sub-elite and elite$_{SE}$ vs. elite respectively, $P \leq$ 0.001) and 2nd halves (Low; 10 and 9 vs. 4 %, P = 0.015 and P = 0.001; Moderate; 4 and 3 vs. 3 %, P = 0.001 and P = 0.005, sub-elite and elite$_{SE}$ vs. elite respectively,). Elite$_{SE}$ had the greatest percentage of time at moderate speed (P = 0.043). Additionally, sub-elite and elite$_{SE}$ spent a greater percentage of time high speed running in the 2nd half (1 and 1 vs. 0 %, P = 0.011 and P = 0.009, sub-elite and elite$_{SE}$ vs. elite respectively).

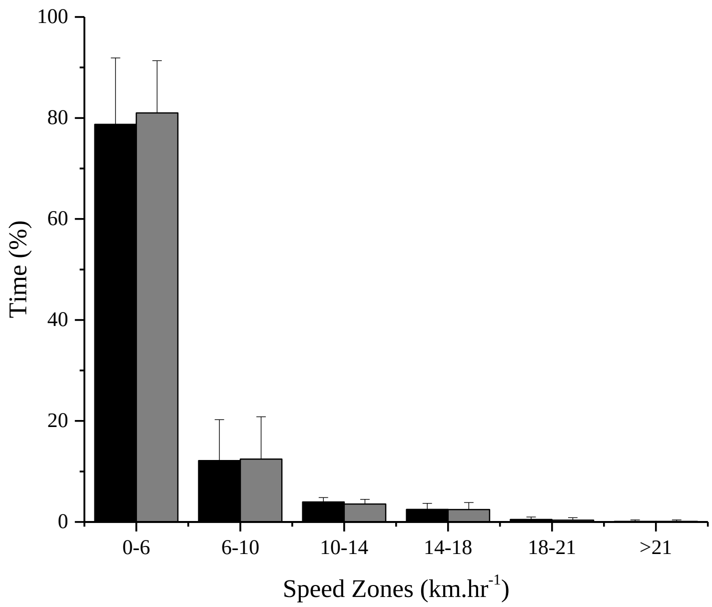

Figure 7.3. Percentage time spent in specific intensity (speed) zones by players during elite competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

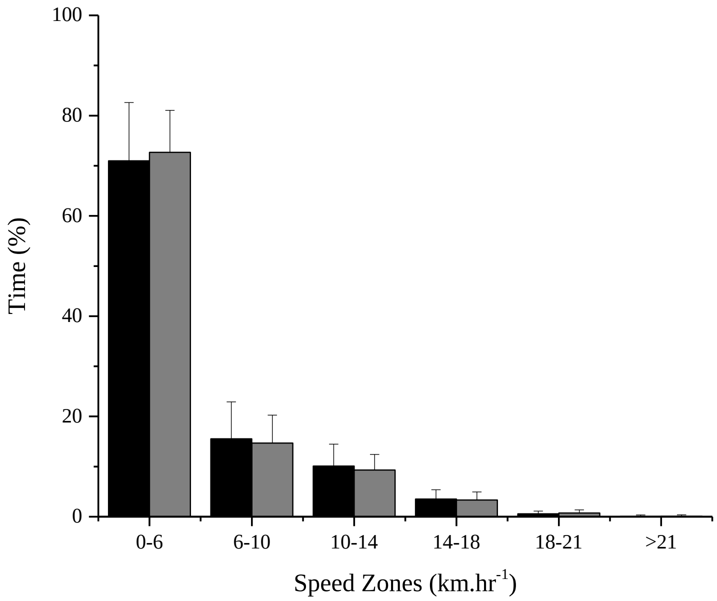

Figure 7.4. Percentage time spent in specific intensity (speed) zones by players during sub-elite competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

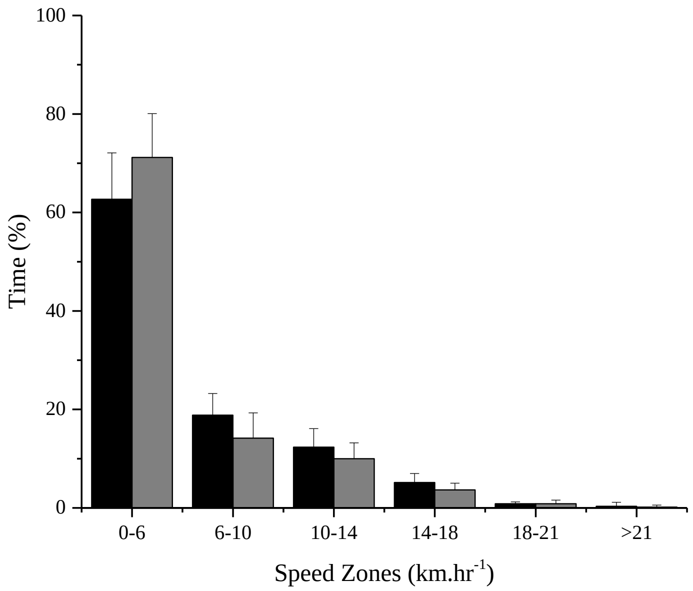

Figure 7.5. Percentage time spent in specific intensity (speed) zones by players during elite$_{SE}$ competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

