PHYSICAL OUTPUTS OF MATCH PLAY IN INTERNATIONAL HOCKEY

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ATTESTATION OF AUTHORSHIP

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

Chapters 3 and 4 of this thesis represent two separate papers that will be submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of the thesis. All co-authors have approved the inclusion of the joint work in this Master's thesis.

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ETHICAL APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC) was granted on 21 October 2014 with a reference number of 14/323.

ABSTRACT

Introduction

Quantification of physical match outputs has become a routine practice in most team sports with such data extensively reported in the literature. However, the match to match variability of key physical output metrics in some team sports is poorly understood. Hockey is a popular fast-paced intermittent team sport for which limited data exists with respect to longitudinal analysis of match to match variability and analysis of the influences of situational factors on match outputs and within player variability of physical outputs. Therefore the aims of this thesis were to 1) determine the variability in match outputs in international hockey and 2) if variability exists; determine causes of the variability and the implications for applying physical output data from matches into a training setting for international hockey teams.

Methods

Twenty-one male international hockey players were monitored using 10Hz GPS units over the duration of an entire international season, resulting in 339 data sets from 29 international matches. Mean physical outputs were determined for key metrics including absolute and relative measures (m/min) of total distance covered, low (<11km/h), moderate (11.01-19km/h) and high (>19.01km/h) speed distance covered across the whole team and by position (strikers, midfielders and defenders). The within and between player coefficient of variations (CV), smallest worthwhile change (SWC) and *likely* worthwhile change (LWC) (study 1) and the effect of rank of opposition, result and score margin of matches on physical output and variability of outputs (study 2) were determined and compared.

Results

Significant difference in mean physical output values were observed between strikers, midfielders and defenders for many metrics with strikers reporting the highest relative distance of 139m/min. There were high amounts of within and between player variability (CV: 27.8-42.5%) observed across all positions for high speed running (>19.01km/h). Relative distance covered typically displayed the lowest variability across all positions (CV: 5.5-10.9%). Smallest worthwhile change and likely worthwhile change values were also lower for relative distance (1.1-2.8% and 9.3-11.3%) than for high speed distance (7.2-8.5% and 34.6-49.4%) respectively. When analysed by situational variables there were typically non-significant changes to mean outputs with the exception of relative distance and high speed relative distance for midfielders which was

increased by 5.9% and 22.9% respectively when playing high ranked teams over low ranked teams. High speed relative distance for defenders increased for highly ranked vs low ranked teams (30.6%), decreased for a win vs a draw (38.3%) or loss (36.6%) and decreased for a big loss vs a close game (34.5%) or big win (43.1%). Within player variability remained relatively unchanged by situational variance across all positions when compared to overall within player variability.

Conclusion

At moderate and high velocities a large degree of match to match variability exists, whilst for relative distances and low speed distances variability of match to match physical outputs is reduced. There appears to be minimal influence of situational variables on within player variability suggesting that the rank of opposition, result or score line of the match does not consistently have a similar influence over the GPS-derived physical outputs from match to match. Significant differences are evident in physical outputs between positions in hockey, suggesting the need to train each position in relation to the demands of their respective position. However within positions significant differences are not as common when analysed by situational variables. The use of likely worthwhile change values based off a ~10% change in relative distance across all positions may be an appropriate method of observing changes in mean outputs that are 'likely' substantial in matches and training.

Chapter 1: Introduction and rationale

In an effort to best prepare athletes for the demands of top level sports, athlete monitoring is becoming more prevalent (Aughey, 2011a). The desire to accurately monitor the locomotion of team sport athletes has led to substantial advances in GPS technologies, which, now at a higher sampling frequency of 10 or 15Hz, can accurately monitor distance, instantaneous velocities and distance covered in various speed zones <20km/h (Johnston, Watsford, Kelly, Pine, & Spurrs, 2014). As more evidence on the physical outputs of team sports is released, a clear understanding of the general physical demands across many team sports including AFL (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010), football (Bradley et al., 2009), rugby codes (Cunniffe, Proctor, Baker, & Davies, 2009) and hockey (Lythe & Kilding, 2011) is occurring.

As the physical demands of these sports have become more evident, the need to find a way to best interpret and apply the findings into a training and performance setting has increased. Recent studies have analysed the variability of the physical outputs based of match to match samples in AFL (Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015), football (Gregson, Drust, Atkinson, & Salvo, 2010) and rugby codes (Kempton, Sirotic, & Coutts, 2014; McLaren, Weston, Smith, Cramb, & Portas, 2015) and have established that at low velocities and for total distance there is a low to moderate, typically <10%, between player variability in GPS-derived physical outputs from match to match (Kempton et al., 2015) whilst distance covered at higher velocities results in a much greater between player variability, typically >15% (Gregson et al., 2010) and in some cases >40% for high speed running (McLaren et al., 2015). These findings have shown that low speeds and total distances are relatively stable from match to match, whilst distance at higher speed zones is relatively unstable.

In applying these outputs and variabilities of metrics into a training and performance settings, two methods of interpreting appropriate changes in mean values have been used. Firstly the smallest worthwhile change (0.2 of CV) has been established in AFL (Kempton et al., 2015), rugby union (McLaren et al., 2015) and rugby league (Kempton et al., 2014), which is equivalent to moving the mean from the 50^{th} to 58^{th} percentile (Hopkins, 2004) and has been established to show changes in the mean value that are greater than ‘trivial’. Secondly, the *likely* worthwhile change values, established from a customised spreadsheet (Hopkins, 2000) have been applied in AFL (Kempton et al., 2015) and rugby union (McLaren et al., 2015) in an effort to establish the amount of change in the mean outputs that would be considered a *likely* substantial (≥75% chance) change. Using these smallest and likely worthwhile changes values in a training setting may be beneficial as interventions and prescription will require training strategies above the average physical demands experienced during games, which may account for some of the variability of the metrics and may increase physiological adaptation (McLaren et al., 2015).

Furthermore, research has attempted to establish the effect of situational variances and their influence on physical outputs in team sports (Bradley & Noakes, 2013). Situational variances such as the effect and influences on physical outputs based on; the oppositions rank, the result or score margin of the game, climate and match location (home or away) have been researched (Lago, 2009). There is evidence that situational variables such as the effect of rank or result have an influence over the outputs of various sports, although typically the influence is not the same within all positions of the sport, with athletes of differing positions being influenced by each situational variance in slightly different ways (Hewitt, Norton, & Lyons, 2014).

Whilst physical outputs from hockey matches have been reported (Gabbett, 2010; Lythe & Kilding, 2011), there has been no longitudinal research observing the variation of physical output metrics in hockey. To date only one study has briefly discussed the influence of situational variables in international hockey over a 6 game tournament (Jennings, Cormack, Coutts, & Aughey, 2012a). The same study reported the variability in match outputs over a tournament and surmised that exercise intensity, based on physical output data, can be maintained over a hockey tournament (Jennings et al., 2012a). Due to the small sample size and short duration involved in that study, an accurate or representative measures of variability might not be possible and the effect of situational variables may also be limited, especially given the results of the team in question (5 wins from the 6 matches observed). Finally to the best of the researchers knowledge there is no published data on whether situational variances such as the rank of the opposition or result of the match may influence the variability of match to match data.

Aim and Questions addressed in this thesis

Given the lack of literature on the variability of match to match physical outputs in hockey, and consideration of situational influences, the overall aims of the thesis were to 1) determine the variability in match outputs in international hockey and 2) if variability exists; determine causes of the variability and the implications for applying physical output data from matches into a training setting for international hockey teams.

The specific research questions underpinning the thesis were:

I. What is the match to match variability in GPS-derived physical outputs in international hockey?
II. How can knowledge of the variability of GPS-derived physical outputs inform / guide interpretation of match physical outputs in elite hockey?
III. Do positional variances in exist in GPS-derived physical outputs in international hockey?
IV. Do situational variances, such as opposition rank, result and score margin, influence the physical outputs, and their variability, during international elite male hockey?

Structure of the thesis

This thesis consists of five chapters that culminate in an overall discussion. Chapters 3 and 4 of the study chapters have been written for the purpose of publication in journals and are written in a style appropriate for publication. As a result of this, there is some repetition in methodology in chapters 3 and 4. References are not included at the end of each chapter, rather, a single reference list is provided at the end of the thesis.

Chapter 2 reviews the current literature regarding the use of athlete monitoring methods in team sport athletes with an emphasis on global positioning systems. This review highlights current forms of athlete monitoring and why there is a need for monitoring systems such as GPS. It then goes on to analyse the current findings of physical outputs in team sports and the reliability and variability of the GPS units. Applications of GPS and physical outputs to international hockey is reported followed by an overview of the variability of match to match physical output performance in team sports, how to interpret the variabilities of metrics so that they can be applied into a practical setting and factors that may cause a change in physical outputs in team sports. The review highlights the need for match to match variability to be established for field hockey and also the demand for a longitudinal breakdown of influencing factors over physical outputs in hockey.

Chapter 3 investigates the match to match variability in international hockey over the course of a 29 match season utilising data from 339 data sets and how best to apply the findings of the data into a training and performance setting.

Chapter 4 advances chapter 3 by investigating the influence of rank of opposition, result of the match and the score margin on strikers, midfielders and defenders physical match outputs as well as the variability of these match outputs.

Chapter 5 is an overall discussion of the key findings of the thesis, limitations of the thesis, areas for future research and concluding statements.

In the appendices section you will find; athlete information form and consent form, ethical approval letter and tables from chapter 4 that show in numeric form the within player variability by rank, result and margin for strikers, midfielders and defenders that were illustrated in chapter 4 in figure form in order to best display the data.

CHAPTER 2: Monitoring physical outputs using GPS: Applications to Field Hockey, A Literature Review

Overview

This review outlines the growing demand for information on team sport athletes physical performance during match play with special reference to global positioning systems and their implementation in team sports. Team sports such as AFL, rugby codes, football and hockey have begun heavily tracking match physical outputs using GPS or video based time motion analysis. AFL athletes typically run the highest distance per match and also the highest relative distance per match. Variability and reliability of GPS systems is reviewed showing that the advances in GPS technology have resulted in increased reliability and validity of GPS as they have progressed from 1 and 5Hz systems to 10 and 15Hz. However despite the advances in technology, there is still a ~10% TEM in data collection in excess of 20km/h. The literature involving field hockey is then reviewed showing that hockey is a game in which moderate amounts of distance are covered in comparison to AFL and football however the relative distance is similar to that reported in AFL and exceeds that of reported measures in football. The final sections of the literature review include more recent research showing the variabilities of match to match physical outputs in team sports, establishing that typically high (>15%) variability occurs from match to match for high speed running metrics whilst variability is lower for low speed distances and total distances (<10%). Implications of this variability are that using high speed metrics for prescription of training may not be suitable whereas using relative distance may be more suited to monitoring changes in match outputs. Finally a review of situational variances that may influence physical output data was completed showing evidence that rank, result and score margin of matches in football and AFL can influence match physical outputs.

Introduction

A critical component of success in invasive style team sports is the ability to produce and repeatedly sustain high intensity, intermittent exercise (Spencer et al., 2004) for the duration of the game, often involving rapid accelerations, decelerations, and changes in directions, with limited recovery (Rampinini et al., 2014). Profiling the movements and demands on team sport athletes during match play, and in training, can help coaches, sport scientists and strength and conditioning coaches better understand the activity profile of the sport which may lead to enhanced training efficiency, recovery protocols and potentially reduced injuries and illnesses

(MacLeod, Morris, Nevill, & Sunderland, 2009). The aim/focus of this review is to summarise the current protocols, metrics used, and reliability and validity of GPS-derived data on team sport athlete's physical outputs in matches with an emphasis on the variability of match to match physical outputs in team sport.

The review is structured in 4 sections. Firstly, current forms of monitoring physical match outputs in team sports will be discussed, highlighting that the use of a monitoring tool that tracks external load can be beneficial in enhancing team sports training efficacy. Secondly, practical use of GPS monitoring in team sports will be discussed and will provide context and insights into the history and evolution of GPS monitoring devices, current metrics used in monitoring using GPS and the variability and reliability of these metrics. The third section will discuss how to interpret the GPS data accurately as it relates to the variability of match to match data collection and practical application into the training environment. Finally, some future directions are identified that, with future research may lead to enhanced knowledge of the variability of match to match metrics in hockey and help guide hockey training protocols as a result.

Section 1: Monitoring physical output in team sports.

Tools used to monitor physical outputs in team sports.

In an effort to determine the physical strain and demands of team sports, various methods of analysis have been used, including the analysis of heart rate response (Casamichana & Castellano, 2010), rate of perceived exertion (RPE) (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004) and time-motion analysis either by video analysis and digitization (Di Salvo, Collins, McNeill, & Cardinale, 2006) or via GPS monitoring systems (MacLeod et al., 2009). The monitoring systems used in research and practice all have their advantages and disadvantages with respect to accuracy, validity, reliability and practicality.

Heart Rate

Heart rate analysis is a well-established tool within sport science as an athlete monitoring tool used to monitor internal response to physical work and respective intensities of the work (Achten & Jeukendrup, 2003; Bangsbo, Mohr, & Krustrup, 2006). Heart rate (HR) analysis is a relatively cheap and user-friendly method of monitoring internal training load by giving an analysis of intensity of the activity which is established via mean intensity, peak intensity and time spent in various heart rate zones (Achten & Jeukendrup, 2003). Heart rate analysis in sport performance and training can also be used to help monitor and prevent overtraining (Bangsbo, Iaia, & Krustrup, 2007). In football players, for example, it is reported that over the course of a 90 min game the average heart rate will be between 80-90% of maximal heart rate (HRmax), which is close to the intensity that reflects the anaerobic threshold (Stølen, Chamari, Castagna, & Wisløff, 2005). Similarly, rugby league players had an average heart rate of 80% HRmax across a match (McLellan, Lovell, & Gass, 2011) and elite hockey players averaged 85.3% HRmax when on the pitch (Lythe & Kilding, 2011). Whilst useful data, heart rate analysis does not provide external load (distances etc.), rather it just gives an objective insight of how the athlete coped with the external response (Achten & Jeukendrup, 2003). The HR response can be influenced by factors other than the demands of the game or training session such as temperature, altitude, hydration, cardiovascular drift, caffeine intake and the parasympathetic nervous system (levels of arousal)(Achten & Jeukendrup, 2003; Bangsbo et al., 2007). Despite the limitations of using HR monitoring, if used in conjunction with other forms of monitoring it can be a very effective tool in monitoring team sport athletes for peak performance (Achten & Jeukendrup, 2003).

Rate of perceived exertion (sRPE)

Subjective session ratings of perceived exertion of a full training session or competition (sRPE), such as the Borg CR 10 Scale (Impellizzeri et al., 2004), can be used to monitor physical load. This method is used with each individual giving a rating of the entire session from a specialised scale of 0-10. The score is reported by the athlete 30mins after the session has been completed. There is an accurate level of within athlete reliability when using the sRPE system (Scott, Black, Quinn, & Coutts, 2013) and changes to the athletes' sRPE typically represent a change in perceived exertion from the session (Foster et al., 2001). Analysis of sRPE for rugby players monitoring the perceived exertion of a full game shows that the mean sRPE in rugby is 8.2 (McLaren et al., 2015), which on the scale is above the description of very hard (7/10) and below maximal (10/10) (Foster et al., 2001). The sRPE score can be tracked as a stand-alone figure or as recommended by Foster et al., (2001) it can be multiplied by the total training time of the session to give a total load score in arbitrary units (AU), i.e. 4 (sRPE) x 120 (session duration in mins) = 840 AU training load (Foster et al., 2001). From this value, the total weeks training load can be calculated by multiplying the sRPE of each session by the duration of each session and adding the scores to create a weekly load. Training monotony (mean sRPE of weeks sessions divided by the standard deviation of the weeks sessions) and strain (weeks total sRPE x duration load multiplied by the monotony value) can also be calculated by using this method (Foster et al., 2001). This method monitors the internal load, or how they individually have responded to the external demands that the athlete has encountered during the training session (Coutts, Chamari, Rampinini, & Impellizzeri, 2008). The sRPE method has established validity of this method to be related to percent of heart rate reserve and also the time spent at various intensities that correspond to heart rate and blood lactate response (Impellizzeri et al., 2004). High correlations with heart rate response have also been observed (Foster et al., 2001). The sRPE method of analysis is a cheap, non-invasive and effective way to monitor internal training load, however does not monitor external load (Foster et al., 2001).

Time-motion analysis (TMA)

Time-motion analysis is a method of monitoring external demands of sports (training and competition), and provides a clear insight into what an athlete physically completed in terms of locomotion during the monitored period (Edgecomb & Norton, 2006). This is of benefit to coaches, sport scientists and strength and conditioning coaches as it could enable the development of more effective training programs (Casamichana & Castellano, 2010; Edgecomb & Norton, 2006), develop specific performance tests (Bradley et al., 2009; Pyne, Spencer, & Mujika, 2014), track over or under training and potentially reduce injury risk (Dupont et al., 2010), which can be very costly for an elite sports team, both financially and in terms of results (Di Salvo et al., 2007). Currently there are two main methods of tracking external load upon athletes during training and competition; video based time motion analysis and global positioning system (GPS) based time motion analysis (Di Salvo et al., 2006). Both systems can monitor activities such as walking, jogging, running, sprinting, acceleration, deceleration and change of direction (Cummins, Orr, O'Connor, & West, 2013; Di Salvo et al., 2006), with the main difference between the two systems being how data is collected and analysed. Video based systems such as ProZone, use multiple cameras (typically 8) located around the stadium so that every part of the pitch is monitored by two camera angles. Data is collected on each individual 5-10 times per second and reported back through a computer system (Bradley et al., 2009). With GPS technology, movement data is collected via satellite signals from the transponder that the athlete wears, typically in a custom made sports vest under their playing shirt with the unit located between the shoulder blades. A position signal is emitted 1-15 times per second depending on the GPS system used. Data is then downloaded onto a computer and analysed (Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Johnston et al., 2014; Larrson, 2003). The associated cost difference between the two systems is extensive with the video-based system being much more costly to run and operate than the GPS devices (Di Salvo et al., 2006). However, until recently, some sports such as football do not allow the use of additional items of clothing and monitoring devices to be on a person, so the demand for both systems is evident in order to monitor both match and training physical loading so that best training systems can be put in place (Di Salvo et al., 2006). Recent rule changes by FIFA have allowed the use of GPS monitoring systems to be used at the referee's discretion.

Section 2: GPS in team sports.

History of GPS

In 1938, Isidor Rabi and his students invented the magnetic resonance method through their precise measures on the hydrogen atom (Rabi, Millman, & Kusch, 1939). This invention enabled the foundation of satellite navigation based off the creation the extremely accurate, atomic clock (Audoin & Guinot, 2001). The precision of the atomic clock allows the ability to calculate the time taken for a radio signal to travel from the GPS receiver on earth to the satellite and back to the GPS receiver (Schutz & Chambaz, 1997). The satellite is equipped with an Atomic Clock. The satellite pairs with the GPS receiver, sending information of the exact time from the atomic clock to the GPS receiver. These signals are performed at the speed of light (Larrson, 2003). From these signals, distance to the satellite can be derived, thus allowing for an accurate measure of location of the GPS receiver, provided a sufficient amount (typically a minimum of four) satellites are in communication with the one receiver (Larrson, 2003). The location of the GPS receiver is established using trigonometry based off the distance to at least four satellites. Once location is established then monitoring movement and the velocity of movement of the receiver can be tracked through repeated transmission signals from the GPS receiver to the satellite (Larrson, 2003).

Until 1999, precise GPS accuracy was deliberately made unattainable by the US Department of Defence (Schutz & Chambaz, 1997). This deliberate error was known as 'selective availability' (SA). By using 'differential GPS' the deliberate error applied to ability to gain precise GPS location could be overcome, reducing the scrambled signal error from 100m to 1cm (Aughey, 2011a). Differential GPS can be attained by having stationary receivers at known locations in or near the area where the portable GPS units are being used. The stationary receivers compare the position given by the satellites with their stationary position. The stationary receiver can then send a corrected signal to the GPS units via use of a differential receiver (Larrson, 2003). As well as selective availability error with the GPS units, there are other restraints to the availability and accuracy of GPS for tracking human locomotion. The proximity of tall buildings or rough terrain as well as being inside a stadium can obstruct clear vision of the sky and therefore create external noise with signals bouncing off local obstructions before reaching the receiver. This influences the total time taken for the GPS receiver to receive the signal from the satellites and therefore can adversely affect the trigonometry equation used to find precise location of the receiver (Larrson, 2003).