The percentage distance covered remained similar between halves for all speeds and levels except elite$_{SE}$ walking distance which increased from 1st to 2nd half (30 % vs. 35 %, 1st and 2nd half respectively, $P = 0.039$) and high speed running by sub-elite players (2 vs. 3 %, 1st and 2nd half respectively, $P \leq 0.017$). The distances covered in the 1st and 2nd halves of competition at each of the different speed zones is shown in Figure 4. Elite players covered more distance than sub-elite and elite$_{SE}$ at walking speeds in both halves (1st; 48 vs. 35 and 30 %, both $P \leq 0.001$; 2nd; 49 vs. 35 and 35 %, both $P \leq 0.001$; elite vs. sub-elite and elite$_{SE}$ respectively). Sub-elite and elite$_{SE}$ were shown to cover more distance low speed running in the 1st (26 and 26 vs. 12 %, both $P \leq 0.001$, sub-elite and elite$_{SE}$ vs. elite respectively) and 2nd halves (25 and 25 vs. 12 %, both $P \leq 0.001$, sub-elite and elite$_{SE}$ vs. elite respectively). This was the same for elite$_{SE}$ at moderate speed in the 1st half (1st (14 vs. 9 %, elite$_{SE}$ vs. elite respectively, $P = 0.011$) and both sub-elite and elite$_{SE}$ at moderate speed and high speed in the 2nd half (Moderate; 12 and 12 vs. 9 %; $P = 0.011$ and $P = 0.009$; High; 3 and 3 vs. 2 %; $P = 0.25$ and $P = 0.039$ sub-elite and elite$_{SE}$ vs. elite respectively).

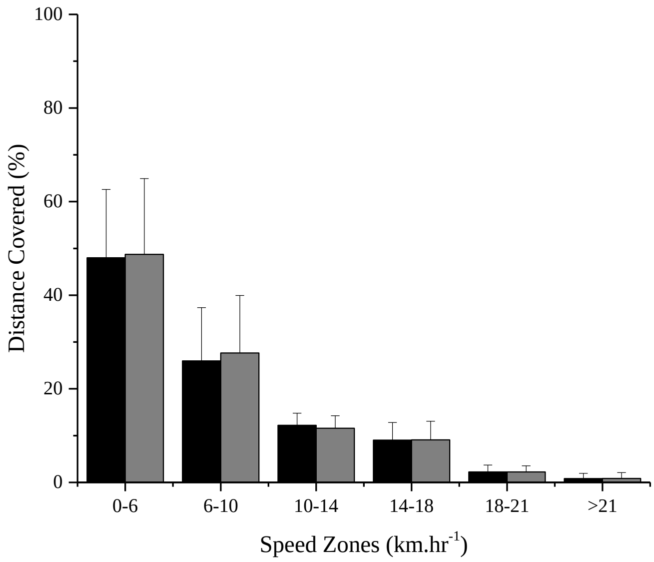

Figure 7.6. Percentage distance covered in specific intensity (speed) zones by players during elite competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

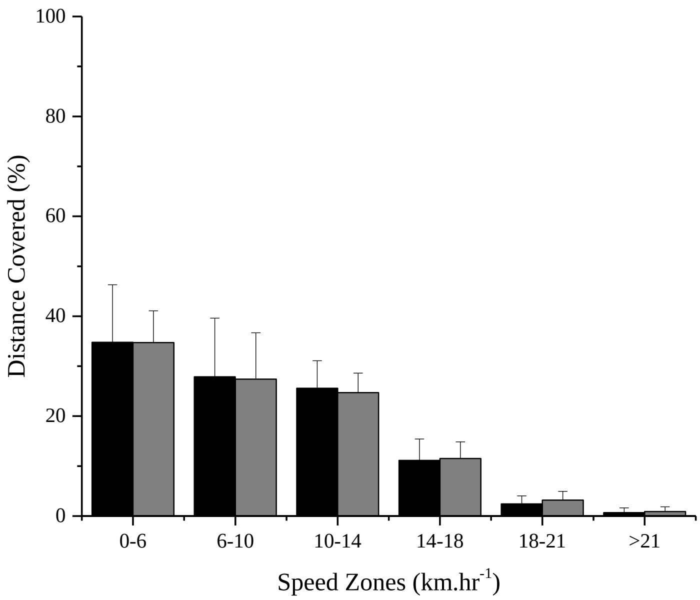

Figure 7.7. Percentage distance covered in specific intensity (speed) zones by players during sub-elite competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