Team Sport relevant GPS “Metrics”

The most commonly reported metric from GPS analysis in team sports is total distance travelled. This is also the first metric that was analysed in team sports to gauge the demands of the sport on an athlete (Cummins et al., 2013). A fast bowler in a Cricket one day international (ODI), typically covers the highest distance of any one day team sport that has been extensively analysed using GPS technology with fast bowlers covering 15,903m per game (Petersen, Pyne, Portus, Karppinen, & Dawson, 2009), followed by AFL in second with mean distances per player of 12,939m(Coutts et al., 2010). Soccer players travel a greater distance than their rugby counterparts with U18 soccer players covering 8,867 meters per game (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010), elite female soccer players covering an average of 9292m (Hewitt et al., 2014) and elite men cover 10,714meters (Bradley et al., 2009) and elite rugby union players covering 6,953 meters per game (Cunniffe et al., 2009).

Within each sport, positional differences occur in total distance travelled and sometimes playing duration, with backs in rugby union and league covering greater distances than the forwards (Cunniffe et al., 2009; Gabbett, Jenkins, & Abernethy, 2012), and midfielders, small forwards and small backs covering greater distances than the Ruckmen, tall forwards and tall backs in AFL (Gray & Jenkins, 2010).

Whilst the distance covered in a game gives a good measure of volume, it does not give an accurate representation of intensity, hence looking at distance travelled as a sole metric may not give the sport scientist, coach or trainer enough information on the game. In order to gauge the most information possible to best prepare and monitor athletes for and during competition further, detailed analysis is needed (Cummins et al., 2013).

The “relative distance” measure is a derivative of the total distance covered in a game and the actual playing time for that athlete (Aughey, 2011a). Whilst distance travelled is a great indicator for volume, relative distance helps provides a more accurate measure for the intensity or average velocity of the given task (Cummins et al., 2013).

Despite covering less distance than a fast bowler in cricket, an AFL player has a higher relative distance covering 120 (Wisbey, Montgomery, Pyne, & Rattray, 2010) to 133m/min (Hiscock, Dawson, Heasman, & Peeling, 2012) in contrast to the fast bowlers covering their respective distance at 63m per min (Petersen et al., 2009). Rugby union backs cover 71.9m per min played (Cunniffe et al., 2009) whilst soccer players travelled 98-118m per min played (Burgess, Naughton, & Norton, 2006) . Total playing distance and relative distance can easily be used to compare locomotion volume and intensity of various sports, teams within sports and trainings (Aughey, 2011a).

The next layer of GPS analysis is breaking down the total distance into distance covered at various speed zones. Large variations in the break down in speed zones occur in each sport and with no position statement for how to use GPS for each sport the speed zones used can depends on the GPS model used, the trainer / coach / sport scientist preferences and the sport being played (Cummins et al., 2013). This “Speed Zone” metric enables you to monitor the distance travelled within two different velocities, e.g. 4.01 – 5.00 meters per second. Speed zones can also be characterised by a description of the activity such as walking, jogging, running and sprinting (Cummins et al., 2013).

The benefit of monitoring distance covered in various speed zones is significant to the support staff working with the athletes as it allows for specific metrics that indicate the intensity and speed that games are played at and how best to prepare the athlete and team for the demands of the game by replicating, exceeding or periodising the speed zone data in training (Abt & Lovell, 2009).

From examining the research it is clear that there are no agreed speed zones that are applied across sports or, within sports (Cummins et al., 2013). Not only does the research show a varied application of speed zones within sports but it also shows that the gap between speed zone comparisons is actually very large(Coutts et al., 2010; Jennings et al., 2012a; Lythe & Kilding, 2011; Wisbey et al., 2010). For example a large proportion of the research focuses on high speed or high intensity running, however even across athletes of similar status (e.g. professional or elite athletes) there is a large range in which this speed zone begins (Table 1) with 'high' speed zones starting at velocities between 14.4km/h (Coutts et al., 2010) and 19.8km/h (Bradley et al., 2009). This again elaborates the differences in speed zones and also the differences in the term 'high speed running'. The high speed running data, despite the apparent lower validity of 10 and 15Hz GPS units at speeds in excess of 20km/h (Rampinini et al., 2014), is thought to be one of the more significant metrics that the GPS can analyse as it captures the distance travelled in each game that may exceed the athletes aerobic capacity, induce high lactate levels and create high fatigue (Bangsbo et al., 2007; Bangsbo et al., 2006; Bradley et al., 2009; Mohr, Krustrup, & Bangsbo, 2005). It is believed that high speed running can also be a determinant of the success of the team or athlete as often, especially in sports such as AFL and soccer/football the high speed running is performed at crucial parts of the game and is known to have an impact on match performance, on fast breaks, leading for the ball, counter attack/defence and in one on one foot race battles for territory or position (Reilly, Bangsbo, & Franks, 2000; Young et al., 2005).

Whilst a lot of literature has focused on arbitrary speed bands and locomotion metrics (Table 1), recent advances in technology have enabled practitioners to individualise speed zones for each athlete. Only a few papers have looked at the possibilities of individualising these speed zones based of individual performance characteristics such as maximum aerobic running speed or maximal sprinting speed (Abt & Lovell, 2009; Hunter et al., 2015). Further research in this field may lead to a more unified position statement with regards to monitoring locomotion across different speeds in team sport athletes.

TABLE 1: *Example GPS locomotion metrics from current literature in team sports*

Study	**Sport**	**Description of athletes**	**Distance**	**Relative Distance**	**Distance covered in reported 'high' or 'very high' speed bands**
Wisbey et al., (2010)	AFL	Professional Males (Aus)	Forward = 11700m ± 2000m Nomadic = 12300m ± 1900m Defender = 11900m ± 1700m	Mean velocity Forward = 6.8km/h ± 0.6 Nomadic = 7.5km/h ± 0.6 Defender = 6.8km/h ± 0.6	
Coutts et al., (2010)	AFL	Professional Males (Aus)	12,939m ± 1145	Meters per min Quarter 1 = 117m/min ± 14 Quarter 2 = 108m/min ± 15 Quarter 3 = 108m/min ± 17 Quarter 4 = 103m/min ± 14	Distance >14.4km/h = 3880m ± 663
Hiscock et al., (2012)	AFL	Professional Males (Aus)		133m/min ± 12	V1 (dist. above players aerobic 'lactate' threshold) meters per min = 39m ± 11
Gabbett et al., (2012)	Rugby League	Professional Males (Aus)	5709m; ± 410 (95%CL)	96m/min; ± 3 (95%CL)	Distance <18km/h = 5279m; ± 378 (95%CL) Distance >18km/h = 429m; ± 38 (95%CL)
Waldron, Twist, Highton, Worsfold, & Daniels, (2011)	Rugby League	Professional Males (UK)	Outside Back = 6917m ± 1130 Adjustables = 6093 ± 1232 Forwards = 4181 ± 1829	Outside Backs = 89m/min ± 4 Adjustables = 94m/min ± 8 Forwards = 95m/min ± 7	Distance 14-21km/h Outside Backs = 926m ± 291 Adjustables = 907m ± 255 Forwards = 513m ± 298 Distance >21km/h Outside Backs = 304m ± 100 Adjustables = 189m ± 78 Forwards = 100m ± 62
Cunniffe et al., (2009)	Rugby Union	Professional Males (UK)	Forwards = 6880m Backs = 7227m *No recorded SD or 95% CL for this data	Forwards = 66.7m/min Backs = 71.9m/min	Distance >20km/h Forwards = 313m/min Backs = 524m/min

McLaren et al., (2015)	Rugby Union	Professional Males (UK)	5720m ± 680	71.7m/min ± 8.7	Distance >20km/h = 300m ± 160
Bradley et al., (2009)	Football	Professional Males (UK)	10714m ± 991		Distance >14.4km/h = 2492m ± 625 Distance >19.8km/h = 905m ± 285
Burgess et al., (2006)	Football	Professional Males (Aus)	10100m ± 1400	110.6m/min ± 1.6	Distance 18-24km/h = 700m ± 200 Distance >24km/h = 400m ± 300

Reliability and validity of GPS metrics in team sport contexts

Validity

In 1997 the first attempt at validating human locomotion using a commercially available GPS device (GPS 45, Garmin), despite the deliberate error applied to the system, was published (Schutz & Chambaz, 1997). The results of this research concluded that the correlation coefficient between GPS and actual velocity, as determined by a Swiss-certified chronometer, was valid ($r=0.99$, $P < 0.001$ and a 5% coefficient of variation for the slope line (Schutz & Chambaz, 1997)). While these results were a promising start to the study of human locomotion using GPS, the research lacked gold-standard validity comparisons (Aughey, 2011a).

There are inherent limitations in establishing the validity of GPS units for team sports, including accurate gold-standard comparison measures for distance travelled and velocity of movement as well as limitations from within the units themselves, such as establishing exact starting times of movements (Aughey, 2011a). With these limitations in mind, it appears that the validity of GPS units to accurately measure distance and velocity has improved as sampling rate ability has increased overtime from 1 to 5, to 10Hz units (Rampinini et al., 2014). However, despite the improved levels of accuracy, it appears that validity of measurement decreases with increased velocities (Rampinini et al., 2014). Furthermore, the shorter the duration of a measured task, the less valid GPS-measured distances become (Aughey, 2011a). Using Catapult Minimax S4 10Hz units, validity was established for accelerations and instantaneous velocity with higher validity seen when accelerating and velocities below $4ms^{-2}$ than above $4ms^{-2}$ (Akenhead, French, Thompson, & Hayes, 2014). These findings again are in line with the general trend with GPS that at higher velocities the validity of GPS is reduced, however it is still a valid tool for monitoring human locomotion (Akenhead et al., 2014). When performing a sport-specific circuit, Catapult Minimax S4 10Hz units showed that there was no statistical difference to actual total distance covered compared to the GPS-monitored distance, however there was statistical difference in peak speed when the two 10Hz catapult units 22.98 and 22.99km/h were compared to the criterion measure of timing lights peak speed of 22.47km/h. This difference could be explained by the inability of timing lights to capture instantaneous velocity like GPS can, rather velocity is calculated based off of the time taken and distance between two timing gates. Despite the statistical difference, there was still a high correlation of $r=0.89$ and 0.91 when comparing the two tested units against the criterion measure (Johnston et al., 2014). These results established higher validity compared to performing the same test with 1 and 5Hz GPS systems (Johnston et al., 2012).

Reliability

Similar factors that affect the validity of GPS to accurately measure human locomotion are found with the reliability of GPS measures (Aughey, 2011a). Reliability studies have established that both; within unit and inter-unit reliability, there is an inverse relationship between reliability and velocity (Jennings et al., 2010). Practical recommendations with inter-unit reliability are that units are not used interchangeably across subjects or care is needed when comparing high speed data from one unit to another(Akenhead et al., 2014). When performing a sport-specific circuit, Catapult Minimax S4 10Hz Units displayed high levels of inter-unit reliability for total distance, peak speed, distance covered and time spent in low speed movement (0-13.99km/h) and high speed movement (14-19.99km/h) and also number of efforts performed in High speed movement with TEM values all ranging from 0.8-4.8% variance across the two units tested and ICC values ranging from 0.8 to 0.97. The only values with lower levels of inter-unit reliability were recorded with very high speed movement (above 20km/h) total distance, time spent above and number of efforts performed above with TEM values of 11.5%, 11.7% and 13.7% respectively with interclass correlations of 0.89, 0.89 and 0.84 respectively. This data shows that 10Hz Catapult Minimax S4 units can reliably compare data between units for all measures under 20km/h (Johnston et al., 2014). Similar findings were reported when comparing a 5Hz (SPI-Pro) and 10Hz (MinimaxX) GPS units from different manufacturers, with only the 10Hz unit demonstrating sufficient levels of reliability at higher speeds (Rampinini et al., 2014). With 1Hz an 5Hz GPS units, measures of acceleration, deceleration and change of direction were not deemed reliable for game and training monitoring purposes, at >10% TEM (Jennings et al., 2010), however newer 5Hz units were considered to be more accurate than 1Hz units (Jennings et al., 2010) suggesting technological advances are improving accuracy. This is exemplified further when 5hz units are compared with 10Hz units, with the latter deemed to be significantly more accurate and reliable for measures quantifying acceleration and deceleration in team sport athletes (Varley, Fairweather, & Aughey, 2012). Similarly to the findings with GPS validity, the effect of velocity and duration of the task have an effect on reliability. Considerations need to be made in relation to reliability of GPS devices to measure locomotion in team sport athletes when reporting differences within a team or within an individual athlete (Varley et al., 2012). Whilst 10 and 15Hz may be reliable and valid for metrics <20km/h with slightly decreased reliability and validity >20km/h, practical recommendations are that these units are capable of monitoring distance covered and distance covered in various speed bands provided that the inherent lack of reliability and validity at higher speeds is understood (Johnston et al., 2014). Caution is recommended when analysing data from lower 1 and 5Hz units in relation to velocity within speed bands, however total distance for these units is considered to be reliable and valid (A. J. Coutts & R. Duffield, 2010; Johnston et al., 2012).

General trends for the reliability and validity of the GPS data show that as velocity is increased, or time of sample decreased, the accuracy of data collection is compromised (Akenhead et al., 2014). Furthermore, validity of total distance is decreased as sharp changes of direction occur (Akenhead et al., 2014). Another trend is that validity and reliability of data is increased with higher data collection frequency units, from 1, 5, (Johnston et al., 2012)and 10Hz units (Johnston, Watsford, Pine, Spurrs, & Sporri, 2013) although little difference is seen between 10 and 15Hz Units (Johnston et al., 2014). Also of note with regard to validity of GPS is that no global position statement on accuracy and validity of the GPS use in team sports can be given due to such constraints as different manufacturers, sampling frequencies, exercise tasks and statistical analysis variants (Akenhead et al., 2014).

Introduction to Field Hockey

Field Hockey is a global sport with over 60 international teams on the FIH world ranking list for both men and women, including many countries that run top level domestic or club leagues. The sport is undoubtedly at its strongest in western Europe with 4-5 countries in each of the men's and women's categories often being ranked inside the top 8 teams in the world (FIH, 2015a).

Field Hockey is an invasion style game, similar to Football / Soccer, where the object of the game is to score more goals than the opposition. Until very recently, the game comprised 2 x 35min periods, however as of January 1 2015 is now played across 4 x 15 min periods, with the clock stopping for penalty corners and goals (FIH, 2015b). The game has been described as a running game which combines speed, agility and aerobic fitness with skilful dribbling, passing, tackling and shooting (Macutkiewicz & Sunderland, 2011). The field is 100 yards (91.44m) long and 60 yards (54.86m) wide. There is a scoring zone at each end of the field. The zone is a "D" shape with the goal in the centre and the perimeter of the zone is 16 yards (14.63m) from the nearest point of the goal. The ball must be touched by an attacking player in this zone before the ball goes into the goal for the goal to be awarded. Hockey is played with two teams of 11 players on the field at any time which includes a designated goalkeeper. Depending on the tournament, there are between 5 and 7 players at any time on the bench often including a goalkeeper and players can be substituted on at any time during the game, except during a penalty corner. There is no limit to the amount of substitutions that can be made during the game (FIH, 2015b). Due to this rule, the game can be played at a very fast pace with the ball often being hit around the field at speeds in excess of 100km/h. Playing positions are again similar to football with each coach and team having slightly different formations of defenders, midfielders and strikers. The primary role of the strikers is to score goals, whilst the primary role of the defenders is to stop goals being scored. The midfielders perform both roles and act as a go between, transitioning the ball from the defensive end to the attacking end of the field (FIH, 2015a). The rules of the game also encourage a fast-paced, action-filled game where game stoppages are minimised. These include: no off-sides and auto free hit after a penalty or when the ball goes out of bounds, where the attacking player can run with the ball straight away from the mark and does not need to pass it or wait for the umpire to start play (Macutkiewicz & Sunderland, 2011). The only time where the game slows down is after a goal has been scored or when a penalty corner has been awarded during which there is a 40 second countdown clock to set up and perform the penalty corner (FIH, 2015b).

At the international level there is a major events calendar where teams can get FIH world ranking points, consisting of: The World Cup and Olympics which currently consist of 12 teams in each gender category and are both on four-yearly cycles; The Champions Trophy consisting of the 8 top qualifying men's and women's nations on a bi-annual schedule and the Champions Challenge consisting of the next top 8 qualifying teams after the Champions Trophy for both men's and women's nations on a bi-annual schedule. There is also a world league series consisting of 4 rounds of tournaments. The World league 1 event is a qualifier for world league 2, which runs as a qualifier for World League 3 where there are two tournaments for men and women held concurrently both consisting of 10 teams with the top 4 from each World league 3 event meeting in the World League 4 event. This league is completed on a bi-annual cycle. As well as this there are the regional championships which often double as world or Olympic qualifiers such as Asian, Oceania or European champs. On top of all of the FIH tournaments there are many other tournaments or international matches happening with events such as; test series, 4 or 6 nations' events, the Commonwealth Games and the Azlan Shah Cup. These are all played under FIH rules and international caps are given, however no world ranking points are bestowed upon them (FIH, 2015a).

With all of these events in the international calendar it is common for countries in the top echelon in the world to be playing 30-40 test matches per year, often playing 6-7 games over the space of 9-14 days (FIH, 2015a). This means that not only do the athletes need to be fit enough for one very high intensity and fast game, but they need to have the capacity to repeat that performance consistently throughout an entire hockey tournament, typically with between 20-50 hours recovery time (Spencer et al., 2005).

Application of GPS technology in field hockey match play

Field hockey is not an extensively researched sport from a physical output or physical conditioning perspective. To date, only a limited number of studies that have reported on the physiological demands of field hockey (Table 2). It has been reported that elite male field hockey players cover between 4,500-9,500m per game (Aziz, Chia, & Teh, 2000; Jennings et al., 2012a; Lythe & Kilding, 2011; Spencer et al., 2004; White & MacFarlane, 2014). This is significantly less than the distances covered in AFL and soccer, where athletes cover 11,000-15,000m (Gray & Jenkins, 2010) and 9000 – 11,000m respectively, but similar to distances covered in rugby and rugby league. A key determinant for total distance, however, is the total playing time. This is typically much lower in Hockey at about 51min per game per player (Lythe & Kilding, 2011) which is less than in other invasion style team sports like rugby, rugby league, soccer and AFL. This is largely due to the sport allowing rolling and unlimited substitutions so players are getting frequent rest periods (White & MacFarlane, 2013). This allows the players to work at very high work rates whilst they are on the turf with players typically averaging 130m travelled per minute played (Lythe & Kilding, 2011) which is comparable to AFL at 120m-130/min (Wisbey et al., 2010) but generally higher than soccer (98 and 118m/min, (Burgess et al., 2006), rugby league (93 and 101m/min, (Gabbett et al., 2012) and rugby union (83m/min, (Cunniffe et al., 2009) confirming that the game is a fast-paced, aerobically demanding team sport (Lythe & Kilding, 2011; Spencer et al., 2004; White & MacFarlane, 2014)

Despite a range in velocity bands used to establish high intensity running in the literature, it is evident that hockey involves high amounts of fast running or sprinting. Elite female hockey players cover an average of 450m at high speed bands. This includes velocities of 5-7m/sec (18-25.2km/hour) and greater than 7m/sec (25.2km/hour). This equates to 6.8% of the total distance covered (Gabbett, 2010). Lythe and Kilding (2011) reported that elite male hockey players covered 482m at velocities exceeding 19.1 km/hour which was 7.1% of the average total of 6798m. Using the same velocity bands, White and McFarlane (2014) saw high speed metres of 571m and 9.7% of the average 5,868m covered. Jennings et al (2012a), using a high speed band of 15km/hour and using normalised data expanding the readings out to equal a full 70min per player, reported that 2,294m would be covered in 70 min of match play at high speeds, which equates to 23.5% of the normalised distance of 9,776m. Using the same velocity bands, athletes covered 2,189m above 15km/hour using normalised data which equated to 22.2% of the data set (Jennings, Cormack, Coutts, & Aughey, 2012b). Extracting the data from Lythe and Kilding (2011) to similar speed bands above 14.1km/h indicated that a total of 21.6% total distance was covered at speeds exceeding 14.1km/hour, similar to that established by Jennings et al (2012a) at greater than 15km/hour. Thus, the available velocity band data suggests that there are considerable amounts of high and moderate speed running in elite men's field hockey regardless of the zones / bands used for analysis (Macutkiewicz & Sunderland, 2011). This higher speed running is considered the most taxing on the body and is often performed in an anaerobic manner inside a predominantly aerobic sport (Mohr et al., 2005).