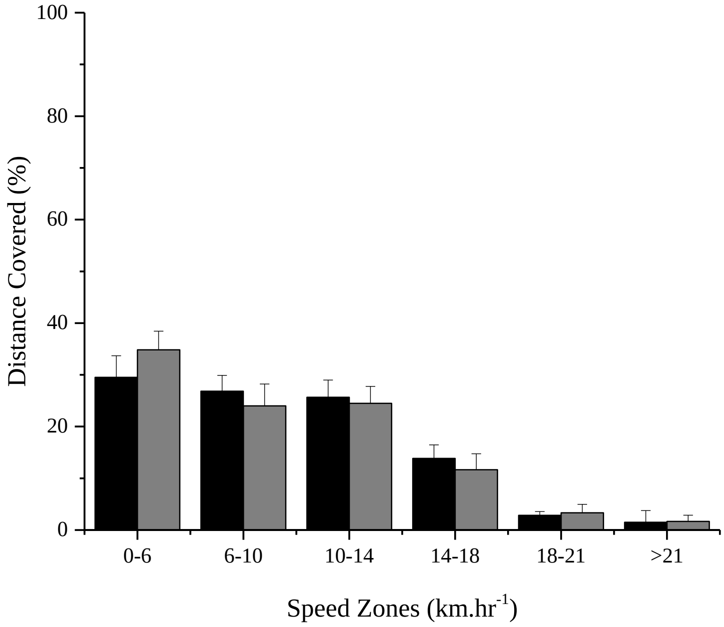

Figure 7.8. Percentage distance covered in specific intensity (speed) zones by players during elite$_{SE}$ competition. Dark columns represent first half values and grey columns represent second half values. All data reported as mean ± SD.

7.4 Discussion

This study observed the physical activity of field hockey players playing in elite and sub-elite competition to determine the inherent pacing strategies utilised in these competitions. Additionally, the study singled out the elite players playing in the sub-elite environment (elite$_{SE}$) in an attempt to describe the effect of competitive level on the physical activity, fatigue and pacing strategies of these players at both levels. The results show differences between all three groups but most markedly between elite and elite$_{SE}$. This discrepancy is largely due to the different exercise and rest times at each level and the subsequent pacing strategies implemented. The pacing strategies utilised were shown to affect the quantity of low intensity exercise completed and the amount of fatigue present in the second half of games.

The differing demands of elite and sub-elite field hockey competition have not been specifically studied in the literature. However by comparing some of the reported activity demands an indication of the difference can be built up. For instance using the elite and sub-elite definitions implemented by this author (see definitions) Macutkiewcz and Sunderland (2011) and Gabbett (2010b) can be defined as 'elite' and 'sub-elite' respectively (N.B. these are not the definitions given in these studies – both are described as elite). These data show the elite attackers in Macutkiewcz and Sunderlands study cover ~ 24 % less, midfielders ~19 % less and defenders ~ 7 % less distance than their counterparts in Gabbetts study. This comparison is flawed in a number of ways but shows the potential for large discrepancies in total exercise during field hockey competition. If the data from this study is included, elite players would cover more distance than Macutkiewcz and Sunderland but less than the players in Gabbetts study. In addition, all sub-elite and elite$_{SE}$ players in this study cover more distance than Gabbetts players. This suggests players of poorer standard run further within games. This is unlikely to be due to superior fitness levels but more likely due to longer playing times and less use of substitutions during sub-elite competition.

In comparison to other elite players this study has highlighted the low intensity nature of Scottish field hockey. Although this can be explain in part by the methodology used (White and MacFarlane, 2013) and the nature of the elite field hockey matches (all friendlies) it is likely that the elite Scottish players have poorer anaerobic capabilities. Further to this, the results reported in $elite_{SE}$ and sub-elite players show more moderately intensity activity which is speculated to be due to the lack of absolute rest periods and the need for players to evenly pace themselves to maintain a level of activity which will be sustainable until the end of the game. For instance other elite players can sustain more high intensity activity due to their increased anaerobic capacities. Conversely, $elite_{SE}$ players in this study know they are required to play the majority of the game with no bench time due to their increased responsibility to the team, for this reason they evenly pace their activity as this is easier to maintain for the entire period. This finding is important to coaches when considering substitution strategies as prolonging pitch time for 'better' players may not be as productive as believed due to the pacing strategies of players and the inevitable reduction in activity.

Intensity	Macutkiewcz & Sunderland	Gabbett	Elite 1^{st}	Elite 2^{nd}	Sub-Elite 1^{st}	Sub-Elite 2^{nd}	$Elite_{SE}$ 1^{st}	$Elite_{SE}$ 2^{nd}
Low	82	88	90	93	87	88	82	85
Mod	17	10	7	5	14	12	17	14
High	1.5	1.5	1	0	1	1	1	1

Table 7.3.A comparison of percentage time in specific intensity (speed) zones by elite, sub-elite and $elite_{SE}$ players during 1^{st} and 2^{nd} halves and those published in the literature. Low ≤ 6 $km\cdot hr^{-1}$, Mod 6 - 18 $km\cdot hr^{-1}$, High > 18 $km\cdot hr^{-1}$

The ability to pace through games is either conscious or sub-conscious (Tucker, 2009) but is illustrated by the fatigue patterns at all three levels. For example, the elite players in this study had virtually no difference in distance covered from first to second half suggesting an even pacing strategy. These results are similar to those reported by Spencer and colleagues (2004b) where no difference was found in different activity categories between the first and second halves of games. In the same way sub-elite and $elite_{SE}$ covered statistically similar distances in the first and second halves.

The substitution strategies seen in the sub-elite environment tended to follow the same pattern as soccer teams – the starting team played for 40 - 60 mins and then substitutes came on for the last period. The substitutes in these games were second choice players, youth players or those coming back from injury and were often played for as little time as possible. Interestingly, the effect of the rolling substitutions rule can be seen by the $elite_{SE}$ players fatigue patterns. Those playing in the top ranked sides were regularly rotated and showed no reduction in distance covered. Whereas those in the lower ranked teams who kept their best players on for the entire game had the largest reductions in distance covered. The combination of players being on the field for long periods and substitutes sitting on the bench for equally long periods skewed the mean results presented. However this study is still limited in its ability to distinguish whether players have reduced activity due to physiological changes or changes in tactics.

As previously mentioned the intensity of exercise (as described by the percentage time and distance in specific speed zones) was largely similar from first to second half in all three groups. Interestingly, the percentage distance covered and time in the high speed running zone was higher for sub-elite and elite$_{SE}$ during the second half. However this is also a result of the soccer style substitution strategies implemented and the introduction of 'fresh' players who are able to run faster than those who have re-entered the game after a short bench period. This may be evidence of tactics and contextual variables influencing the physical activity outputs as reported by the GPS data.

The differences reported between the levels of competition influence the conditioning stimulus given to players. The rotation and subsequent pacing strategies result in differing requirements from each of the energy systems. For instance elite players have more off field, low intensity activity, allowing for on field pacing to be increased and more utilisation of the anaerobic energy system. On the other hand, elite players in the domestic game have less off field rest and more moderate intensity activity requiring more energy from aerobic mechanisms. As such the elite players are inappropriately conditioned for elite competition and pace themselves for long periods. Not only does this have a temporal effect on performance the differences in substitution strategy and subsequent conditioning can have other negative effects. For instance in Australian rules football it has been shown that having more substitutions in a game reduces the chance of hamstring injury and interestingly increases the injury risk for the players in the opposition team (Orchard *et al*, 2012).

7.5 Conclusion

The results of this study show that field hockey players evenly pace themselves through games – that is they distribute their activity to maintain a similar level from start to finish (Abbiss and Laursen, 2008). This is shown by the consistency of first and second half distance and percentage time spent in the majority of specified speed zones for all groups. Pacing and substitution strategies in these groups allow for this consistency – giving adequate recovery in the form of low and moderate intensity exercise or bench time. The type of the recovery period was shown to effect the high intensity exercise completed. For instance, elite players have more absolute rest (in the form of bench time) allowing for high intensity exercise when they are on the field whereas elite_{SE} players have more moderate activity and less high speed exercise. As such at each of these levels players experience a different conditioning stimulus which may be detrimental to the adaptation of elite players when playing domestic field hockey.

It is accepted that all coaches will want their best players on the field at all times and that tactical/technical level is more important to the outcome of game. Furthermore it is obvious that elite players will be important to club teams and as such these players will play large periods of time to have their greatest influence on the game. However the effect of increased fatigue on skill level and reduced high speed running may have a bigger impact on the outcome of the game. More importantly for this thesis, adverse effects on physiological conditioning of elite players and reduced experience of performing skills at high intensity during the largest part of their season is likely to be one of the reasons why Scottish elite teams are unable to compete with the elite teams in the world rankings.