The available data verifies that hockey is a fast-paced team game covering moderate to high amounts of total distance. However, in hockey it is seldom that a single game is played in isolation. Specifically, due to the nature of hockey tournaments, physical performances need to be repeated up to 7 times over the space of 9-14 days, making the physical demands of international hockey extremely challenging (Spencer et al., 2005).

Positional Differences

The major field positions in hockey are striker (forward), midfield and defender (back). From GPS studies to date, there are positional differences among the physical output metrics. It is apparent that defenders cover the least total distance (9,453m), whilst the midfield cover the most (10,160m) with strikers in between (9,819m) when data are normalised to a full game (Jennings et al., 2012b). However, when data are expressed relative to actual playing time per individual, defenders are found to cover more distance (7,724m) than midfielders (7,148m) and strikers (6,219m) (Jennings et al., 2012b). This is due to the greater amount of game time that defenders play (57.2 mins) in comparison to the other positions (midfielders: 49.3 min and strikers: 44.3 min), (Jennings et al., 2012b). This shows the importance of measuring actual playing time and monitoring the metres covered per minute of playing time per position as a reference for guiding playing time per individual and training protocols. With respect to overall mean work rate, defenders cover 135m per min, whilst strikers are at 140m/min and midfielders at 145m/min. A midfield player will also cover the greatest distance above 15km per hour with 1,796m covered, defenders with 1,416m covered and strikers with 1,386m covered (Jennings et al., (2012b).

This data from Jennings et al. (2012b) shows the large variation in positional differences for their team over one major international tournament and highlights the need to 1) monitor players according to position rather than team averages and 2) provide different conditioning stimulus to athletes across positional layers. As every team is different on the international level with tactics and number of substitutions it would be also very important to work out the positional requirements of the team that you are working with for total distance, minutes played, meters per minute and high speed running metres.

TABLE 2: *Current review of locomotion studies in hockey.*

Study	Description of Athletes and monitoring device	Distance and relative Distance	Reported High Speed Bands	
(Buglione et al., 2013)	12 elite and 10 sub-elite males 1Hz GPS	Elite 7062m ± 1363 121m/min Sub-Elite 6186m ± 705 110m/min	Elite Distance 19.1-23km/h = 349m ± 164 Sub-Elite Distance 19.1-23km/h = 346m ± 139	Elite Distance >23km/h = 102m ± 74 Sub-Elite Distance >23km/h = 102 ± 101
(Gabbett, 2010)	14 national level women 5Hz GPS	Striker = 6154m ±271 Midfield = 6931m ±1882 Defence = 6643m ±1618 Distance 18-25.2km/h= 423m ± 195	Striker Distance 18-25.2km/h= 423m ± 195 Midfield Distance 18-25.2km/h= 571m ± 244 Defence Distance 18-25.2km/h= 369m ± 178	Striker Distance >25.2km/h= 46m ± 57 Midfield Distance >25.2km/h= 77m ± 69 Defender distance >25.2km/h= 52m ± 62
(Jennings et al., 2012b)	16 international level men and 16 national level men 5Hz GPS	*Results are % difference of international player vs national level player (+ =international is higher)* Striker Distance = +10% Distance per min =+ 8% Midfielder Distance = +12.1% Distance per min =+11.1% Defender Distance = +13.8% Distance per min =+ 11.9%	Striker Distance <15km/h= +7.1% Midfielder Distance <15km/h= +4.3% Defender Distance <15km/h= +10.9%	Striker Distance >15km/h= +19.9% Midfielder Distance >15km/h= +32.1% Defender Distance >15km/h= +30.3%
(Jennings et al., 2012a)	15 international level men 5Hz GPS	Striker = 9819m ± 720 Midfield = 10160m ± 215 Defender = 9453m ± 579 *Metrics normalised to 70min game time	Striker Distance >15km/h = 2189m ± 456 Midfield Distance >15km/h = 2554m ± 134 Defender Distance >15km/h = 1734m ± 177 *Metrics normalised to 70min game time	
(Liu et al., 2013)	38 national level men 2Hz Video motion analysis	Striker = 7709m ± 720 Midfielder = 7733m ± 729 Defender = 6672m ± 745 *All players played 70min game time	Striker Distance >20.5km/h = 672m Midfielder Distance >20.5km/h = 659m Defender Distance >20.5km/h = 522m *All players played 70min game time	
(Lythe & Kilding, 2011)	18 international level men 1Hz GPS	6798m ± 2009 130.9m/min	Distance >19km/h = 479m ± 108 Average playing time = 51.9min ± 17.8	
(MacLeod & Sunderland, 2007)	12 national level women Video motion analysis	All values are % of total time in each movement classification for the team average (mean ± SD) Standing = 11.4% ± 3.2 Walking = 45.1% ± 4.1 Jogging = 35.6% ± 8 Cruising = 5.1% ± 5.1 Sprinting = 1.5% ± 1.3 Lunging = 1.3% ± 0.7		

(Macutkiewicz & Sunderland, 2011)	25 international level women GPS (Hz not stated)	Striker = 4700m ± 918 123m/min Midfield = 5626m ± 787 113m/min Defender = 6170m ± 977 110m/min	Striker Distance >19km/h = 232m ± 100 Midfielder Distance >19km/h = 236m ± 90 Defender Distance >19km/h = 231m ± 92	
(Spencer et al., 2005)	14 international level men Video analysis with manual description of locomotion	All values are % of total game time spent in each category, results are analysed by game rather than by position (mean ± SD) Game 1 Standing = 7.4% ±1.2 Walking = 46.5% ± 8 Jogging = 40.5% ± 7.3 Striding = 4.1% ± 1.3 Sprinting = 1.5% ± 0.8	Game 2 Standing = 11.2% ±2.7 Walking = 47.7% ± 5.6 Jogging = 34.8% ± 7.4 Striding = 5.1% ± 0.9 Sprinting = 1.2% ± 0.4	Game 3 Standing = 15.5% ±5.6 Walking = 48.3% ± 9.9 Jogging = 29.4% ± 5.7 Striding = 5.8% ± 1.4 Sprinting = 1% ± 0.3
(White & MacFarlane, 2013)	16 international level men 5Hz GPS	5819m; ± 158 124m/min; ± 4 *Results are across the full team and displayed as mean; ± 95%CL		
(White & MacFarlane, 2014)	16 international level men 5Hz GPS	5868m; ± 150 *Results are across the full team and displayed as mean; ± 95%CL	Distance 19-23km/h = 457m; ± 13	Distance >23km/h = 114m; ± 12

Section 3: Interpreting GPS-Derived metrics

Variability in GPS match outputs

Despite wide spread understanding of the physical match outputs in soccer (Bangsbo et al., 2006; Bradley et al., 2009), AFL (Coutts et al., 2010; Gray & Jenkins, 2010), rugby (Cunniffe et al., 2009; Lacome, Piscione, Hager, & Bourdin, 2014) and rugby league (Gabbett, 2005; Waldron et al., 2011), until recently there has been little understanding of the typical variability that these metrics may incur from game to game and season to season (Gregson et al., 2010). It is important that sports science practitioners understand that there will be variability in match physical outputs in team sports especially when using the data to prescribe training guidelines or to monitor physical loading of their athletes / teams or gauge match intensity or reliable performance measures (Gregson et al., 2010). Purely prescribing training loads from the mean for each position, or in some situations the team mean of physical output measures, can lead to large variances in prescribed to actual work completed, adversely affecting the physical preparation of athletes in the training setting (McLaren et al., 2015). It has been established that in many team sports, positional differences of significant magnitude are apparent with regards to GPS based match output metrics (Carling, 2013). Understanding not only what the mean values are for each GPS based physical output metric but also what the variability and range of these outputs are is essential in the optimal physical preparation in team sport athletes (Kempton et al., 2015).

Variability in physical performance is greater in magnitude in team sports (Gregson et al., 2010) compared to individual sports where distances may be set or there is a target or goal directly related to physical capability such as cycling and track and field events (Hopkins, 2005; Paton & Hopkins, 2006). In team sports there is not necessarily a link between variability in physical output data and result of the performance (Taylor, Mellalieu, James, & Shearer, 2008), due to the inherent unpredictable nature of team sports with tactics, strength of opposition and climate having an effect on how each game is played (Bradley & Noakes, 2013; Kempton et al., 2015; Mohr, Nybo, Grantham, & Racinais, 2012). Moderate to large variability in physical output match loads are apparent across team sports (Table 3) in each code, team and competition with variability (CV) in team sport physical match outputs typically ranging from 4-30%+ (Gregson et al., 2010; Kempton et al., 2014; McLaren et al., 2015).

The variability of physical match outputs is based off GPS derived metrics, including both absolute and relative to time; total distance, distance in various speed bands, repeated high intensity efforts and agility/explosive efforts (McLaren et al., 2015). The variability of these metrics in team sports mirrors that of the reliability of GPS metrics, with the lowest variability seen in low speed or total distance and variability increasing as the speed of the data sample increases with the highest variability being seen in match output sprinting or high speed distances in excess of 20km/h (Kempton et al., 2015; McLaren et al., 2015). Variability of total distance and total distance relative to time across football, AFL, rugby union and rugby league is typically between 3.5-10% (Kempton et al., 2014; Kempton et al., 2015; McLaren et al., 2015), whilst speed bands within the range of 0-15km/h also have match variabilities of under 10% (McLaren et al., 2015). Large increases in the amount of variability in physical match output are seen at speeds in excess of 15km/h with 13-33% variability seen across research within speed bands starting between 14.4-15km/h and going up to 19-23km/h and variabilities of 19.8-69% seen for speed bands that start between 19-23km/h (Gregson et al., 2010; Kempton et al., 2014; Kempton et al., 2015; McLaren et al., 2015). The lower reliability of GPS measures above 20km/h may be a reason for the high variability seen in physical match outputs above 20km/h (A. Coutts & R. Duffield, 2010; Johnston et al., 2014; Rampinini et al., 2014), as well as the inherent variability in match to match high speed running, with not all matches being equal(Gregson et al., 2010).

TABLE 3: *Variability of physical match outputs*

Study	Sport and description of athletes	Variability of GPS metrics				
(McLaren et al., 2015)	Professional Rugby Players	Forwards Within player (CV; ± 90%CL) Distance = 10%; ± 2.1 Distance <15km/h = 8.7%; ± 1.9 Distance 15-20km/h = 27.6%; ± 6.9 Distance >20km/h = 68%; ± 19 Metres per min = 10%; ± 1.4 Forwards Between player (CV; ± 90%CL) Distance = 5.5%; ± 1.5 Distance <15km/h = 2.2%; ± 5.3 Distance 15-20km/h = 16.5%; ± 5.1 Distance >20kmh = 58%; ± 63 Metres per min = 4.2%; ± 3.3	Backs Within Player (CV; ± 90%CL) Distance = 10.8%; ± 2.1 Distance <15km/h = 810.1%; ± 2 Distance 15-20km/h = 20.1%; ± 4.1 Distance >20km/h = 34.1%; ± 7.5 Metres per min = 10.1%; ± 1.5 Backs Between player (CV; ± 90%CL) Distance = 6.7%; ± 4.7 Distance <15km/h = 6.1%; ± 4.4 Distance 15-20km/h = 32%; ± 19 Distance >20kmh = 19%; ± 17 Metres per min = 6.7%; ± 3.3			
(Gregson et al., 2010)	Professional Football Players	Variability of Distance above 19.8km/h (CV; ± 95% CL) Central Defender = 20.8%; ± 1.2	Wide Defender = 17.9%; ± 1.2	Central Midfielder = 18.8%; ± 1.2	Wide Midfielder = 14.7%; ± 1.3	Attacker = 16.3%; ± 1.5
(Kempton et al., 2014)	Professional Rugby League Players	Results expressed as CV; (90% CL) Distance = 3.6%; (3.2-4.2) Distance >15km/h = 14.6%; (12.7-17.1) Distance >21km/h = 37.9%; (32.8-45)				
(Kempton et al., 2015)	Professional AFL Players	Backs (CV; 95%CL) Distance = 7%; (6.1-8.3) Metres per min = 6.4% (5.5-7.5) Distance >19.9km/h = 20%; (17.3-24)	Midfield (CV; 95%CL) Distance = 5.6%; (5-6.4) Metres per min = 4.5% (4-5.2) Distance >19.9km/h = 20.9%; (18.5-24.2)	Forwards (CV; 95%CL) Distance = 4.9%; (4.2-6.1) Metres per min = 4.8% (4-5.9) Distance >19.9km/h = 15.1%; (12.8-18.8)		

Effect of situational variables on physical match outputs and variability.

In addition to understanding the positional differences and variabilities amongst match physical output data it is also important to understand what may cause the variability in match outputs (Kempton et al., 2015). There are many possible causes of the variability in physical match outputs in team sports including, heat, travel, result, score line, rank of the opposition, tactics, strategy, pacing, levels of arousal, importance of the game, time of the season, fatigue levels and recovery time from the last high load training or match (Aughey, 2011b; Lago, Casais, Dominguez, & Sampaio, 2010; Mohr et al., 2012; Spencer et al., 2005; Taylor et al., 2008). With such an array of potential influencing factors on match physical outputs it is not surprising that all of the literature on team sports variability shows moderate to high levels of variability within physical outputs metrics (Kempton et al., 2014; Kempton et al., 2015; McLaren et al., 2015).

To optimise training and preparation for matches, understanding some key trends may be of benefit to coaches, such as what the effect of the ranking of the opposition typically has on the teams levels of physical outputs (Hewitt et al., 2014). Knowing this in advance can help tailor training programs and guide periodisation (Aughey, 2011a; Neville, Rowlands, Wixted, & James, 2012), recovery protocols and injury prevention / tracking (Cummins et al., 2013; Dupont et al., 2010).

As mentioned earlier, many situational variables can have an affect both on the match physical outputs and the variability of these outputs (Bradley & Noakes, 2013). It is documented that in AFL there is an increase in high speed running in finals series games when compared to regular season games by an average of 9.2% and an increase in relative distance (m/min) of 11% (Aughey, 2011b). This finding brings into question the reason for the increase in physical load of final series AFL matches. Internal variables such as arousal levels which are inherently heightened during play off football may have something to do with the increase in physical output with players pushing themselves closer to their maximum physical capacity, as well as external variables such as the tactical and strategic differences and technical ability of the other highly ranked teams that play in the final series causing higher physical outputs (Aughey, 2011b). In football, highly ranked opposition is one situational variable that has an effect on physical outputs with greater low and moderate speed running completed when playing strong or highly ranked opponents (Hewitt et al., 2014; Lago et al., 2010) and can increase the amount of high speed running performed in pre-season matches (Folgado, Duarte, Fernandes, & Sampaio, 2014). Unlike in AFL, high speed running in football is said not to be influenced by match importance, however can be influenced by score line, with positional variances showing a change in amount of high speed running in matches heavily won or lost, and substitutions with players completing higher percent of total distance of high speed running when coming on as a substitute than a starting player (Bradley & Noakes, 2013). It has also been reported in football that when playing games in hot climates, football players run lower total distance and lower high speed running distances than when compared to playing games in in thermoneutral temperatures (Mohr et al., 2012). Conflicting evidence on the effect of recovery time on multiple games in a short period of time exits. When playing 3 hockey games in a four day period, there were significant reductions in time spent at moderate and high intensity running zones with an increase in time spent at low intensity running zones (Spencer et al., 2005), suggesting that there was not enough time to recover between games to successfully maintain physical match output. Conversely, in a hockey tournament setting, it was reported that playing 6 games in a period of 9 days against top 10 ranked opposition that it was possible for elite hockey players to maintain physical output and intensity with no significant changes in physical output values across the tournament (Jennings et al., 2012a). In football it has been reported that playing two games in a short period of time, with 72-96 hours recovery time between games, provides enough recovery time to maintain physical match outputs with no significant differences to when playing one game per week, however match congestion does increase the risk of injury when compared to playing one game a week (Dupont et al., 2010).

Making meaningful inferences about change in GPS metrics.

Once variability has been established for physical output data, it is important to know how to apply the values given so that meaningful observations can be made (Batterham & Hopkins, 2006). This is important for both training and competition so that inferences of smallest and likely worthwhile changes to the mean can be applied to the data (Batterham & Hopkins, 2006), allowing the sports science practitioner to better understand the collected data and any changes to the mean in matches or purposeful description off mean values in a training setting. Smallest worthwhile changes in team sport athletic performance is determined by using the standardised change or difference which can be calculated using 0.2 of the between athlete variability of the sample (Hopkins, 2004). Once calculated for all metrics you have a value of the smallest worthwhile change that is needed to see in the mean value in order for that change to be considered worthwhile or above trivial change. The smallest worthwhile change or change greater than trivial change in the mean can sometimes be affected by noise or TEM of the mode of data collection (Hopkins, 2004). Using ‘likely’ limits will provide with the ‘likely’ change in mean value that would be needed to effect significant change, with likely referring to >75% of the time (Hopkins, 2004). The reliability of GPS shows higher than recommended TEM (Rampinini et al., 2014) to use the smallest worthwhile change with GPS monitoring at speeds in excess of 20km/h so likely worthwhile change would be considered a more appropriate method of analysing change to the mean (Hopkins, 2004). Likely worthwhile changes in mean value can be calculated using a custom made spreadsheet (Hopkins, 2000). Values of likely worthwhile change, however, may be not be practically suitable to apply to physical output match data as they may deem too high (Hopkins, 2004). This could be related to a number of factors such as; high TEM of the test, for example GPS data collected above 20km/h with a TEM of >10% on 10Hz GPS units (Johnston et al., 2013; Rampinini et al., 2014), high variability of the sample and the likelihood that such a change could be elicited within the constraints of the sport (Hopkins, 2004). However, for values with a low TEM or high reliability such as total distance, relative distance and distances 0-15km/h (Johnston et al., 2013; Rampinini et al., 2014) likely worthwhile change may provide valuable insight in how to make training drills or sessions have a >75% chance of being clinically greater than the mean value (Hopkins, 2004) of match play and appropriate prescription of these overloaded, supramaximal activities may lead to enhanced physical gains (Hill-Haas, Coutts, Rowsell, & Dawson, 2009; Neville et al., 2012).

Section 4: Future Directions

Conditioning of elite hockey players needs to effectively enhance their physical capabilities whilst also enhancing technical and tactical hockey skills and knowledge (Gabbett, 2010). Through appropriate loading schemes adopted in training, hockey players can be best prepared for the physical demands of international competition (Gabbett, 2010). To assist with this programing, insight into the variability of match physical outputs, smallest and likely worthwhile change of match loads and knowledge into what factors may affect the variability need to be better understood. As yet, despite knowledge of the physical outputs of elite hockey players (Table 2), there is still no longitudinal analysis of the variability of match output metrics in hockey as seen in other sports such as AFL (Kempton et al., 2015), rugby union (McLaren et al., 2015), rugby league (Kempton et al., 2014) and football (Gregson et al., 2010). Due to the nature of hockey competitions, often involving 6-7 international matches over 9-14 days, against a wide range of opposition, it is possible that the between- and within-player variability may indeed be greater than previously reported in AFL, soccer and rugby. Understanding the magnitude of overall variability, variability by position and potential causes of variability in light of meaningful changes in mean values of key physical match outputs in international level hockey may help practitioners enhance training strategies so that teams are appropriately prepared for the rigors of international hockey.

Conclusion

Monitoring of physical outputs is common across many team sports, with various monitoring tools which can be used to assess the demands of match play and training. The ability to collect information of external physical outputs can be accomplished through the use of time-motion analysis in the forms of GPS or video tracking. As technology has advanced, the reliability and validity of GPS measures has improved, making it possible to accurately monitor locomotion based outputs using 10 or 15Hz GPS units, however there is still a degree of caution recommended when analysing distance covered in speeds in excess of 20km/h. There appears to be positional differences within sports, meaning the monitoring of teams and athletes should be performed on an individual or within position level rather than broad spectrum across the team. Within AFL, football and rugby codes there is a moderate to large amount of variation from match to match in physical output loads with the highest variability occurring at high speed velocities. Variability for total distance, low speed running and work rate is typically below 10%. The low variability at these zones means that meaningful inferences can be made about changes to mean values which may indicate an increase or decrease in physical outputs across match play or be used to guide training protocols in an effort to maximise training time and fitness characteristics by training above match demands. The demands of match play have been analysed in hockey, however, as yet there is no clear evidence on the match to match variability in hockey. Understanding the variability of physical outputs in hockey may help enhance the application of the physical outputs into a training and performance setting.

Chapter 3: Variability of physical outputs based of GPS data in Elite Field Hockey matches.

Abstract

Aim: To determine the match to match physical outputs and variability of physical outputs by position for international male hockey players. *Methods:* Twenty-one international hockey players were monitored using a Catapult Minimax 10Hz GPS unit over the course of twenty-nine international hockey matches, with ~12 athletes being monitored per match. The physical outputs of each outfield position (striker, midfield and defender) were compared with a one-way ANOVA and Bonferroni post-hoc ($P<0.05$) tests applied to report significant differences in mean outputs between positions. Physical outputs were expressed as mean ± SD. Within player and between player variability (CV) was established based off either each athletes variability of data (within player) or each positions variability of data (between player). Variability was expressed as a CV; ± 95% CL. Smallest worthwhile change was established based off 0.2 of the between player SD and using a customised spreadsheet the *likely* worthwhile change was established which related to a ≥75% chance of change in the mean value. *Results:* Significant differences in physical outputs existed between strikers and all other positions with strikers reporting significantly lower total distance and low speed distance compared to midfielders and defenders. Further significant differences were, higher moderate and high speed absolute and relative metrics compared to defenders. Also reported were significantly lower absolute moderate and high speed distance compared to midfielders, however significantly higher relative moderate distance compared to midfielders. Significant differences in mean outputs also existed between defenders and all other positions for total distance (lower than midfielders, higher than strikers), and moderate speed distance, high speed distance and high speed relative distance where all significantly lower for defenders compared to strikers and midfielders. Between and within player variability was higher for absolute analysis than it was for relative analysis, whilst moderate and high speed metrics observed high variability (13-43% between player CV and 20-39% within player CV) and relative distance and low speed relative distance observed the lowest variability (4-11% between player CV and 5-11% within player CV). Smallest worthwhile change values were lower at total distance and low speeds (0.7-3.4%) than at moderate and high speeds (2.6-8.5%) with '*likely*' worthwhile change also following the same trend with lower values at low and total relative distances (5.4-12.3%) than at moderate and high speed relative distances (22-49.4%). *Conclusion:* Within and

between player variability of high speed distances in international hockey is large, yet by comparison relative distance and low speed distances are more stable from match to match. Knowledge of the percent threshold for a *likely* worthwhile change for a given metric, in light of established variability and smallest worthwhile change, could be useful in applying these results into a training setting.

Introduction

Monitoring locomotion and movement of athletes in elite team sports is now common practice as coaches and sports science practitioners seek to better understand the movement requirements of team sport match play in order to optimise training strategies and physical preparation for optimal match performance (Coutts & Duffield, 2010). With advancing accuracy of GPS technology (Johnston et al., 2014), it is possible to quantify and track several metrics related to the movement and physical demands of training and games. Typically, these include distance covered, acceleration, volume of running in various speed categories (absolute and relative) and work rate (Cummins et al., 2013). However, team sports are played in an unstable and unpredictable environment with inherent variation in GPS established metrics from game to game (within-player), between players and between positions. Specifically, this variation may occur due to tactical differences, positional differences, rank of the opposition, score line, physical condition of players and time of the season (Gregson et al., 2010; McLaren et al., 2015). Understanding the variability of match day performance is an important factor in best planning training loads to ensure that players are well trained for the highest probable loads they may encounter in a game rather than just the average load (Bangsbo et al., 2006; Bradley et al., 2009).

The reported magnitude of variability in physical outputs in team sports is typically moderate to high with variability of GPS derived physical outputs ranging from 4-68% across several team sports such as AFL (Kempton et al., 2015), soccer (Gregson et al., 2010) and rugby (McLaren et al., 2015). It appears that the total distance covered and distance covered at low speeds (<15km/h) present the lowest variability in GPS based physical match loads regardless of whether distance is expressed in absolute or relative terms with typical variability of 4-11%. The variability of distance covered at moderate speeds (~11-20km/h) shows higher variability between 11-33% and distance at high or sprinting speeds (>20km/h) showing the highest levels of variability between 15-68% (Gregson et al., 2010; Kempton et al., 2015; McLaren et al., 2015). It should be acknowledged that these findings of variability from team sports also mimic the findings of variability and accuracy of GPS technology itself to measure metrics of interest with commercially available GPS units showing low typical error (1.3-4.8%) for total distance and distance covered at speeds under 20km/h and a high typical error (11.5%) for distance covered above 20km/h or high speed running (Johnston et al., 2014) (Akenhead et al., 2014; A. Coutts & R. Duffield, 2010; Johnston et al., 2012)

To date, several studies have quantified the player and position outputs in elite male (Jennings et al., 2012a, 2012b; Lythe & Kilding, 2011; White & MacFarlane, 2014) and female (Gabbett, 2010) field hockey. The average distance covered per game appears to be between 5800-6700 per game with most players not playing the full 70min duration as the sport allows rolling and unlimited substitutions (Lythe & Kilding, 2011; White & MacFarlane, 2014), whilst the average amount of high speed running above 19km/h is reported to be between 5-10% of the total distance covered in each game and the average work rate is typically between 120 and 140 metres per minute played (Jennings et al., 2012a, 2012b; Lythe & Kilding, 2011; White & MacFarlane, 2014).

To our knowledge, there is very little data on match to match variability of physical outputs during hockey. Previously it was established that a 6 game tournament over 9 days did not significantly change the volume of high speed running across playing positions when data was compared to either game 1 of the tournament or the tournament average (Jennings et al., 2012a). Further exploration is required to establish the variability in physical match performance measures with a greater sample size and greater number of matches. One factor that may cause further variability in hockey players than that seen in other team sports is that the game is played with unlimited rolling substitutions. This means that each players game time can vary from performance to performance depending on the team's substitution strategies (Lythe & Kilding, 2013). For this reason it is important to gauge not only absolute metrics to establish match variability but also metrics relative to the duration each player is on the pitch. Therefore, to further our understanding of positional variability in field hockey, the purpose of this study is to establish the match to match (within-player) and between-player variability of GPS-derived physical performance metrics for strikers, midfielders and defenders in elite male hockey.

Methods

Players and match data

Match physical output data was collected from 21 international players (strikers/forwards, n=8; midfielder, n=5; defender, n=8), weight 77.2kg ±5.9, height 180cm ± 6.4 and age 24 years 8 months ±20 months, from the New Zealand Men's Hockey team across an ~8month period in 2014 during which 29 international test matches were played. A total of 339 physical performance data sets were analysed. The opposition ranged from teams ranked 1-29 in the world average 10.2 ± 6.5, whilst the ranking of the NZ team remained constant through the year at 6th. Some opposition teams ranking changed throughout the year. There were six matches at Hockey World League Finals, three matches as a home test series, two matches as an away test series, six matches at the Hockey Champions Challenge event, six matches at the Hockey World Cup and six matches at the Commonwealth Games. Across the tournaments and test series there were minor changes to the team that was selected. Ethical approval was granted through AUTEC and players all signed consent forms for data to be used in research.

Data collection and analysis.

Match physical output data was collected using Catapult Minimax S4 10Hz GPS units (Catapult Innovations, Melbourne, Australia). All data was downloaded using Logan Plus software Catapult Sprint V5.1.7 (Catapult Innovations, Melbourne, Australia). A minimum of six satellites in connection with the GPS system are required for data to be analysed, with zero data sets being excluded due to lack of satellite connection. The reliability of this GPS system is well documented, with TE typically being under 5% for total distance, and low-moderate speed running <20km/h though greater 10-12% TE at speeds >20km/h (Johnston et al., 2014). Due to the permitted rolling and unlimited substitutions in field hockey, only time on pitch (TOP) was recorded for each player, eliminating any time that the player was substituted. This was consistent with earlier research (White & MacFarlane, 2013) and allows calculation of relative measures. For each game 12-13 players were monitored depending on number of GPS units available. Several metrics were obtained: Total distance (TD) covered on pitch during the match; low speed distance (LSD) between 0-11km/h, moderate speed distance (MSD) between 11.01 and 19km/hand high speed distance (HSD) in excess of 19.01km/h. In addition, measures relative to game time were also used. Specifically, Total Metres per minute (RD) was established by dividing the total distance covered in the match divided by TOP as well as velocity based metres per minute using the above mentioned low (LSRD), moderate (MSRD)and high (HSRD) speed velocity bands. The velocity bands were set with the same bands as previous hockey literature (Lythe & Kilding, 2011; White & MacFarlane, 2014). The terms 'high speed, moderate speed and low speed distance' have been used rather than the term 'high, moderate and low intensity' as we are not accounting for individual differences in aerobic or anaerobic capacity, thus a judgement on whether or not the movement is high intensity for each athlete would be a generalisation. The terms high, moderate or low speed distance are used across most literature where there is no individualisation of velocity bands (Abt & Lovell, 2009; Hunter et al., 2015). For an individual's data to be included in this research, they needed to be monitored via GPS for a minimum of 4 games in the data collection time frame with the mean number of games that individuals were monitored for being 19 games out of 29 matches. Due to minimal changes in the playing squad throughout the data collection block only 2 athletes did not meet the inclusion criteria of 4 games. There was no minimum playing time required for inclusion in the study given that both relative and absolute metrics are being analysed.

Statistical Analysis

The mean, standard deviation (SD) and match to match variability (typical error expressed as coefficient of variance, CV), was established using IBM SPSS Statistics v22 (IBMCorporation, Armonk, New York, U.S.A). Two forms of variability analysis were conducted: game to game (within player) variability and between player and position variability. The between and within player variability was determined using a mixed model linear approach and analysis of repeated samples from each game and player resulting in a CV value for every GPS metric from the total number of games that were monitored for a given athlete and an overall between game CV for all players. These individual CV values were then grouped into the three positions (Striker, Midfielder and Defender) and the mean CV, standard deviation of the CV and 95% confidence intervals generated for each respective position. A one way ANOVA was used to compare the mean data from each position. Significance was set 0.05. We also wished to establish the threshold for a 'likely worthwhile change (%)' in a typical individual's physical performance and match load. Using a custom-made spreadsheet (Hopkins, 2000), we specified a smallest worthwhile change (%) of 0.2 of the between player CV, as previously adopted by McLaren et al., (2015), and used the determined within-player CV for a given metric to obtain the percentage change that would be necessary for a change in the mean to be deemed 'likely' substantial.

Results

The absolute and relative physical output data from 29 games comprising 339 data sets is presented in Table 4. The mean total distance completed for all players was 5612m with 3280m (58.4% total distance) covered in the LSD band, 1913m (34% total distance) covered in the MSD band and 419m (7.5% total distance) covered in the HSD band. The mean work rate (RD) during games was 130m/min.

Table 4: *Descriptive GPS derived physical outputs for all players and by playing position (M ± SD)*

Absolute Physical Outputs	All players n= 339	Strikers n= 132	Midfielders n= 93	Defenders n= 114
Playing Time (mins)	44 ±10	36 ±7*‡	49 ±6	49 ±7
Total Distance	5612 ±1097	4979 ±965*‡	6349 ±903 ≠	5745 ±960
LSD	3280 ±738	2672 ±550*‡	3614 ±425	3711 ±647
MSD	1913 ±532	1892 ±543*‡	2209 ±472≠	1696 ±451
HSD	419 ±191	415 ±169*‡	525 ±212≠	336 ±151
Relative Physical Outputs	**All players mean**	**Strikers mean**	**Midfielders Mean**	**Defenders Mean**
RD	130 ±17	139 ±16*‡	131 ±10≠	119 ±15
LSRD	75 ±7	75 ±9	75 ±3	77 ±6
MSRD	45 ±13	53 ±14*‡	46 ±8≠	36 ±10
HSRD	10 ±4	12 ±4‡	11 ±4≠	7 ±3

LSD = Low Speed Distance; MSD = Moderate Speed Distance; HSD = High Speed Distance; RD = Relative distance; LSRD = Low Speed Relative Distance; MSRD = Moderate Speed Relative Distance, HSRD = High Speed Relative Distance (mean±SD). * = significant difference between Strikers and Midfielders; ‡ = significant difference between Strikers and Defenders; ≠ = significant difference between Midfielders and Defenders ($p < 0.05$).

Table 4 shows how the physical outputs of the game are different for each position. For absolute metrics, all of the strikers means values were significantly lower than both the midfielder's and defender's. There were similarities between midfielders and defenders for several metrics, though total distance, MSD and HSD were greater in midfielders. For relative metrics, strikers have a significantly higher work rate than other positions and greater MSRD and HSRD than other positions.

A summary of the between and within player variability for absolute and relative physical output metrics, by position, is presented in Table 5. Regardless of position, the greatest between and within player variability was associated with HSD and HSRD compared to other speed categories.

Variability for relative metrics was mostly lower than variability for absolute metrics for all positions. Smallest worthwhile change values range from 0.7-8.5% of mean values with all relative distance and LSRD SWC values being ≤2.2%. Likely worthwhile change values ranged from 5.4-47% change in mean values again with relative distance and LSRD consistently producing the lowest LWC values of ≤12.2% for a ≥75% chance in a likely significant change in mean physical output values.

Table 5: *Between and within player variability for absolute and relative physical output metrics, and practical interpretation of physical outputs.*

Strikers				
Absolute Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
Total Distance	16; ± 2	18; ± 4	3	21
LSD	17; ± 3	20; ± 7	3	23
MSD	25; ± 4	28; ± 14	5	33
HSD	35; ± 5	32; ± 9	7	39
Relative Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
RD	9; ± 2	10; ± 3	2	11
LSRD	9; ± 3	11; ± 4	2	12
MSRD	22; ± 4	26; ± 10	4	30
HSRD)	31; ± 5	28; ± 9	6	35
Midfielders				
Absolute Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
Total Distance	12; ± 3	11; ± 2	3	13
LSD	11; ± 2	10; ± 2	2	12
MSD	18; ± 4	20; ± 6	4	24
HSD	35; ± 5	35; ± 11	7	42
Relative Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
RD	6; ± 2	9; ± 3	1	9
LSRD	4; ± 1	5; ± 1	1	5
MSRD	13; ± 4	20; ± 10	3	22
HSRD)	32; ± 4	34; ± 14	6	41
Defenders				
Absolute Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
Total Distance	14; ± 3	14; ± 3	3	16
LSD	14; ± 3	16; ± 4	3	18
MSD	25; ± 4	21; ± 6	5	26
HSD	39; ± 7	38; ± 16	8	47
Relative Physical Outputs	Between Player CV (%;± 95% CL)	Within Player CV (%;± 95% CL)	Smallest Worthwhile change (%)	Likely worthwhile change (%)[a]
RD	11; ± 3	8; ± 3	2	10
LSRD	5; ± 2	6; ± 3	1	7
MSRD	26; ± 5	21; ± 8	5	26
HSRD)	43; ± 7	39; ± 16	9	49

CV =coefficient of variation; CL = confidnece limits; LSD = Low Speed Distance; MSD = Moderate Speed Distance; HSD = High Speed Distance; RD = Relative distance LSRD = Low Speed Relative Distance; MSRD = Moderate Speed Relative Distance, HSRD = High Speed Relative Distance (mean±SD). [a] = 75% chance.

Discussion

This is the first study to report the variability of physical performance data in international hockey over an international season. Our data provides evidence that the physical outputs of international hockey vary significantly across each of the three major positions and that hockey is a non-stable performance environment with a moderate to large degree of variability of physical performance measures.

Whilst the GPS-derived time-motion analysis values quantified in the present study cannot be directly compared to other hockey literature due to positional differences, team strategies and minor rule changes over the publication period, the values observed appear consistent with previous studies (Lythe & Kilding, 2011). The only main difference between the present study and previous literature is the greater mean total 6,798m, (Lythe & Kilding, 2011) and 5,819m, (White & MacFarlane, 2013) compared to the mean distance (5612m) in the present study. This is likely due to the lower playing time in the present study (43.1min) compared to other studies 51.9min, (Lythe & Kilding, 2011) and 46.9min, (White & MacFarlane, 2013). When data are expressed in metres covered per minute of actual on pitch playing time per player as recommended and described in White and MacFarlane, (2013) there is little difference between the present Study (130.1m/min) and previous studies 130.8m/min, (Lythe & Kilding, 2011) and 124m/min, (White & MacFarlane, 2013). Similarities are also apparent for volume of running in the various speed categories (Lythe & Kilding, 2011) with strikers covering significantly higher relative distance and moderate speed distance than midfielders and defenders, whilst strikers and midfielders cover significantly higher high speed distance than defenders.

Irrespective of position and absolute or relative measures, Total Distance and Low speed distance had the lowest variability in the present study (Table 5). However, in support of previous studies (McLaren et al., 2015) the variability in absolute or relative distance covered, both within and between player, increased substantially as velocity bands increased from low to high speed running, except for defenders between player variability at MSRD compared to MSD, and for strikers and midfielders, but not defenders, with HSRD compared to HSD. This is likely due to the rolling substitutions that can be used in hockey, which can vary player's playing time, with each position typically having different rotations and overall playing times. This relationship was not seen in professional rugby with seemingly no relationship between lower relative than absolute variables (McLaren et al., 2015).

For all positions, the results showed reduced variability with relative physical outputs. This suggests that for elite hockey it is important to not only monitor absolute physical outputs but also monitor physical outputs relative to game time for each position (White & MacFarlane, 2013). While early studies reported only absolute outputs in fixed speed ‘zones’, many studies now report a combination of relative and absolute metrics to monitor playing load (Aughey, 2011a). Furthermore, due to unlimited rolling substitutions in hockey, players may have different amounts of game time and therefore the positional requirements change from each position (White & MacFarlane, 2013). Evidence of the impact of this is seen when analysing the positional metrics per game with strikers covering the greatest relative distance per minute whilst covering the least absolute distance of the three positions, due to strikers have a significantly lower game time (36.1min) compared to both midfielders (48.5mins) and defenders (48.5mins). The same relationship was seen with relative distance at low speeds compared to absolute distance at low speed with strikers covering lower absolute low speed distance than midfielders and defenders despite the relative low speed distances being very similar. To address varying amount of time on pitch in the reporting of physical output metrics, previous studies in sports without the rolling substitutions rule have chosen to either exclude data sets from analysis of absolute values when a player did not play a full game (McLaren et al., 2015) or played less than 90% of a game (Kempton et al., 2014). This approach is not suitable for hockey due to the rolling substitutions that are permitted. On analysis of the data, especially between playing positions the most worthwhile metrics will be those relative to game time as there are established differences in playing time between a striker, midfielder and defender in international hockey (Lythe & Kilding, 2011). AFL is another team sport where rolling substitutions are permitted, although substitutions are not as frequent as in hockey. GPS outputs in AFL indicate that analysis of relative metrics for both variability and descriptive measure is important in determining accurate physical match outputs (Gray & Jenkins, 2010).

The reduction in variability within the relative metrics is not uniform with rugby showing little difference between absolute and relative variability metrics with variability often slightly lower on the absolute group (McLaren et al., 2015). Conversely, relative distance in AFL does show a decrease in variability levels when compared to total distance across all positional lines (Kempton et al., 2015).