7.6 Future Direction

The results of this study suggest it may be appropriate to assess the impact of additional training interventions to stimulate the anaerobic energy system. This type of training intervention may be required to properly prepare elite$_{SE}$ players for international competition. Further to this a long term strategy to improve performance in sub-elite competition is required. A bottom up approach focused on the sub-elite players is more likely to produce long term success as this would provide a greater training stimulus to subsequent generations. This could be achieved by amending current rules such as the minimum requirement for playing squads – currently only 11 players are needed to fulfil a fixture, increasing this to 16 (11 on-field and 5 subs) would allow for better use of the unlimited substitution rule. This study has shown that competition intensity is increased and fatigue reduced for elite players when the whole squad are utilised. It can be hypothesised that changing the rules would create the environment to do this in sub-elite competition.

8. Limitations

8.1 GPS

The validity and reliability of GPS systems was previously discussed in Chapter 1. The validity of devices, specifically 5 Hz devices, was questioned for short distances, sport specific circuits, high speeds and decelerations. It was shown that 5 Hz devices had a standard error of estimate (SEE) of ~ 30 % during short linear runs and sport specific circuits (Jennings *et al,* 2010). Further to this, 20 m sprints had a SEE of ~ 24 % (Petersen *et al,* 2009) and CV of ~ 33 % during a 10 m deceleration (Varley and Aughey, 2012).

The reliability of GPS measurements from 5 Hz devices have also been questioned in the literature. A CV of 40 % was shown for 40 m sprints repeated on two occasions (Waldron *et al,* 2011), ~ 59 % for flying 50 m efforts and 112 % for a sport specific circuit (flying 50 m repeated on 10 occasions per participant and 10 laps of the sport specific circuit per participant) (Johnston *et al,* 2012). Furthermore, the use of 5 Hz GPS technology has been shown to be less reliable than the 10 Hz systems currently available (particularly in identifying high-speed efforts) (Varley, Fairweather and Aughey, 2012). Although these values are alarming and must make investigators consider the reliability of their own results there are some limitations within the studies mentioned – low subject numbers, poor methodologies and lack of gold standard criterion are evident in each study.

It is accepted that the use of 5 Hz devices in an observational study or intervention could result in less accurate data being reported. Unfortunately this system was the only one available at the time of investigation. This limitation should be acknowledged when considering the data in relation to the physical performance of elite field hockey players.

In the validation study reported in Chapter 3 the same data was used for both analysis procedures removing any error due to low-frequency data recording. Further to this, the same units were used for both competition and training in both elite and sub-elite environments meaning the inherent inaccuracy of the 5 Hz devices is nullified for any comparison between groups. However, comparison to other studies and devices such as those discussed in Chapter 4 will be effected by the 5 Hz inaccuracies.

Another possible limitation of this study is the interchangeable use of GPS devices in all studies. Due to logistical constraints players used different units for each game – this is against the suggestion by Coutts and Duffield (2010) who said that "devices should not be used interchangeably" to allow more accurate comparisons. This was practically possible across such a large series of investigations. For this reason all data was presented as means and 95 % confidence intervals to give an illustration of the range of results which are possible.

8.2 Multi Stage Fitness Test (MSFT)

The aerobic capacity of the elite players studied was used as a point of reference to explain the discrepancy between the physical activity results of the players studied and those published in the literature. This topic was of some significance but is limited by the method of measurement of aerobic capacity utilised within these squads. The multi-stage fitness test was used for both male and female players as part of the international squads normal test battery. The test results were then inputted in to a predictive formula used to give VO_{2max} values. This test has previously been shown to be a good indicator of aerobic capacity (Leger *et al*, 1988).

The multi-stage fitness test has been shown to be correlated (r = 0.92) to VO_{2max} (Ramsbottom, Brewer and Williams (1988). Conversely another study reported that using the regression equations of Leger and colleagues (1988) under predicts VO_{2max} in a group of young men and women (Stickland, Peterson and Bouffard, 2003). In addition the prediction of VO_{2max} from the MSFT was shown to be 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ lower than a direct measurement from a treadmill test in young males (Grant, Corbett, Amjad, Wilson and Aitchison, 1995). However it has been shown to be correlated to treadmill measurement in squash players (r = 0.61), runners (r = 0.71) and athletes as a whole (r = 0.67) (St Clair Gibson, Broomhead, Lambert and Hawley, 1998). Further to this it has been shown that predicted VO_{2max} from MSFT is similar in team sport athletes but not endurance athletes likely due to the team sport athletes being more capable at turning (Aziz, Chia and Teh, 2005).

However, the Yo-Yo Intermittent Recovery 1 and 2 (Yo-Yo IR1 and Yo-Yo IR2) tests have been shown to be better correlated to measures of physical performance in intermittent team sports (Reilly, 2003, Krustrup, Mohr, Amstrup, Rysgaard, Johansen, Steensberg, Pedersen and Bangsbo, 2003, Bangsbo, Iaia and Krustrup, 2008, Bradley, Mohr, Bendiksen, Randers, Flindt, Barnes, Hood, Gomez, Andersen, Di Mascio, Bangsbo and Krustrup, 2011 and, Bradley, Bendiksen, Dellal, Mohr, Wilkie, Datson, Orntoft, Zebis, Gomez-Diaz, Bangsbo and Krustrup, 2014) and may have provided a more appropriate measure to correlate to field hockey performance. However it has been shown that the Yo-Yo IR1 (r = 0.70) and Yo-Yo IR2 (r = 0.58) tests are both poor predictors of VO_{2max} (Bangsbo, Iaia and Krustrup, 2008).

We recognize the multistage fitness test is not the most appropriate test for the prediction of performance but were constrained to use of this data from the test during the study as this was the specified test used in their normal testing battery. However the main use of this data was for the prediction of VO_{2max} which has been shown to be valid and reproducible and secondly to compare to other literature as a large number of published studies have used this test to predict aerobic capacities in field hockey players (see Table 1.1 and 1.2).

8.3 Contextual variables

Castellano and colleagues (2011) have shown that contextual variables such as being home or away can affect the resulting work-rate profiles of players. In the current study this was not accounted for in the initial study design. This limitation was nullified in the validation of GPS procedures as the same data set was used for comparison between procedures. Additionally the comparison of competition and training in elite teams was completed on neutral grounds for the majority of matches so removes the effect of home and away variances. However, the investigations into the sub-elite environment were completed at random with teams playing home and away – due to the random selection of games home and away ties were equally distributed.

9. Key Findings

Study 1 - Validation of Full Game Analysis Procedures

- FG analysis reports similar results to current procedures (TOP) for all time independent parameters
- FG analysis reports lower results for time dependent factors in comparison to TOP
- FG analysis provides more accurate data than TOP in regards to exercise-to-rest ratios in field hockey where unlimited rolling substitutions are allowed

Study 2 - Analysis of International Competition and Training in Male and Female Field Hockey

- In comparison to other literature male players have poorer aerobic capacities and cover less overall distance in a match.
- Female players cover less distance in competition which is likely due to poor speed capabilities rather than aerobic capacity
- Training data reported as absolute, relative and normalised data provides evidence that the current training regimens for field hockey can provide an appropriate stimulus for adaptation

Study 3 - Comparison of Elite and Sub-Elite Field Hockey Competition

- Elite players produce more high speed efforts than sub-elite counterparts
- Greater rest times in elite competition allow for more high speed work and less walking on the field.

- $Elite_{SE}$ players are conditioned to maintain activity throughout a match which is converse to what they do during international competition

Study 4 - Opposition and Ranking Effects on Physical Activity of Competition and Training

- Playing against similarly ranked opposition produces more physical activity than when playing against higher or lower ranked teams
- The differences in physical activity may be due to opposition skill level and strategy
- In contrast to opposition ranking, there is no substantial relationship between the team rank and physical activity
- A strong ranking effect was seen in SSGs with the greatest activity levels in the highest ranked team

Study 5 - Pacing Strategies Utilised by Elite and Sub-Elite Field Hockey Players During Competition

- Field hockey players evenly pace themselves through the game
- Off field recovery was shown increase the amount of high intensity exercise completed

10. Conclusion & Future Directions

10.1 Conclusion

The aim of this thesis was to understand the physical activity demands of elite and sub-elite field hockey using GPS technology. Through this process it was expected that areas for intervention could be identified with the overriding aim of improving the standard of field hockey in Scotland. As well as this it was hoped that a more specific field hockey analysis procedure could be produced. The studies conducted have observed elite and sub-elite field hockey of both genders in competition and training. The results highlighted a number of discrepancies between levels - both physically and logistically. However the intricacies of field hockey competition have provided us with questions as to the efficacy of interventions in the sub-elite environment.