In agreement with previous literature (Kempton et al., 2015; McLaren et al., 2015), the highest levels of variability across all positions occurred with high speed running distance – both absolute and relative - and between and within players analysis whilst high levels of variability where also reported with moderate speed running. Specifically, CV's ranged from 27.8-42.5% across positions. In support, McLaren et al., (2015) also reported very high levels of high speed running variability above 20km/h with backs having a similar variability in high speed running (CV, 19-44.5%) and forwards having a much higher variability than reported in the present study (CV, 58-69%) (McLaren et al., 2015). McLaren et al., (2015) explained that a reason for the very high spread in forwards CV and the high spread in backs CV could be due to different subgroups within those positions such as front rowers or loose forwards. Hockey probably does not have a similar range of subgroups within positions to the extent that rugby does, however there may also be a small influence of these subgroups, especially in defenders where centre back and free man may perform slightly different roles to the left and right half positions (Jennings et al., 2012a). In contrast, in AFL, Kempton et al., (2015) showed much less variability at speeds above 19.9km/h (15.1-20.9%) and 23km/h (23.9-30.4%) as did Gregson et al., (2010) in football with variability of 14.7-20.8% across the positional lines at speeds above 19.8km/h, suggesting high speed running in some sports are less variable. Possible reasons why the variability of the high speed data observed in the current study could be much greater than observed in AFL and football could be related to positional break down of the analysis with football using 5 positional lines for analysis across 10 field players per game as opposed to the 3 used in the current study over 10 field players.

McLaren et al., (2015) discusses that more defined and precise positional groups may decrease the variability such as breaking rugby forwards into front row forwards, locks and loose forwards. Within hockey the strikers, midfielders and defenders position descriptives could be further broken into small subgroups of positions, which may result in reduced variability. However, increased positional breakdown does not explain the low variance in AFL which also used only three positional lines over a greater number of players (Kempton et al., 2015). Other factors that may have led to increased variability in the current study could be the large range of opposition played across the 8 month period (teams ranked 1-29 in the world) (Hewitt et al., 2014), the tournament-style of hockey with games every 1-2 days over a 9-14 day period which may result in fatigue (Spencer et al., 2005) or pacing when a game result may be secure (Jennings et al., 2012a) , tactical strategies such as defensive full press or half press options (Jennings et al., 2012a), change in fitness levels across the season (Gregson et al., 2010) and climate (Mohr et al., 2012).

When considering variability in the context of team sports, the variability of devices used as well as the actual player variability needs consideration. Since the emergence of GPS use in team sports several studies have reported on the accuracy and reliability of various GPS units (Coutts & Duffield, 2010; Jennings et al., 2010), especially as technology has progressed rapidly. In the present study, commercially available 10Hz GPS devices were used which have reported CVs (typical error) of 1.9% for total distance and 11.8% at high speeds > 20km/h (Johnston et al., 2014), which was close to the highest speed band in the present study. It is difficult to partition the technical and player variability from actual team sport data and therefore interpreting the total variability to get a better sense of player variability alone is a challenge, as previously alluded to by Maclaren et al (2015). Whilst the high typical error of data collection at speeds in excess of 20km/h may provide some explanation to the high variability seen in the present study at high speeds, the magnitude of the variability values for HSD and HSRD are much greater than the noise of typical error of the units showing that high speed running in hockey is still highly variable despite the inability to separate the noise of error from the GPS units to the variability reported in this study.

Practical Applications

This data set has implications for those involved in physical preparation and coaching of elite male hockey players and would suggest that neither the team or the players re-produce consistent physical output measures from game to game, with HSR variability being the greatest physical output variable. This can data can affect both, training regimes for international hockey players as well as having an effect on applied research studies that use game physical outputs as a performance indicator (Bangsbo et al., 2006; Gabbett, 2010; Gregson et al., 2010).

Due to the typically moderate to large variability of physical output data across all positions, a relatively large change in mean value for a given metric, especially HSD/HSRD, may not necessarily represent a substantial change. Therefore, it is important to establish the smallest worthwhile and 'likely' worthwhile change in mean values (Batterham & Hopkins, 2006; Hopkins, 2004). The importance of this is two-fold: 1) to ascertain whether changes to training or recovery or strategy is required if a game is substantially more (or less) physically demanding; and 2) to establish what physical outputs need to be achieved in training drills, games and interventions if the coaches and sport science practitioners want to expose players to training intensities and volumes beyond the typical demands and variability of matches. This was addressed by adopting the same approach as McLaren et al., (2015) who established the 'likely' substantial change (chance ≥75%) in the mean for a given metric in rugby union players, with respect to the observed within player CV and the smallest worthwhile change (0.2 of determined between-player variability). The concept of identifying a threshold for a 'likely' substantial change is valuable for the practitioner as it can be used as a guide for assessing efficacy of training interventions, monitoring potentially higher match demands and adapting recovery protocols. However, because of the high CV of some metrics in the present study, a very large percentage change in mean is needed to reach the threshold of a 'likely' substantial change, often 30-50% (Table 5). With the lowest variability observed for overall work rate across positions, a 'likely' substantial change in work rate could be the most appropriate intervention in hockey. For example, using conditioning drills with an 11.3%, 9.3% and 10.4% higher value than the means for striker, midfield and defender respectively, would impose a stimulus that would be 'likely' substantially higher than the mean match play work rate load for each position. Further analysis into what causes the variability in each position and across each metric may provide further insights and more accurate estimations of the 'likely' substantial change thresholds.

Conclusion

In summary, considerable variability exists for common GPS-derived physical output metrics in elite male hockey, regardless of field position. Use of the variability data in light of the smallest worthwhile change and the percent threshold for quantifying a 'likely' substantial change in a given metric, indicated that the overall work rate (m/min) of players would be the most useful metric in elite field hockey with which to ascertain a change in physical load. In this regard, a ~10% change in work load would signify a substantial change in work rate for all positions. Further research is needed to explore factors that might influence the variability in elite field hockey to further refine the practical implications of this study.

Chapter 4: Situational Variances and the influence on physical output measures and within player variability

Abstract

Aim: To determine the influence of the 'situational' variances of the; rank of the opposition, result of the match and match score margin on, physical match outputs and the variability of physical match outputs. *Methods:* Twenty-one international hockey players were monitored using a Catapult Minimax 10Hz GPS unit over the course of twenty-nine international hockey matches, with ~12 athletes being monitored per match. The physical outputs of each outfield position (striker, midfield and defender) were reported in relation to each situational variable with a one-way ANOVA and Bonferroni post-hoc tests applied to report significant differences in mean outputs between situational variables. Physical outputs were expressed as mean ± SD. Within player variability (CV) were established based off each athletes variability of data as they related to each situational variable. Variability was expressed as CV; ± 95% CL. *Results:* Significant changes in physical outputs were established for midfield moderate absolute and relative distance and well as high speed relative distance and relative distance between highly ranked opposition and low ranked opposition. Defenders reported significant changes between high speed relative distance for the same rank effect of highly ranked teams vs low ranked as well as, in a win vs a loss, and a big win vs a big loss. Situational variables did not reduce the within player variability of hockey players with moderate and high speed metrics still producing variability results in excess of 15% whilst low and relative distance also remained at similar levels of variability (<10%). *Conclusion:* Within player variability is not reduced when compared to within player variability by rank, result or score margin. There is a small effect of situational variance on physical outputs however these effects do not exceed the magnitude of variability observed.

Introduction

The physical outputs measured by GPS have been established in elite hockey with typical total distances ranging from 5000-8000m of which 5-15% is performed above 19km/h (Jennings et al., 2012a; Lythe & Kilding, 2011; White & MacFarlane, 2014). The physical output metrics are largely positional and time dependant with midfielders typically covering the highest distance (Jennings et al., 2012a). Conversely, strikers, who typically play the least amount of minutes, cover the least distances (Lythe & Kilding, 2011; White & MacFarlane, 2014). However, in relation to time on pitch, strikers typically have the highest work rate when expressed as metres covered per minute, indicating that when they are on the pitch, they are playing at a higher intensity than other positions (Lythe & Kilding, 2011).

Whilst several studies have reported mean physical outputs during games from club (Buglione et al., 2013) to elite level (Jennings et al., 2012b) in males (Lythe & Kilding, 2011) and females (Macutkiewicz & Sunderland, 2011), there has been little consideration of the variability of these metrics in elite hockey. It has previously been established that physical loads of team sports are predominantly unstable in nature with moderate to high variability in match physical outputs in different running speed zones (Lago et al., 2010). Specifically, the highest variability (CV 20-60%) is typically observed at running speeds in excess of 19km/h, whilst moderate variability (4-15%) is evident at lower speed zones from 0-11km/h or for total distance covered (Gregson et al., 2010; Kempton et al., 2015; McLaren et al., 2015).

While establishing the between and within player variability is useful information for the practitioner, to further understand the data so that it can be used to guide training protocols, it is important to consider the causes of moderate to very high levels of physical match load variability in team sport athletes. One approach is to assess the physical outputs and the variability of these outputs in relation to the factors associated with the games. For example, in football, better quality, higher ranked teams cover less distance at walking and jogging or low intensities than lower quality and lower ranked teams (Lago et al., 2010). In AFL, the total distance, high intensity distance and number of maximal accelerations all increased in AFL finals series (8 teams) as opposed to regular season games (Aughey, 2011b) suggesting that game importance impacts on physical outputs in highly ranked teams. However, in contrast to Lago et al., (2010) and Aughey., (2011), it was reported that in women's football, significantly greater high intensity distance and less low speed distance was performed when playing teams of similar ranking as opposed to higher and lower ranked opposition (Hewitt et al., 2014). With regard to score line, it has been reported that top level football players perform less amounts of high speed running (>19.1km/h) when winning rather than when losing, however covered more distance at low intensities (<14.1km/h) when winning rather than losing (Lago et al., 2010). There is evidence that the result has an effect of the physical outputs of elite male hockey players with defenders (but not strikers or midfielders) performing less high speed running when the game was won by a large score line (Jennings et al., 2012a). Similar findings were reported for large wins in football with central defenders covering less high intensity running and attackers covering greater distance of high intensity running in games that were heavily won versus heavily lost (Bradley & Noakes, 2013). Collectively, these results suggest that situational variability exists in team sports and also that the effects of situational variability are position dependant. Situational variability could, therefore influence the between and within player variability, although as yet there are no studies that either support or refute this. Therefore, the aim of this study was 1) to determine whether game factors such as opposition rank, result and score line effect GPS physical load outputs of elite male hockey players in differing field positions and 2) how such game factors influence the between and within-player variability of GPS derived physical outputs.

Methods

Players and match data

Match physical output data was collected from 21 international players (strikers/forwards, n=8; midfielder, n=5; defender, n=8; weight 77.2 ± 5.9 kg, height 180 ± 6.4 cm and age 24 .6 ± 1.6 yrs.) from the New Zealand Men's Hockey team across an ~8month period in 2014 during which 29 international test matches were played. A total of 339 physical performance data sets were analysed. The opposition ranged from teams ranked 1-29 in the world (mean: 10.2 ± 6.5), whilst the ranking of the NZ team remained constant through the year at 6th. Some opposition team's rankings had minor fluctuations throughout the year although no team increased or decreased their ranking by more than two positions. There were six matches at Hockey World League Finals, three matches as a home test series, two matches as an away test series, six matches at the Hockey Champions Challenge event, six matches at the Hockey World Cup and six matches at the Commonwealth Games. Ethical approval was granted through AUTEC and players all signed consent forms for data to be used in research.

Data collection and analysis.

Match physical output data was collecting using Catapult Minimax S4 10Hz GPS units (Catapult Innovations, Melbourne, Australia). All data was downloaded using Logan Plus software Catapult Sprint V5.1.7 (Catapult Innovations, Melbourne, Australia). A minimum of six satellites in connection with the GPS system are required for data to be analysed, with zero data sets being excluded due to lack of satellite connection. The reliability and validity of this GPS system is well documented, with percent typical error (TE) typically being under 5% for total distance, and low-moderate speed running under 20km/h. At high speeds in excess of 20km/h validity and reliability is compromised with 10-12% TE (Johnston et al., 2014). Due to the permitted rolling and unlimited substitutions in field hockey, only data from time on pitch (TOP) was recorded and analysed for each player, consistent with previous research (White & MacFarlane, 2013), which allows calculation of relative measures. For each game ~12 players were monitored. To be consistent with previous hockey literature (Lythe & Kilding, 2011; White & MacFarlane, 2014), several absolute metrics were obtained: total distance covered on pitch during the match; distance covered at low (0-11km/h), moderate (11.01 and 19km/h) and high speeds (>19.01km/h). Relative to game time, overall work rate expressed as total metres per minute as well as metres per minute covered in low, medium and high speed bands were determined. The terms 'high speed, moderate speed and low speed distance' have been used rather than the term 'high, moderate and low intensity' as we did not account for individual differences in aerobic or anaerobic capacity, thus a judgement on whether or not the movement is high intensity for each athlete would be a generalisation. The terms high, moderate or low speed distance are used across most literature where there is no individualisation of velocity bands (Abt & Lovell, 2009; Hunter et al., 2015). For an individual's data to be included in this research, they needed to be monitored via GPS for a minimum of 4 games in the data collection time frame with the mean number of games that individuals were monitored for being 19 games out of 29 matches. Due to minimal changes in the playing squad throughout the data collection block only 2 athletes did not meet the inclusion criteria of 4 games. Given the nature of this research question, there also needed to be a minimum of 2 games in any given set of situational variables (e.g. a minimum of 2 wins) for the data to be included. Because of the minimum requirement of 4 games to be included that meant that all subjects also met the criteria of a minimum of 2 games in any given situational variable. However some athletes with lower amounts of games monitored did not meet the criteria to have all situational variables analysed (e.g. they had 4 wins, 2 losses but only 1 draw the draw data could not be analysed for this study, however it could be analysed in the close game data with 3 large wins and 3 close games). This criteria resulted in 4 data sets being partially excluded from the research. There was no minimum playing time required for inclusion in the study given that both relative and absolute metrics are being analysed.

Statistical Analysis

Using IBM SPSS Statistics V22 (IBM Corporation, Armonk, New York, U.S.A), the mean and standard deviation (SD) was established for all data sets, overall and by playing position, both for absolute and relative metrics. Mean data (mean ± SD) for physical outputs and position were also determined according to game result (win, draw or loss), score line margin ("large win": a win by 2 or more goals; "close game": a win/loss by 1 goal or draw; and "large loss": a loss by 2 or more goals) and by world ranking of opposition ("highly ranked": teams ranked 1-5; "moderately ranked": teams ranked 7-11; and "low ranked" teams ranked >12 at time of game). A one-way ANOVA was used to compare differences in mean values for each situational variable (result, margin, rank) and position (striker, midfielder, defender). Bonferroni adjusted post-hoc tests were employed to explore differences between the three subgroups for each situational variable.

The within player variability (expressed as a percent CV; ± 95% CL), was determined for all absolute and relative metrics, for each athlete, based off the CV of each athlete's results that met the situational variance criteria (e.g. Big win, 4 samples from athlete X with a CV of Y). A minimum of two data sets / matches was needed in each criterion (win, loss, draw etc.) for a CV to be produced based off the athlete's variation in physical outputs. The mean CV for each athlete and situational variable was put into positional groups of strikers, midfielders and defenders where the mean CV and 95% CL was established for the within player variability of each position. Within player variability was also established for each position irrespective of situational variance.

Results

Effect of rank on physical output

When analysed by opposition ranking, the results for strikers (Table 6) show that playing time was significantly greater (13.4%) when opposing highly ranked teams compared to moderately ranked. No difference in playing time existed with low ranked teams and there was no difference in playing time across the situational variables for midfielders or defenders. Total Distance (TD) (10.2%) and Moderate Speed Distance (MSD) (16%) for strikers was significantly higher when playing teams ranked highly than against low ranked teams. Table 6 shows that for midfielders, there were significant difference in output values between highly ranked and low ranked teams with the higher ranked teams producing greater physical outputs for MSD (13.4%), Total Relative Distance (TRD) (5.9%), Moderate Speed Relative Distance (MSRD) (11.1%) and High Speed Relative Distance (HSRD) (22.9%). No differences were observed between high and moderately ranked team or moderate and low ranked teams. Significantly greater values were also observed (Table 1) for defenders when playing teams ranked highly over low ranked teams for High Speed Distance (HSD) (34%) and HSRD (30.6%).

TABLE 6: *The effect of ranking on GPS-derived match physical outputs (mean ± SD) for strikers, midfielders and defenders.*

Effect of rank				
Strikers	Highly ranked (n=47)	Moderately Ranked (n=28)	Low Rank (n=57)	Overall (n=132)
Absolute Physical Outputs				
Time (min)	38 ± 9*	34 ± 7	36 ± 6	36. ± 7
TD (m)	5286 ± 1089‡	4829 ± 1026	4799 ± 755	4979 ± 964
LSD (m)	2788 ± 620	2536 ± 522	2643 ± 488	2672 ± 550
MSD (m)	2054 ± 640‡	1866 ± 561	1771 ± 405	1892 ± 543
HSD (m)	445 ± 168	427 ± 202	385 ± 150	415 ± 169
Relative Physical Outputs				
TRD (m/min)	140 ± 17	144 ± 21	136 ± 12	139 ± 16
LSRD (m/min)	73± 8	76 ± 14	75 ± 8	75 ± 9
MSRD (m/min)	55 ± 16	55 ± 13	51 ± 12	53 ± 14
HSRD (m/min)	12 ± 4	13 ± 5	11 ± 4	12 ± 4
Midfielders	Highly ranked (n=33)	Moderately Ranked (n=21)	Low Rank (n=39)	Overall (n=93)
Absolute Physical Outputs				
Time (min)	49 ± 6	49 ± 7	48 ± 5	49 ± 6
TD (m)	6575 ± 955	6445 ± 1084	6105 ± 691	6349 ± 903
LSD (m)	3645 ± 412	3654 ± 495	3567 ± 401	3614 ± 425
MSD (m)	2355 ± 543‡	2226 ± 459	2077 ± 381	2209 ± 472
HSD (m)	576 ± 225	565 ± 251	460 ± 160	525 ± 212
Relative Physical Outputs				
TRD (m/min)	135 ± 10‡	132 ± 8	127 ± 10	131 ± 10
LSRD (m/min)	75 ± 4	75 ± 3	74 ± 3	75 ± 3
MSRD (m/min)	48 ± 9‡	46 ± 5	43 ± 8	46 ± 8

HSRD (m/min)	12 ± 4‡	11 ± 4	10 ± 3	11 ± 4
Defenders	Highly ranked (n=34)	Moderately Ranked (n=21)	Low Rank (n=59)	Overall (n=114)
Absolute Physical Outputs				
Time (min)	49 ± 7	47 ± 8	49 ± 8	49 ± 7
TD (m)	5837 ± 77	5884 ± 1417	5643 ± 862	5745 ± 960
LSD (m)	3679 ± 484	3774 ± 1024	3707 ± 566	3711 ± 648
MSD (m)	1769 ± 441	1741 ± 412	1638 ± 469	1696 ± 451
HSD (m)	399 ± 149‡	361 ± 140	297 ± 147	337 ± 151
Relative Physical Outputs				
TRD (m/min)	121 ± 14	125 ± 17	116 ±13	119 ± 15
LSRD (m/min)	76 ± 5	79 ± 9	76 ±4	77 ± 6
MSRD (m/min)	37 ± 10	38 ± 10	34 ±10	36 ± 10
HSRD (m/min)	8 ± 3‡	8 ± 2	6 ±3	7 ± 3

Time= minutes of actual on field game time; Rank = Highly Ranked (1-5); Moderately Ranked (7-11); Low Rank (>12); m = meters covered / distance; m/min= meters covered per min / relative distance TD= Total Distance; LSD= Low speed distance 0-11km/h; MSD= Moderate Speed Distance 11.01-19km/h; HSD= High Speed Distance >19.01km/h; TRD= total relative distance to time; LSRD= Low Speed Relative Distance; MSRD= Moderate Speed Relative Distance; HSRD= High Speed Relative Distance (mean ± SD). *= significant difference in mean between rank 1-5 and 7-11; ‡= significant difference in mean between rank 1-5 and >12; ≠=significant difference in mean between rank 7-11 and >12 (p= <0.05)

Effect of Ranking on positional physical outputs

Figures 1A, B and C all clearly show that physical output across all positions and most metrics is higher than the overall mean value of each position when playing highly ranked teams. When playing moderate ranked teams, all relative metrics are also higher than the overall mean value for each position. All GPS metrics for the low ranked teams show lower physical output measures than the overall mean value. The largest difference from the overall mean across all positions occurs with HSD or HSRD with defenders producing the large percentage difference from overall mean values for HSD (+18.4% high rank and -11.6% low rank) and HSRD (+14.1% high rank and -12.7% low rank). Midfielders also observed large differences from the absolute mean for low teams for HSR (-12.3%) and HSRD (-11.1%).