Prior to the analysis of field hockey competition and training it was felt that the procedure used for GPS data analysis needed to be reviewed as it was a remnant of TMA studies and its usage in soccer competition. The rationale for this investigation was the difference in substitution rules for soccer and field hockey and the ability for field hockey players to get a dedicated rest whilst substituted and be able to return to the field of play. The currently used TOP procedure produces relative intensity values in female field hockey players superior to professional male soccer players (Aughey, 2011 and Cummins *et al*, 2013) but does not account for periods on the bench. Using this method skews the intensity and can have a detrimental effect on future training prescription, return to competition protocols and performance assessment. The proposed FG analysis procedure includes rest periods and provides a better understanding of the total load and intensity of competition. By including rest periods the relative intensity is reduced and is similar to intermittent sports with regular stoppages such as rugby union.

The assessment of field hockey competition and training was completed on both elite and sub-elite field hockey to build a picture of the requirements at each level and the differences between the two. As well as this a comparison of Scottish international players with players from other international teams was used to identify what was 'elite' - due to Scotland's poor ranking in both genders it was acknowledged that they are not within the top 20 elite teams in the world. By viewing the physical activity demands of field hockey in this way it was hoped that interventions could be identified in the sub-elite environment to allow for development of the sport.

The initial observations of male and female Scottish international teams showed players completed less overall activity as other international players. The reasons for this discrepancy were different in each gender: the male players lacked the aerobic capacity to cover the distances of other elite players and the female players had poorer speed capabilities reducing their ability to cover large distances at sprint speeds. The differences between elite and sub-elite Scottish players was less well defined due to the physical and technical levels of players and logistical issues within the sub-elite environment. Physically it was clearly shown that elite players have greater speed capabilities than sub-elite players in both genders. These findings highlighted the importance of speed to field hockey as the maximum speeds reached increase as the level of competition gets harder. Additionally it was shown that aerobic markers such as total distance covered were skewed due to players playing for longer periods in sub-elite field hockey competition, increasing the TOP and as such the distance covered. Furthermore, the poorer technical ability of players means that there is an increased ‘unnecessary’ load due to miss placed passes, poor ball control and poorer use of passing and space.

In addition to the observation of competition in both genders and levels, training was investigated to see whether players were being appropriately conditioned. Drills were categorised into full pitch practices, SSGs, technical/tactical and running to allow for better comparison across groups. It was shown that drill specificity and duration of drills had a large impact on their ability to achieve their required aim. For instance, SSGs produced adequate accelerative stimulus to prepare players for competition. However pitch size reduced high speed exercise and inappropriate timings reduced the impact of the stimulus given to players. Another finding from the training observations was the effect of technical ability on physical activity. Sub-elite players produced more low to moderate intensity activity during drills largely due to mistakes being made and subsequent stoppages to retrieve balls. This becomes an issue when small sided games are used for conditioning – increased stoppages shift the exercise-to-rest ratios reducing the impact on the targeted energy system.

When specifically analysing the sub-elite environment two key findings were observed: 1) opposition effects on physical activity and 2) pacing strategies of sub-elite in comparison to elite. The investigation into the effects of opposition on physical activity produced some interesting results which could impact on interventions attempted in the sub-elite environment. A ranking effect was seen in both competition and training which resulted in reduced activity against lower standard teams in competition and amongst poorer players in training. Similarly activity was reduced when the mid-table team observed was playing against top ranked opposition. These results were suggested to be due to changes in tactics and/or psychology in these games. In games against similarly ranked teams or in training with players of similar ability the physical activity was highest. In these scenarios there may have been more motivation to perform and more chance of a successful outcome.

The second of the key findings in the sub-elite environment – pacing strategies – may have larger logistical implications as well as a negative physical impact on players. This investigation observed elite competition, sub-elite competition and elite players playing in sub-elite competition (*termed* elite$_{SE}$). It was seen in both genders that elite players had large amounts of rest time due to substantial use of the unlimited substitution rule. Interestingly the average rest times for players in sub-elite competition had were similar. However the mean values concealed the soccer style substitution strategies still utilised - players on the bench for the first half coming on to play the last 15 – 20 mins or players playing the whole game with no bench time. Further to this the elite$_{SE}$ players were being asked to pace themselves differently at this level. All elite$_{SE}$ players in the top two or three ranked teams utilised the substitution strategies vaguely like the elite team. However elite$_{SE}$ players in lower ranked teams were playing the whole game with no bench time. Neither used the strict rolling substitution strategy of the national team meaning players were being inappropriately conditioned – more aerobic than anaerobic. This becomes a logistical issue governed by player numbers, coach knowledge and overall team skill level. It is a logical rationale for coaches to want to have their best players playing all of the time, however this may be at the detriment of the players development and potentially their immediate and future performance.