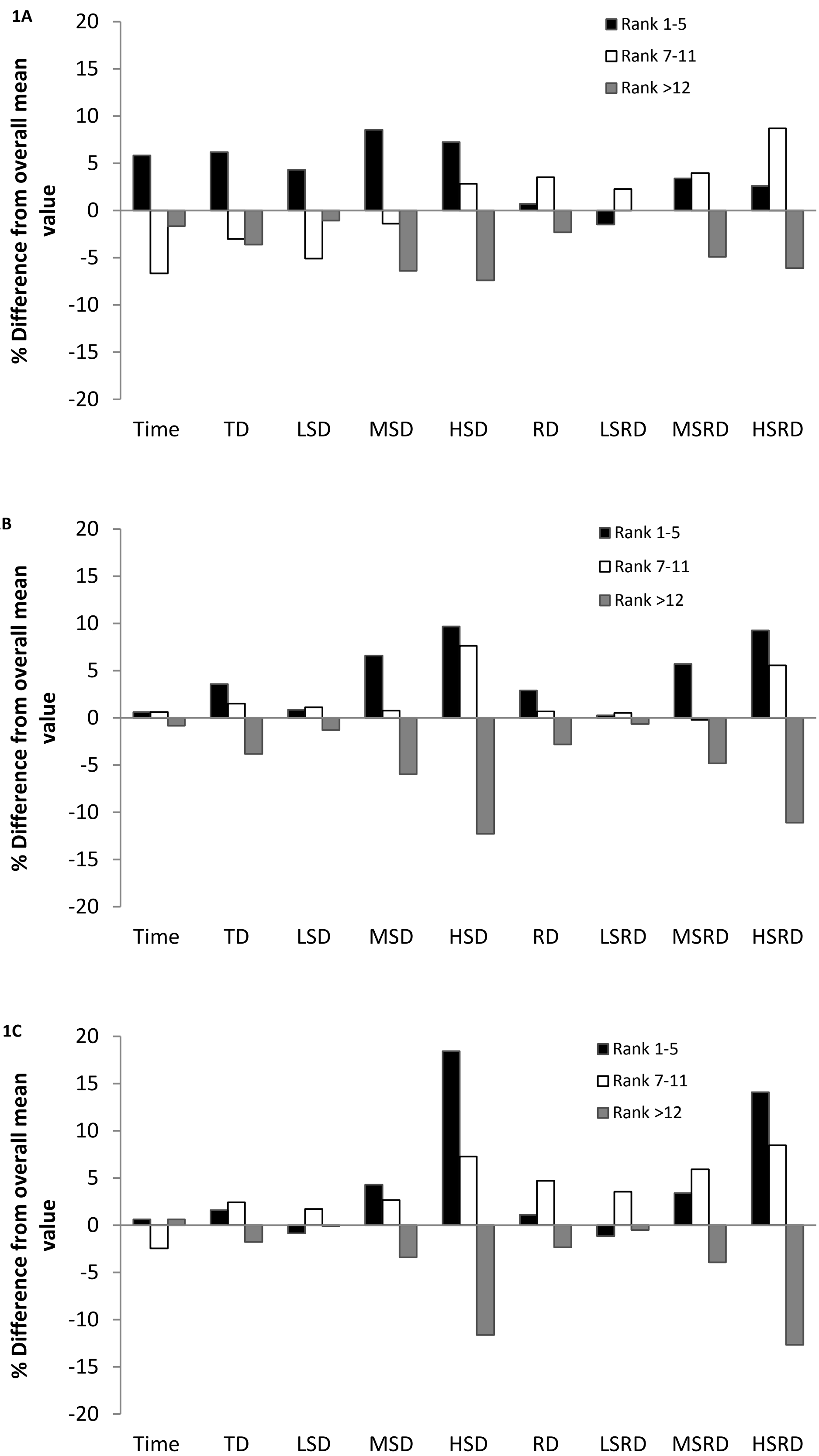

Figure 1 A-C: *Percentage difference, compared to the mean of each position, of opposition rank for A) strikers, B) midfielders, and C) defenders*

Effect of Result on physical outputs

When analysed by effect of result on physical outputs, Table 7 shows that across all positions there is a significant difference between the rank of opposition that results in a win (14.6, 14.6, 14.8), draw (7.6, 7.2, 8.2) and loss (4.1, 4.4, 4.3) for strikers, midfielders and defenders respectively. In a winning result, defenders covered significantly less HSD (35.1% and 36.1%) and HSRD (38.3% and 36.7%) than in a draw or loss respectively and significantly less MSRD (17.3%) than in a draw.

TABLE 7: *The effect of match result on GPS-derived match physical outputs (mean ± SD) for strikers, midfielders and defenders.*

Effect of result				
Strikers	Win (n=60)	Draw (n=40)	Loss (n=32)	Overall (n=132)
Absolute Physical Outputs				
Rank	15 ± 5*‡	8 ± 5≠	4 ± 3	10 ± 6
Time (min)	36 ± 6	35 ± 8	39 ± 9	36 ± 7
TD (m)	4915 ± 830	4917 ± 991	5175 ± 1155	4979 ± 964
LSD (m)	2664 ± 498	2566 ± 540	2819 ± 635	2672 ± 550
MSD (m)	1835 ± 498	1942 ± 531	1934 ± 732	1892 ± 543
HSD (m)	415 ± 160	410 ± 160	422 ± 201	415 ± 169
Relative Physical Outputs				
TRD (m/min)	139 ± 11	143 ± 20	135 ± 19	139 ± 16
LSRD (m/min)	75 ± 8	74 ± 12	74 ± 9	75 ± 9
MSRD (m/min)	52 ± 11	56 ± 13	51 ± 18	53 ± 14
HSRD (m/min)	12 ± 4	12 ± 4	11 ± 5	12 ± 4
Midfielders	Win (n=45)	Draw (n=26)	Loss (n=22)	Overall (n=93)
Absolute Physical Outputs				
Rank	15 ± 6*‡	7 ± 5	4 ± 3	10 ± 7
Time (min)	48 ± 5	48 ± 6	50 ± 7	49 ± 6
TD (m)	6242 ± 759	6351 ± 958	6565 ± 1095	6349 ± 903
LSD (m)	3621 ± 383	3530 ± 431	3700 ± 497	3614 ± 425
MSD (m)	2126 ± 395	2278 ± 477	2297 ± 593	2209 ± 472
HSD (m)	494 ± 187	542 ± 197	569 ± 270	525 ± 212
Relative Physical Outputs				
TRD (m/min)	129 ± 10	133 ± 8	132 ± 12	131 ± 10
LSRD (m/min)	75 ± 3	74 ± 4	74 ± 3	75 ± 3
MSRD (m/min)	44 ± 8	48 ± 7	46 ± 10	46 ± 8
HSRD (m/min)	10 ± 3	11 ± 3	11 ± 5	11 ± 4
Defenders	Win (n=61)	Draw (n=27)	Loss (n=26)	Overall (n=114)

Absolute Physical Outputs				
Rank	15 ± 6*‡	8 ± 8≠	4 ± 3	10 ± 6
Time (min)	49 ± 8	47 ± 6	49 ± 8	49 ± 7
TD (m)	5668 ± 857	5867 ± 1238	5799 ± 882	5745 ± 960
LSD (m)	3765 ± 560	3630 ± 818	3670 ± 655	3711 ± 648
MSD (m)	1614 ± 455	1842 ± 440	1737 ± 425	1696 ± 451
HSD (m)	289 ± 137*‡	390 ± 150	393 ± 150	337 ± 151
Relative Physical Outputs				
TRD (m/min)	117 ± 14	125 ± 15	119 ± 4	119 ± 15
LSRD (m/min)	77 ± 4	77 ± 8	75 ± 5	77 ± 6
MSRD (m/min)	34 ± 10*	39 ± 9	36 ± 11	36 ± 10
HSRD (m/min)	6 ± 3*‡	8 ± 3	8 ± 3	7 ± 3

Time= minutes of actual on field game time; Rank = mean rank of opposition; m = meters covered / distance; m/min= meters covered per min / relative distance TD= Total Distance; LSD= Low speed distance 0-11km/h; MSD= Moderate Speed Distance 11.01-19km/h; HSD= High Speed Distance >19.01km/h; TRD= total relative distance to time; LSRD= Low Speed Relative Distance; MSRD= Moderate Speed Relative Distance; HSRD= High Speed Relative Distance (mean ± SD). *= significant difference in mean between win and draw; ‡= significant difference in mean between win and loss; ≠=significant difference in mean between draw and loss (p= <0.05)

Effect of result on positional outputs (Figures 2A, B, and C) shows that strikers relative outputs on a loss are lower (1-4.3%) than the overall mean and lower than a win or draw. Conversely midfielders and defenders both show an increase in mean from the overall values in a loss. Midfielders mean results are all above (0.1-8.4%) the overall mean with the exception of LSRD (-0.5%). Defenders results are also slightly above or equal (0-2.4%) to mean value with the exception of HSD (16.8%) and HSRD (15.5%) being much greater in a loss than the overall mean, whilst LSD (-1.1%) and LSRD (-2.5%) are lower than the overall mean. Across all positions a draw resulted in an increase in relative physical outputs from the overall mean value for RD, MSRD and HSRD. A draw had the largest effect on RD (4.6%) MSRD (11%) and HSRD (16.9%) for defenders with all strikers and midfielders RD, MSRD and HSRD increasing by only 1.7-6%. A win resulted in minor (±2%) changes to mean values for all positions for RD and LSRD. Strikers (-2.5%) and midfielders (-3%) and defenders (-5.4%) MSRD were lower than the overall mean whilst strikers saw no change to overall mean values for HSRD, midfielders were 5.5% lower and defenders 15.5% lower for a loss.

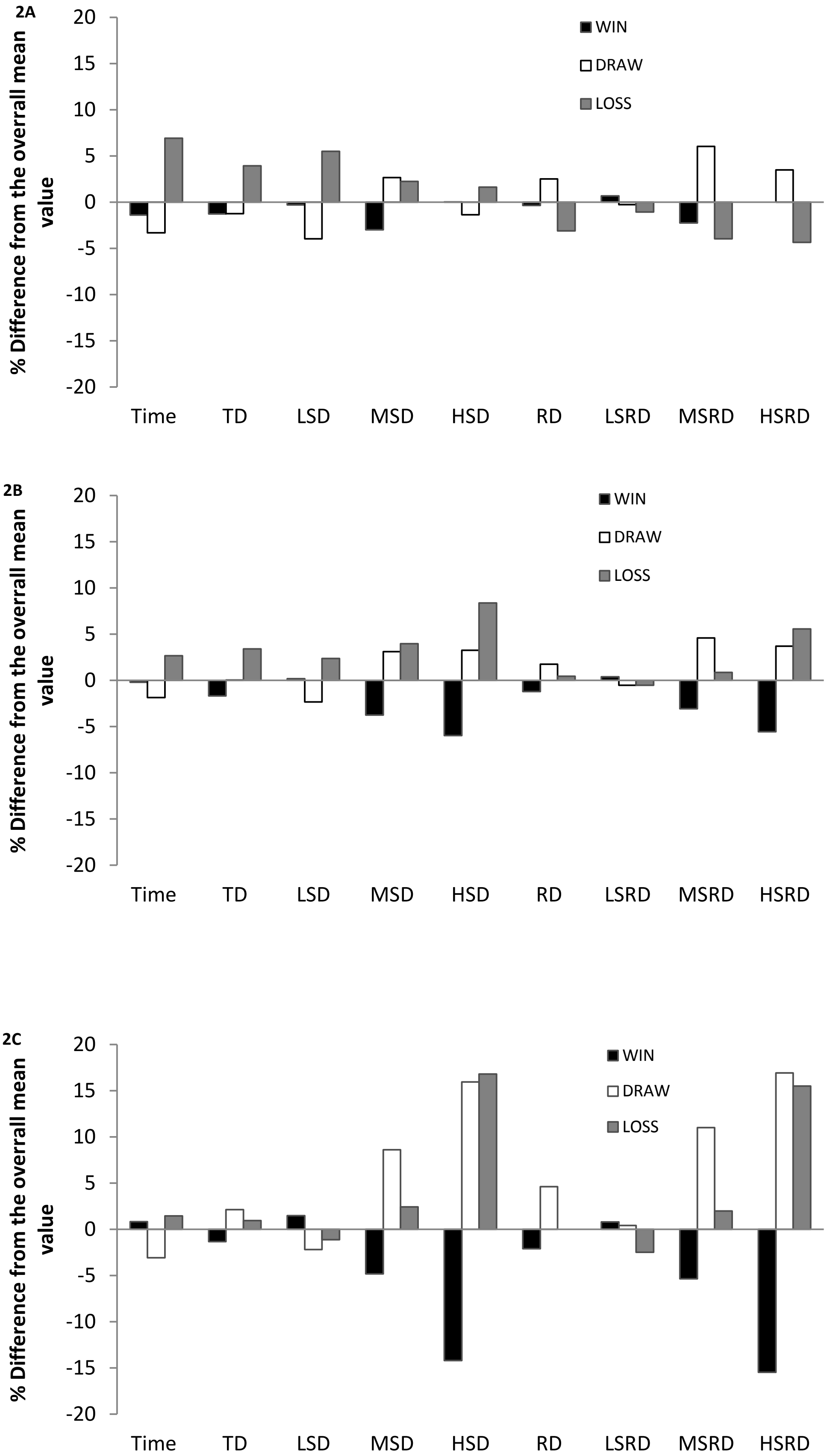

Figure 2 A-C: *Percentage difference, compared to the mean of each position, of result for A) strikers, B) midfielders, and C) defenders*

Effect of match score margin on physical outputs

Similarly to effect of result, there were significant differences in mean rank of opposition across all positions for big wins (15.9, 16.3, and 16.1), close games (8, 8, and 8.6) and big losses (3.4, 3.3, and 3.2) for strikers, midfielders and defenders respectively. There were no significant differences in mean GPS-derived physical outputs for strikers and midfielders whilst for defenders HSD (27.2% and 44.1%) and HSRD (34.5% and 43.1%) were significantly lower in a big win than both a close game and big loss respectively (Table 8).

TABLE 8: *The effect of match score margin on GPS-derived match physical outputs (mean ± SD) for strikers, midfielders and defenders.*

Effect of Score margin				
Strikers	Big Win (n=47)	Close Game (n=57)	Big Loss (n=28)	Overall (n=132)
Absolute Physical Outputs				
Rank	16± 5*‡	8 ± 5≠	3 ± 2	10 ± 6
Time (min)	35 ± 6	36 ± 7	39 ± 9	36 ± 7
TD (m)	4854 ± 791	5015 ± 966	5114 ± 1210	4979 ± 964
LSD (m)	2643 ± 503	2616 ± 534	2834 ± 640	2672 ± 550
MSD (m)	1802 ± 420	1975 ± 500	1873 ± 763	1892 ± 543
HSD (m)	409 ± 158	424 ± 169	408 ± 193	415 ± 169
Relative Physical Outputs				
TRD (m/min)	138 ± 11	143 ± 18	134 ± 18	139 ± 16
LSRD (m/min)	75 ± 9	74 ± 10	74 ± 9	75 ± 9
MSRD (m/min)	51 ± 11	56 ± 12	49 ± 18	53 ± 14
HSRD (m/min)	12 ± 4	12 ± 5	11 ± 4	12 ± 4
Midfielders	Big Win (n=34)	Close Game (n=41)	Big Loss (n=18)	Overall (n=93)
Absolute Physical Outputs				
Rank	16 ± 5*‡	8 ± 4≠	3 ± 2	10 ± 7
Time (min)	49 ± 5	48 ± 6	49 ± 6	49 ± 6
TD (m)	6230 ± 805	6376 ± 906	651 ± 1080	6347 ± 903
LSD (m)	3604 ± 412	3611 ± 440	3641 ± 437	3614 ± 425
MSD (m)	2135 ± 426	2231 ± 439	2297 ± 618	2209 ± 472
HSD (m)	491 ± 200	532 ± 179	572 ± 292	525 ± 212
Relative Physical Outputs				
TRD (m/min)	128 ± 11	133 ± 7	132 ± 13	131 ± 10
LSRD (m/min)	74 ± 3	75 ± 4	74 ± 3	75 ± 3
MSRD (m/min)	44 ± 9	47 ± 6	47 ± 10	46 ± 8
HSRD (m/min)	10 ± 4	11 ± 3	12 ± 5	11 ± 4
Defenders	Big Win (n=49)	Close Game (n=44)	Big Loss (n=21)	Overall (n=114)
Absolute Physical Outputs				

Rank	16 ± 5*‡	8 ± 5≠	3 ± 2	11 ± 7
Time (min)	49 ± 8	47 ± 6	50 ± 8	49 ± 7
TD (m)	5692 ± 930	5725 ± 1061	5909 ± 822	5745 ± 960
LSD (m)	3797 ± 608	3613 ± 723	3719 ± 565	3711 ± 648
MSD (m)	1613 ± 466	1748 ± 446	1782 ± 411	1696 ± 451
HSD (m)	284 ± 146*‡	361 ± 134	409 ± 13	337 ± 151
Relative Physical Outputs				
TRD (m/min)	116 ± 13	123 ± 16	119 ± 13	119 ± 15
LSRD (m/min)	77 ± 3	77 ± 7	74 ± 6	77 ± 6
MSRD (m/min)	33 ± 10	38 ± 11	36 ± 9	36 ± 10
HSRD (m/min)	6 ± 3*‡	8 ± 3	8 ± 3	7 ± 3

Time= minutes of actual on field game time; Rank = mean rank of opposition; m = meters covered / distance; m/min= meters covered per min / relative distance TD= Total Distance; LSD= Low speed distance 0-11km/h; MSD= Moderate Speed Distance 11.01-19km/h; HSD= High Speed Distance >19.01km/h; TRD= total relative distance to time; LSRD= Low Speed Relative Distance; MSRD= Moderate Speed Relative Distance; HSRD= High Speed Relative Distance (mean ± SD). *= significant difference in mean between a big win and close game; ‡= significant difference in mean between a big win and a big loss; ≠=significant difference in mean between a close game and a big loss (p= <0.05)

Effect of score margin on physical outputs

Analysis of the effect of score margin against the percent difference from the absolute mean for each position (Figure 3A-C) shows midfielders have a minor increase (0.4-2%) in close games across all GPS metrics and an increase in big losses (0.7-8.9%) compared to the overall mean midfielder result with moderate shifts in HSD (8.9%) and HSRD (6.5%) and a decrease in all values (0.1-7.4%) to the mean for a big win with moderate decrease in HSD (6.4%) and HSRD (7.4%). A reduction in mean values was observed with defenders in a big win compared to the overall mean for HSD (15.7%) and HSRD (18.3%) whilst a big loss results in large enhancements to overall mean values for HSD (21.5%) and HSRD (16.9%). A close game also results in moderate enhancements to the overall mean for defenders with 6.7-9.6% increase in mean values for HSD, MSRD and HSRD. Striker's relative physical outputs are all lower than the average for a big loss (0.2-8.7%) the main difference being seen in MSRD (7.3%) and HSRD (8.7%). A big win results in very little change to overall mean values for strikers, whilst a close game sees an increase in RD (2.7%), MSRD (6%) and HSRD (5.2%)