10.2 Future Direction

The findings in this doctoral thesis have provided an in-depth appreciation of the physical demands of male and female elite and sub-elite field hockey in Scotland. As with any scientific study the findings open up multiple other questions especially in the area of training intervention. The most common discriminator between players of different levels was maximal speed in both genders. It can be speculated that having a higher maximal speed will mean players have more potential to effect games, whether in attack or defence. For this reason it may be appropriate to implement a training intervention to improve this physical facet. This may be done via specific speed drills, strength training or plyometrics (Komi, 1992). Additionally it was shown that players had higher activity levels during games against teams of a similar standard. This suggests that thinking you can win the game or needing to win the game to maintain league position can have a big effect on physical outputs. As such psychological skills training, especially in the female population, may produce higher physical activity outputs and could be another area for intervention.

Lastly, the spread of elite players in the sub-elite environment – two or three teams with all of the elite players – has been shown to detrimentally effect the elite players physical performance at this level. The domestic environment is where elite players acquire the majority of their conditioning and as such inappropriate training can have a negative effect on the national team. A novel intervention may be to ‘draft’ elite players (like the NFL or Scottish Rugby Union teams) across all teams so there is an even distribution of these players. This would mean that every week teams are more closely matched – which this study has shown will increase physical activity levels. Another logistical change may be the requirement for full squads (16 players). This is currently not the case and teams play with reduced number of substitutes which means they cannot fully utilise the rolling substitution rule. Obliging teams to fully load their benches would increase rest time for some players and mean that players could pace themselves more like elite competition.

These findings and potential interventions highlight a number of reasons why Scottish elite teams are lagging behind their international counterparts. Short term fixes such as the investment in the international teams during international periods will go some way to help better prepare the elite players. However unless interventions in the sub-elite environment and changes to infrastructure are put in place the elite players will continue to be inappropriately conditioned during the sub-elite season. Furthermore, only focusing on a small cohort of players will not have the impact desired due to the effect of opposition ranking and team skill level.

However , one of the overarching outcomes of this thesis was the need for specificity when using GPS analysis. The requirement for a field hockey specific analysis procedure was highlighted in the first study completed. It was concluded that using a ‘standard’ procedure derived from soccer provides a skewed impression of the demands of hockey which can impact on training prescription and injury rehabilitation. In addition to this it was shown that analysis of speed is a difficult construct to get right – across a team sport it can be difficult to accurately assess what is a sprint or fast running for each individual. As such intensity zones must be derived from accurate information, ideally individualised to their thresholds and practitioners must be consistent in their analysis, using the same standards for their group throughout. If this is not done and non-specific methods are used, the findings might be comparable to other athletes and literature but will not be beneficial to the training prescription for the group.

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Appendix i.

Investigation Information Forms

University of Glasgow | College of Medical, Veterinary & Life Sciences

Investigation Information Form

Title of Project:

Global Positioning System Analysis of Elite and Sub-Elite Scottish Field Hockey: Understanding the Physical Demands of Competition and Training

Name of Researcher:

Andrew White BSc (Hons)

What is the study about?

This doctoral study is a series of investigation into field hockey competition and training. The main aim of the study is to find out how much physical activity is completed during elite (international) hockey and sub-elite (club) hockey. This will be done over two seasons and include international and club competition and training session. Information will be gather using a small global positioning system (GPS) unit which players will wear. This collects information on how far players run, how fast they run and other variables such as work-rest ratio and accelerations.

What will I be required to do?

As a participant you will be asked to wear a GPS unit, which is the size of a small mobile phone, in a bib similar to a sports bra. You will wear this in the warm up to get used to it and then throughout competition or training. The same units are worn during rugby union games and are safe for field hockey.

What will happen to the information

All information will be downloaded post-session and input into the researchers computer. Information will be logged by participant number and position on the field. Names will not be kept. All information will be kept confidential.

Right to withdraw at any time

You have the right to withdraw at any time. There is not requirement for you to wear the unit at all. Furthermore it can be taken off at any time if it is uncomfortable. Additionally information can be deleted on request.

Appendix ii

Parental Consent Form

University of Glasgow | College of Medical, Veterinary & Life Sciences

Consent Form

Title of Project:

Global Positioning System Analysis of Elite and Sub-Elite Scottish Field Hockey: Understanding the Physical Demands of Competition and Training

Name of Researcher:

Andrew White BSc (Hons)

1. I confirm that I have read and understand the Investigation Information Form for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
3. I give consent that the information arising from this investigation can be used for publication.
4. I agree / do not agree (delete as applicable) to take part in the above study.

Name of Participant	Date	Signature
Name of Person Giving Consent (if different from participant, e.g. parent)	Date	Signature
Researcher	Date	Signature