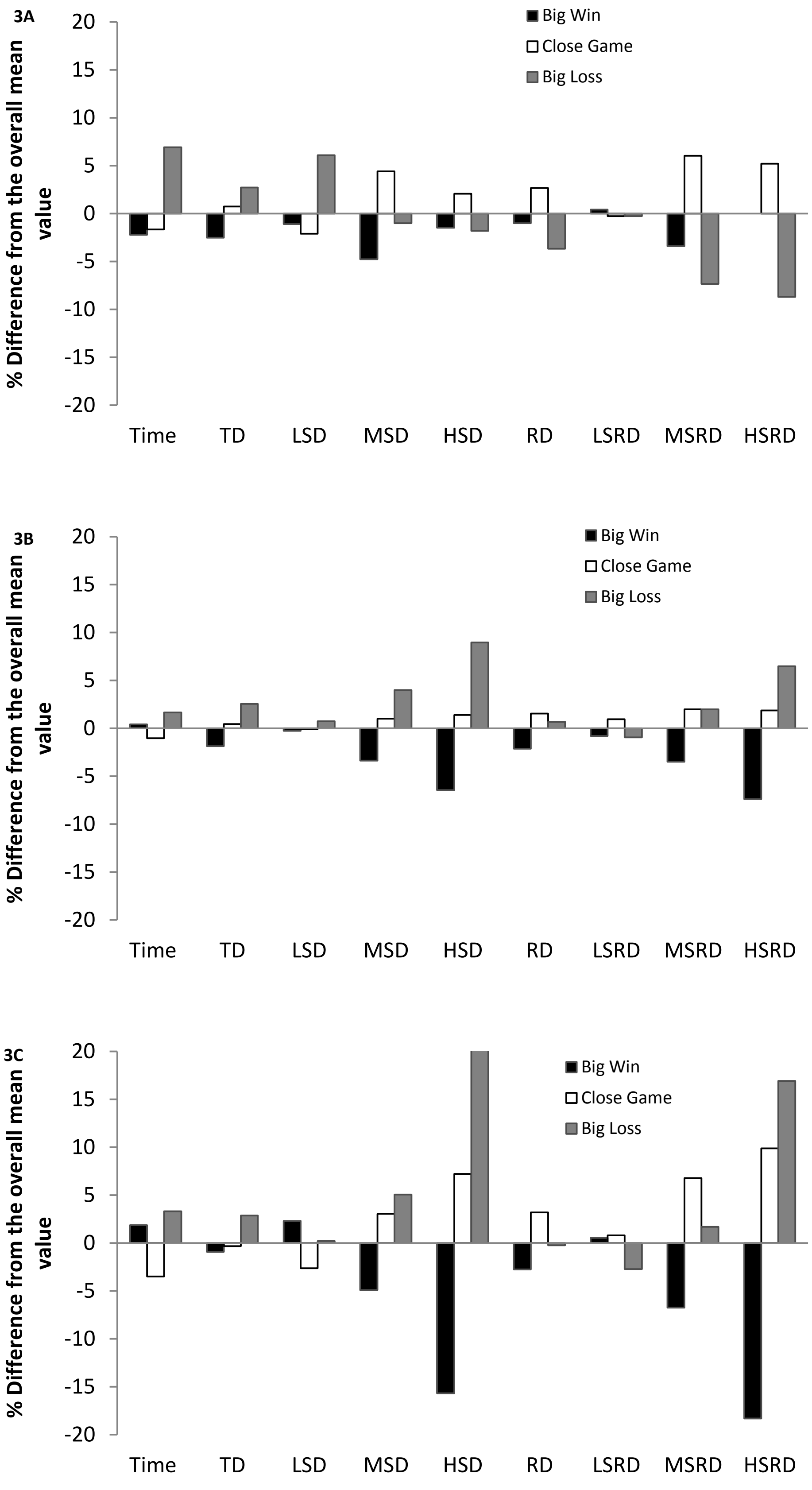

Figure 3 A-C: *Percentage difference, compared to the mean of each position, of score margin for A) strikers, B) midfielders, and C) defenders*

Effect of rank on variability

Figure 4A-C shows the within player variability, expressed as a CV, for absolute and relative physical outputs when games for each position are categorised according to rank of opposition. For strikers, the variability across all GPS outputs was lower for games against moderate and low ranked teams compared to highly ranked and overall within player variability. Whilst this was not necessarily the same for midfielders and defenders, almost all physical outputs had a minimum of 2 rank groups produce lower variability results than the overall variability. For all midfielders' outputs except TD, variability was lower for all ranking groups than it was for overall variability and for defenders there were no major trends apart from 2 or 3 rank groups constantly being lower than overall variability. Regardless of rank and position, the TRD and LSRD displayed the lowest variability (<10%) and moderate (9.5-33.1%) and high speed (22-45.6%) bands for absolute and relative values produced higher levels of variability.

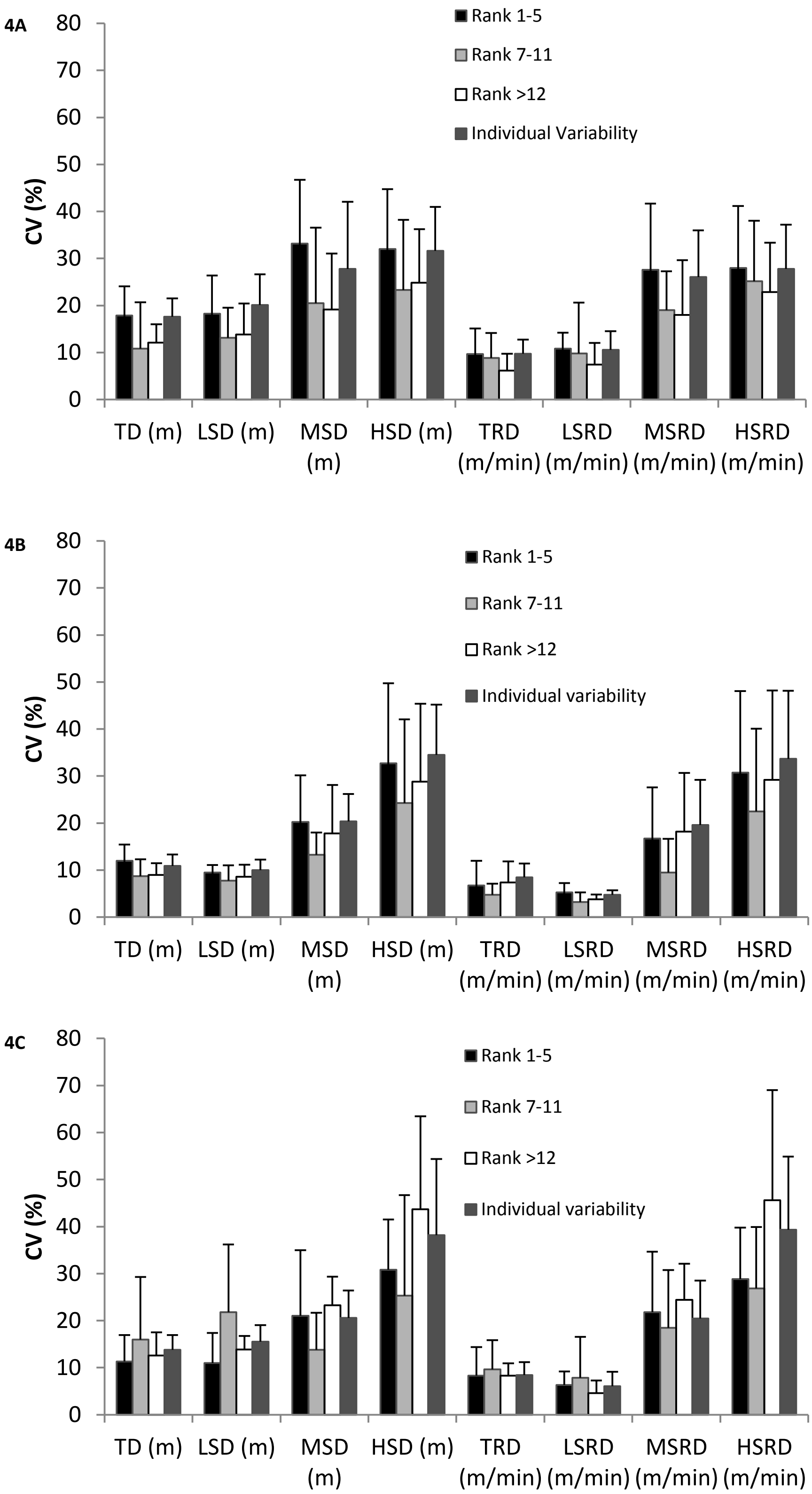

Figure 4A-C: *The effect of rank on A) strikers, B) midfielders, C) defenders within player variability of physical output measures with 95% Confidence limits.*

Effect of Result on Variability

Figure 5A-C shows the within player variability, expressed as a CV, for absolute and relative physical outputs when games for each position are categorised according to the match result. For strikers (Figure 5A), a loss typically provided the highest level of variability for all metrics except TRD whilst a win always had the lowest amount of variability in physical outputs. For all metrics other the TRD a win and a draw produced lower levels of variability than the overall level of within player variability for strikers. A loss also saw higher variability than a draw or win for defenders for all metrics except TRD and LSRD with a win and draw producing lower variability than the overall variability for midfielders for all metrics. Defenders followed the same trend with higher levels of variability in physical match loads during a loss than when a win or draw occurs for all relative metrics excluding LSRD. The lowest variability occurred for all results and positions with TRD and LSRD (<12.3%) whilst absolute and relative moderate (12.3-40.2%) and high (22-39.7%) speed metrics producing the highest levels of variability across all results and positions.

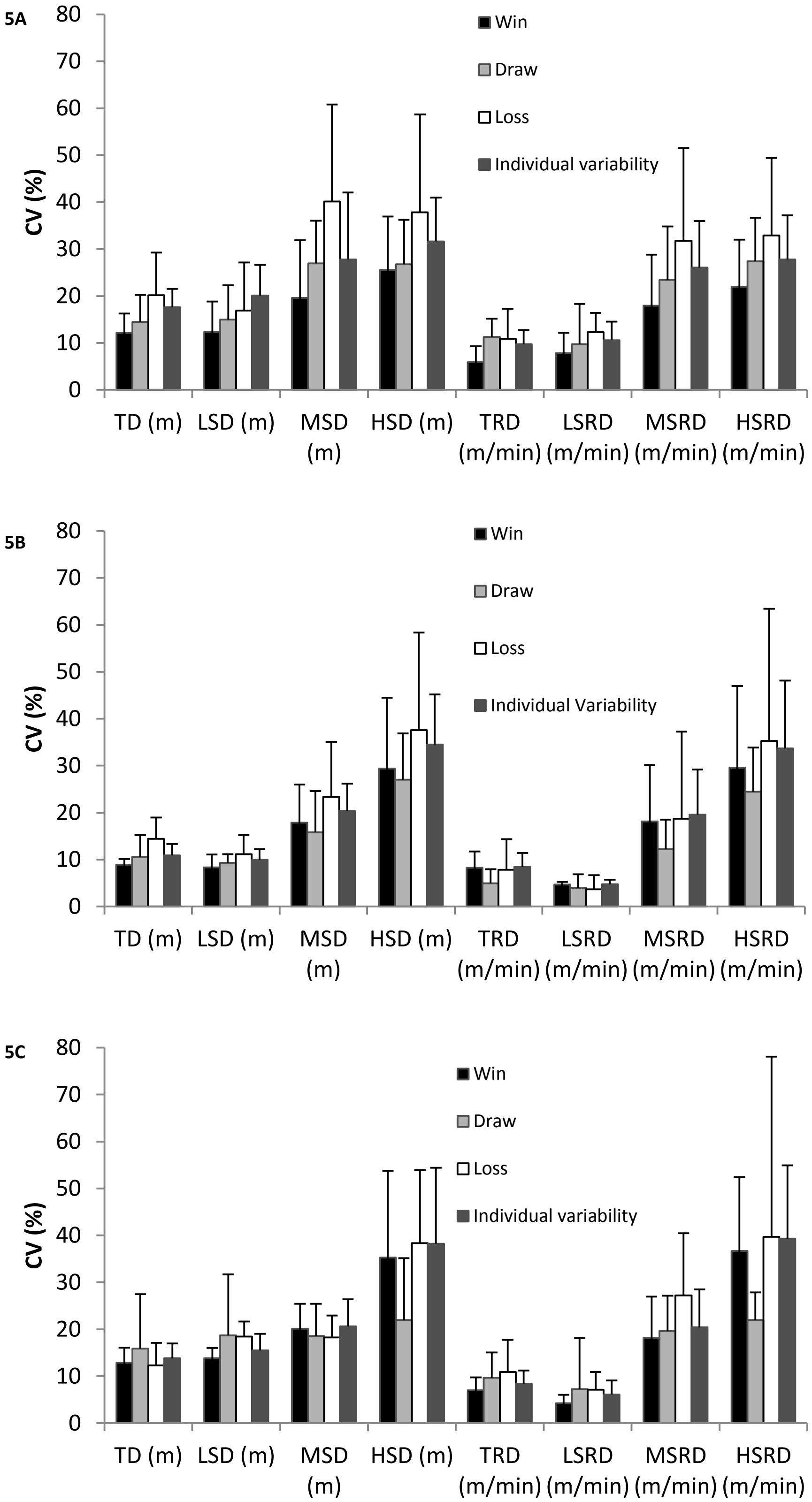

Figure 5A-C: *The effect of result on A) strikers, B) midfielders, C) defenders within player variability of physical output measures with 95% Confidence limits.*

Effect of score margin on variability

Figure 6A-C shows the within player variability, expressed as a CV, for absolute and relative physical outputs when games for each position are categorised according to the match score margin. For strikers and midfielders, variability for a big loss was greater than that of the variability for a big win, close game or overall variability for all metrics. For defenders the overall variability saw the highest levels of variability. TRD and LSRD observed the lowest variability (<12.4) for all score margins and positions whilst absolute and relative distances for moderate (11.2-40.71%) and high (21.4-43.25%) speed resulted in the highest levels of variability.

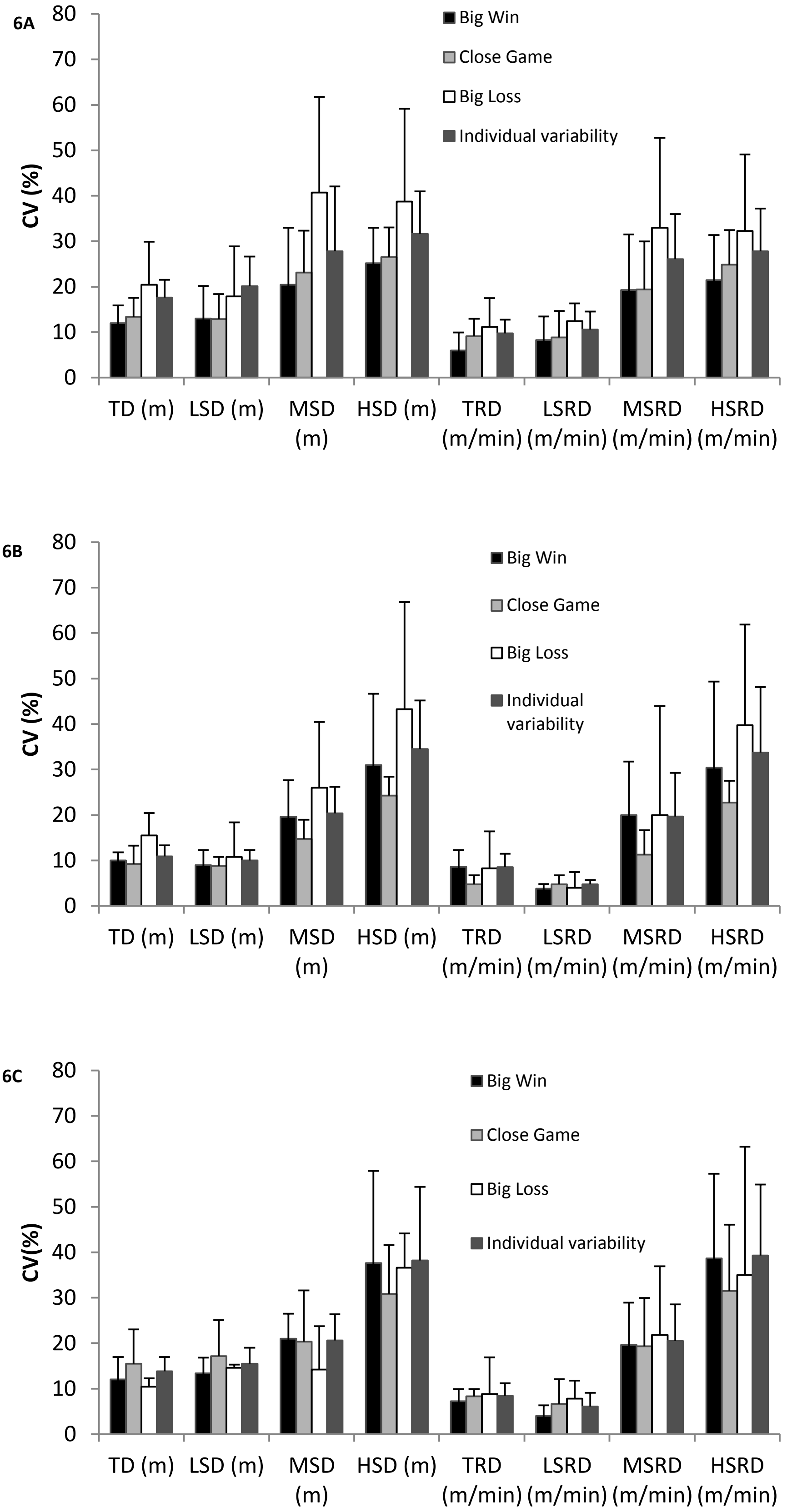

Figure 6A-C: *The effect of score margin on A) strikers, B) midfielders, C) defenders within player variability of physical output measures with 95% Confidence limits.*

Discussion

The is the first study to examine the influence of rank, result and score margin on the physical outputs of international male hockey players by outfield positional groups of striker, midfielder and defender. The main findings indicate both positional differences and influence of game factors on physical outputs derived from GPS technology. We also determined the effects of situational variances on the within player variability of physical match outputs and revealed that within player variability differed across each situational variable.

Effect of Opposition Rank on Physical outputs

On analysis by ranking, all positions reported an increase compared to the mean physical outputs of up to 8% for strikers, 10% for midfielders and 18.5% for defenders when playing highly ranked opposition. All positions observed lower than overall mean physical outputs (up to 12.3%) when playing low ranked opposition. Higher than the overall mean values for each position were also reported when playing teams moderate ranked with relative metrics increasing 2-8% from mean values for strikers, 0.2-5% with midfielders and 3-8% for defenders.

When playing against higher ranked teams, the Australian women's football team performed greater amounts of high intensity movements and less low speed movements when compared to playing of similar or lower ranked opposition (Hewitt et al., 2014). Similar observations occurred in the current study with an increase in HSD and HSRD for all positions as well as a decrease in LSRD for strikers and defenders when playing higher ranked opposition, however, there was also an increase against teams of similar and slightly lower ranked opposition (7-11) for HSD and HSRD across all positions. In AFL, higher work rates and amounts of high intensity activity were seen in finals matches against teams ranked in the top 8 in the league (Aughey, 2011a).

In the present study, we divided the opposition into discrete rank groups (1 higher, 2 lower than their ranking) making inferences about opposition ranked the similar to the NZ may not be practical based off the rank groups used, however it can be stated that, for this sample, teams ranked 1-11 elicit higher values for TRD and HSRD than when playing teams ranked >12. From these results we can infer that in hockey, teams ranked 1-11 in the world will elicit higher HSRD than teams ranked more than >12 which is similar to the finding in women's football (Hewitt et al., 2014) and AFL as well as higher work rates when playing high and moderate ranked opposition (1-11) than lower ranked (>12) which is also observed in AFL finals series versus regular season games (Aughey, 2011a). Greater MSRD values are also observed when playing teams rank high and moderate ranked teams than low ranked teams.

Playing against highly ranked opposition in football has been found to reduce the amount of ball possession, an attribute that could lead to increased running in an effort to try win the ball back (Lago, 2009). If hockey follows similar patterns then the lack of ball possession against the higher quality teams or conversely the increased amount of ball possession against low ranked opposition could be a reason that higher relative physical output metrics are observed when playing teams ranked in the top 11.

Relative distance and low speed distance produce relatively stable metrics across each position, only observing small changes by rank in TRD and LSRD (<4%), whilst moderate to large changes (>12%) were reported for moderate and high speed distance based off the effect of rank of opposition in hockey.

Effect of Match Result on Physical outputs

Our findings in midfielders and defenders are consistent with those reported in football where players performed less high speed running when winning compared to losing using the same velocity bands (Lago et al., 2010). However the low speed running outputs for midfielders and defenders did not reflect that of football, with football seeing increased low speed running when losing and this study reporting a slight decrease in low speed running when losing. The results of strikers were in contrast to the observations of a reduction in high speed running reported in football when winning, with higher HSRD in a win than observed in a loss. However strikers did follow the observations reported in football with an increase in LSRD when winning versus losing (Lago et al., 2010).

It has been reported that winning can be a comfortable status for a team and that when ahead, teams may attempt to adopt a ball retention strategy (Lago et al., 2010). Conversely to playing highly ranked opposition, this may lead to a decreased physical output for players on or near the ball such as defenders or midfielders. The increase in strikers HSRD in a win versus a loss may be explained by this theory as well the fact that with increased amount of ball the strikers may be required to do more off the ball leading, stretching the defence allowing the defenders and midfielders more time to possess the ball (Jennings et al., 2012a). Despite the ball retention theory, a draw in the present study consistently elicited the highest TRD, MSRD and HSRD for all positions with the exception of a loss for defenders producing 0.2m/min more HSRD. For strikers a loss saw the lowest physical outputs and for midfielders and defenders a loss saw higher relative outputs than a win. These outputs may be partially explained by tactical influences as a result of the evolving score line in a game and the fact that both teams in a drawn result are typically aiming for the win, therefore the game can become more open as neither team adopts a pacing strategy in order to hold on to their lead (Bradley & Noakes, 2013). Unfortunately, we do not have evolving match status and physical outputs to support this statement.

Effect of Match Score margin on Physical outputs

In the present study, the greatest relative physical outputs by match score line for TRD and MSRD occurred when playing in a close game for all positions, whilst the highest HSRD occurs for midfielders and defenders on a big loss and for strikers on a close game. For midfielders and defenders a big loss elicits higher relative physical outputs than a big win, whilst for strikers a big win produces higher relative physical outputs than a big loss. These results closely mirror those from the analysis by results where a draw typically elicited the highest physical outputs and midfielders and defenders produced higher outputs on a loss over a win with strikers producing the opposite.

Previous literature in football revealed that attackers cover 15% more high speed distance in a big winning result than covered in a big losing result (Bradley & Noakes, 2013). The present study reported that players of a similar position (strikers) in hockey also observed an increase in HSRD (8.7%) in a big win when compared to a big loss, showing similarities between hockey and football with strikers / attackers high speed running both being influenced by score line. Central defenders in football had a reduction in HSD of 17% in big wins compared to big losses (Bradley & Noakes, 2013). Using the present data from defenders, a 30.1% difference was seen between mean HSRD values for big wins and big losses for HSRD with a big win eliciting much greater amounts of HSRD. Similar high speed distance trends for score margin are observed between attackers / strikers and defenders / defenders in football and hockey respectively. It is theorised that in AFL, athletes may play a higher percentage of their individual physical capacity in final series games compared to regular season games (Aughey, 2011b). If this is the case for finals series games, the same may also be evident when playing in a close game as the pressure to have a winning result for both sides is increased and players may perform at a greater percent of their maximal effort. Future research could look at the perceived efforts of individuals in hockey by score margin to see if this theory is supported.

Effect of Situational Variables on Variability of physical outputs

Figures 4,5&6 A-C show that for all situational variabilities and across striker, midfield and defensive positions, that variability of physical match outputs is lowest for TRD and LSRD metrics, a trait which follows the overall variability for ranking and common trends in literature with total distance and lower speed activities being more stable than higher speed activities between matches (McLaren et al., 2015). Whilst the variability of some of the sub groups within rank, result and score margin may be lower than the individual variability, the variability for each metric still remains relatively unchanged with moderate and high speed metrics still providing high levels of variability in excess of 10-20% and variability still being evident at lower speeds and for total distances (typically 5-10%).

Whilst there is promising evidence on the influence of rank, result and score margin on the physical outputs for all positions, none of these changes are more significant than the degree of variability by rank group, result or score margin. In order to make inferences to the data set a larger pool of games may be necessary (Kempton et al., 2015). Absolute and relative distance and low speed distance were always the most stable metrics, whilst higher speed activities had large amounts of within player variability, as observed in football (Gregson et al., 2010), AFL (Kempton et al., 2015), rugby union (McLaren et al., 2015) and rugby league (Kempton et al., 2014). Similarly to AFL (Kempton et al., 2015), the total distance data displayed lower variability when expressed as relative distance per minute and this trend was consistent across most metrics, situational variances and positions even at higher speeds. With large degrees of variability at moderate and high speeds there are inherent implications for interpreting the physical outputs of matches (Kempton et al., 2014). Means based off low sample sizes may show inappropriate values in relation to the 'true' mean for moderate and high speed data and further issues arise when attempting to use this data in a training prescription (McLaren et al., 2015).

Practical Implications

A larger sample size may be necessary in order to get truly accurate variability measures within each situational variance. The smaller sample size in this research may be a reason we have seen higher variability than previously seen in football at high speeds (Gregson et al., 2010) and may also provide a rationale for seeing some values producing much greater magnitude 95% CL than reported with the overall within player variability. The use of smallest worthwhile change and likely worthwhile change in mean values would be recommended, although previous literature has shown that at high velocities, extremely large changes to mean values would need to be observed to ensure a likely worthwhile change of high speed running data (McLaren et al., 2015). More appropriate to take into a training setting may be relative distance per min, which typically has a variability of below 10% and relatively low values for smallest and likely worthwhile change (McLaren et al., 2015). Whilst this study only looked at the physical effects of various situational variances it must be noted that pacing strategies, tactical differences, and environmental effects may also influence physical match loads and the within player variability of these match loads.

Conclusion

This study is the first to analyse the GPS derived physical work outputs with respect to situational variances in hockey and the first to consider the effect these situational variances on the variability of the outputs of international male hockey players. We were able to determine that game factors such as rank of opposition, match result and match score margin, typically had a small to moderate (<10%) influence on the physical outputs strikers, midfielders and defenders in international hockey, however for defenders there was a large influence (10-20%) of all situational variables on the amount of high speed running.

We were also able to determine that despite the influence of the situational variables on physical outputs, the within player variability of all metrics remained relatively unchanged from the overall within player variability. Findings suggested that the degree of the within player variability by situational variance exceeds that of the magnitude of change seen between the effect that situational variances have on the physical output metrics. It appears that moderate and high speed activities are not consistently reproduced within player's match to match performance. Caution and consideration of the within player variability must be taken when applying the effects of the situational variances to the GPS-derived physical outputs in practice. Relative distance may be an appropriate measure to monitor the influence of situational variability due to its relatively low variability across all positions and by rank, result and score margin, although further research with a larger sample size may be needed.

Chapter 5: Final Discussion

The aim of this thesis was to quantify the variability in match outputs in international hockey, whilst also considering the implications of interpreting and applying physical output data from matches into a training setting for international hockey teams. This was achieved by: 1) establishing the magnitude of the match to match variability in GPS-derived physical outputs and how the variability of these metrics can be applied into a training setting and 2) analysing the influence that rank of opposition, result and score line of matches had on the GPS-derived physical outputs and variabilities of these outputs in international hockey.

The findings of chapter 3 and chapter 4 of this thesis suggest that the physical outputs in international male hockey are variable and that physical output qualities are not reproduced from match to match with higher variability reported at higher velocities than for low speed and total distances. In attempt to establish the cause of variability we found that situational variabilities such as rank of opposition, result and score margin of the match did not influence the degree of variability observed in the physical outputs in international hockey.

Relative and absolute measures of moderate and high speed running show substantially greater variability than distance and low speed distance metrics, irrespective of situational variance. This suggests that distance and low speed distance are much more stable than moderate and high speed running distances. Hockey players will typically cover fairly similar amounts of distance from game to game but there is a large variability in how that distance is achieved and the breakdown of distances in each speed zone. Similar evidence of this is seen in rugby with McLaren et al., (2015) showing variability under 10% for total distance and distance >14.9km/h and much higher variability of up to 33.4% and 69% for distance between 15-19.9km/h and >20km/h respectively (McLaren et al., 2015). Accounting for situational variances such as rank, result and score margin did not significantly reduce variability of metrics to a sufficient magnitude to confidently show that; rank, result or score margin produce significantly difference mean values across positions and most metrics to show a true change in mean values. Given the high level of variability at moderate and high speeds, likely worthwhile change figures in mean values are not practical to apply in training situations based of the current results (Table 5) with often a change of 30-50% mean value needed at higher speeds to elicit a likely worthwhile change. Using likely worthwhile change of a value with lower variability such as work rate / TRD may be more applicable to the training setting with all positions needing a ~10% shift in TRD to deem likely worthwhile. This ~10% change may be further reduced if analysed by effect of rank, result or score margin however the change in value from ~10% may not be substantial based of the results provided in chapter 3, figures 4,5,6 A-C. Using the likely worthwhile change of work rate / TRD in a training setting may help improve match specific fitness and encourages tasks to be done at a higher level of fatigue adding further challenge to the training setting.

While there have been several studies reporting the physical match outputs in hockey (Gabbett, 2010; Lythe & Kilding, 2011), the most relevant for comparison with the present study is the data reported by Jennings et al (2012) which to our knowledge is the only study that has looked at the variation in GPS data and also the only study that has looked at potential situational variables in elite male field hockey players. However, this was only over a short 6 game tournament (Jennings et al., 2012a). The findings were that whilst there was variation in physical outputs across the tournament and there was less HSR completed in all matches than match 1, the amount of HSR did not significantly decrease across the tournament. In contrast, the current study reported substantial variability of high speed running within each position and situational variability. The greatest change in mean values reported in Jennings et al., (2012) occurred when the team had a very large win resulting in a large decrease in distance >15km/h in midfielders and defenders. When compared to the opening game of the tournament however only defenders had a decreased amount of HSR in comparison to the tournament average (Jennings et al., 2012a). Similar findings are reported in the current research (Table 8) with defenders showing significantly lower mean high speed running distances in a large win compared to both a close game and large win. In the Jennings et al., (2012) study the teams only losing result reported an increase in distance run <15km/h when compared to the tournament average and in a close result (a win by 1 over England), defenders had an increase in distance >15km/h compared to the tournament average. Findings of the current study show that midfielders and defenders both increased moderate and high speed relative distance in a close result (Table 8). The increase in defenders load during a loss or close game may be partially explained by the amount of ball possession the opposing teams had causing defenders to spend more time marking players in their own half as opposed to the decrease in distance above >15km/h in large win when win the team spend the majority of the time attacking and very little defending was needed to be done (Jennings et al., 2012a).

Using a secondary analysis of the data presented by Jennings et al., (2012) it is possible to estimate work rate. Specifically, if it assumed game time was equal to 70minutes meaning that there were no stoppages in the game during which players may still be moving, the strikers had an average work rate of 140.2m per min, midfielders 145m per min and defenders 135m per min. Comparing this to our data from 29 games (table 4), the strikers had an average of 139m per min which is very similar to that of the Australian team. In contrast, midfielders (131m/min) and defenders (119m/min) had lower values than the Australian teams estimated work rate.

When analysed by the ranking of the opposition (Table 6) all positions had higher work rates / TRD when playing teams ranked 1-11 in the world than compared to when playing teams ranked >12. In the tournament analysed by Jennings et al., (2012) all games were played against teams ranked in the top 9 in the world at the time of the tournament. This could result in an increased work rate as seen in the current study when compared to Australia playing teams of lower ranking. The six game tournament is also a prestigious tournament that all hockey teams over the world aspire to win and was played in Australia, their home country. This may result in the players giving a physical effort closer to their maximum physical capacity than if the games were not as important and prestigious (Aughey, 2011b). Our current study reports on games played over a year rather than a one-off tournament with games played in various climates (11-44degrees Celsius), against a wide range of rankings (1-29), with varied importance and prestige on the result and tournament (1 major tournament, 2 mid-range tournament, 1 low level tournament and 2 test series not playing for a shield or trophy) and at various stages of the year which may influence fitness levels / fatigue level and readiness to perform. All of these may be influencing factors in players giving or being able to give a near maximal physical effort game in, game out and may explain some differences in work rates between the Australian and New Zealand data set. These factors may also help explain and influence the high level of variability, especially at high speeds that are seen in the current studies with or without situational variances. As, mentioned above there are a much wider range of situational variances than the three that were used in this study that can be encountered across a full international season of hockey.

Evidence in football suggest that playing in a hot climate >40 degrees Celsius results in a decrease of 7% of total distance and 26% in distance >14.1km/h when compared to playing in 23 degrees Celsius (Mohr et al., 2012). Of the 29 game data set, 6 games were played in temperatures >38 degrees Celsius in Malaysia. The large reduction seen in distance >14.1km/h in football may be an influencing factor that results in the high amounts of variability seen especially at moderate (11.01-19km/h) and high (>19.01km/h) speed bands.

Technical and tactical differences between the two teams may also be apparent. These technical and tactical differences could help explain the high level of variability with anecdotal evidence (non-published Australian Hockey data) suggesting that when a hockey team plays in a full press on defence, both teams end up having a higher work rate and higher amounts of high speed running when compared to when teams play in a half court press. The tactical effect of physical output variability is recognised in football (Bradley & Noakes, 2013), AFL (Kempton et al., 2015), rugby (McLaren et al., 2015) and hockey (Jennings et al., 2012a). This research did not account for tactical variation in play and with increased amounts of opposition scouting prior to matches teams are coming up with various defensive and offensive strategies that differ from team to team in order to try and win the game.

Hockey, unlike most other team sports, is played in repetitive match style where matches are played in clusters across tournaments often involving 6-7 matches in a 9-14 day period (Jennings et al., 2012a). Despite evidence that ~90 hours recovery time between matches in professional football results in no significant change in physical outputs (Dupont et al., 2010) and that distance above 15km/h can be sustained across a hockey tournament (Jennings et al., 2012a), several games in close succession(20-60 hours) have been reported to cause fatigue and a drop off in physical outputs in elite hockey players from game 1 to game 3 (Spencer et al., 2005). The nature of hockey tournaments with the short turnaround may influence the variability of physical outputs with varying reports on the influence of short turnaround and its effect on repeated performance in hockey.

Furthermore, because of the tournament structure, teams may adopt a pacing strategy (Bradley & Noakes, 2013). Several scenarios of this may occur depending on tournament structure. In games where a team has a lead, that team may resort to a ball retention strategy whereby dominating ball control slows the speed of the game down (Jennings et al., 2012a). European teams anecdotally are extremely proficient at this (Jennings et al., 2012a). Conversely if trailing teams are able to get the ball they may attempt to speed the game up (Lago, 2009) in a rush to score goals, which may be indicative of the current study with all positions showing the highest

TRD / work rates in a close game (Table 8) and the highest amounts of high speed metrics in a close game for strikers and a close game, loss or big loss for midfielders and defenders. Another potential model of pacing that may occur in hockey is that teams may have reduced physical exertion and effort in pool games, especially if winning, in order to save themselves for a must-win quarter final and semi-final match. In AFL it is reported that in finals games players may push themselves to higher than normal levels of physical exertion (Aughey, 2011b). This may occur come knockout time in hockey tournament which are normally 4-7 games into the tournament and high levels of fatigue may be setting in. Keeping fresh during the tournament may allow athletes to push to higher levels of their individual physical capacity at knock out stages of the tournament. If pacing does exist in hockey matches and tournaments, it may be another influencing factor on the moderate to high levels of variability reported in chapters 3 and 4.

Limitations and Further Research

It is acknowledged that there a limitation to the current thesis. One factor around both studies reported in this thesis is that not all players in the playing team were monitored every game, due to lack of resources, which may affect the mean physical outputs and estimations of variability produced in chapters 3 and 4. However, as with most international teams, there was a core group of regular first team players that were monitored so the impact of a player missing a game should be minimal. Of course, if all players in the playing team were monitored, there would be an increased sample size with which to establish within and between player variability. Another limitation was playing time which in hockey is not always equal across each position and therefore there may be within-position differences that are influenced by playing time. These differences could skew the data set for each position with players who play less playing time within a position potentially able to play at a higher physical demand when on the pitch as they have less total playing time and potentially less fatigue with more time to recovery between rotations. Variation in within position playing time will have an influence on the absolute measures of variability with less or more time on pitch increasing the spread of data and can also affect the absolute variability of physical outputs by playing at differing amounts of maximal physical capacity as match playing time changes. However whilst varying playing time could be considered a limitation of the study, the influence of playing time has been accounted for by expressing results as both absolute and relative metrics, giving valuable data to use to train each position in a specific manner. Typically this research had 12 of 16 field players monitored for each game with 3-5 players in each position being monitored for each game. Further research would include analysis of each player in the playing tournament team over a prolonged period of time.

Future research may further divide the positional groups as recommended by McLaren et al., (2015). It was noted that within rugby global positions (forwards and backs) large variability was observed. A discussion point for a potential cause of the variability was that with these global positions there are still differing requirements and tasks that are completed in the game for example front row forwards vs lose forwards and inside backs versus outside backs. With differing job roles within these global positions variability of physical outputs may be enhanced. It was suggested that future research break down these global positions (McLaren et al., 2015). Applying this concept to hockey may also help account for inter-positional variances such as the defenders being subdivided into centre backs and the outside bikes (right and left half), midfielders into centre mids and attacking mids and strikers into centre striker and wide strikers (left and right) or whatever typical position breakdown is used by the particular team.

Another recommendation is that future research uses a greater collection size over 2-3 years. This would allow year to year comparisons and would also provide a great sample size to not only compare match to match but also across tournaments, which may lead to further discoveries about the situational variances that may exist from tournament to tournament that may influence the physical outputs and variability of international hockey.

As mentioned earlier, the analysis of other situational variables outside of rank, result and score margin could have an effect on the physical outputs and variability of these outputs in field hockey. Situational variables such as; games played in hot climates have substantial evidence that shows there is a reduction is high speed distance when compared to a 'normal' climate (Mohr et al., 2012), tactical and technical variations and methods of playing influence match outputs in football (Lago, 2009) and, despite lack of evidence could also influence hockey outputs. Evolving match status (Bradley & Noakes, 2013) and amount of recovery time from the last game or before the next game are also recommended variables that may influence pacing strategies (Bradley & Noakes, 2013) in hockey and therefore influence physical match outputs and so may too influence the variabilities of these physical match outputs.

One major limitation of this thesis centred on the rule changes that the FIH made in January 2015, 4 months after data collection for this thesis had ended. FIH introduced a change to the game format from 2 x 35 min halves to 4 x 15 minute quarters, reducing the total playing time of a match by 10minutes and adding in extra breaks with a 2min break between the 1st and 2nd, and 3rd and 4th quarters and a 10min break between quarters 2 and 3. These changes may affect both absolute and physical outputs of international matches. Whilst there are no published data on the 'new' format of hockey there are a number of implications that may occur due to the new format that could influence playing time. Due to the extra breaks at quarter time, some players such as defenders who typically play high minutes at a lower relative distance than midfielders and strikers may be able to increase their playing time and potentially play an entire game, increasing absolute physical output loads. Furthermore, due to the increased stoppages in the game, players with less squad depth may be able to play their top line players for greater minutes as recovery time at the quarters may be enough for top players to recover enough to maintain physical outputs without needing an extra substitution. This may increase the playing time of top line players whilst also decreasing the playing time of 'bench' players, whom may be used more sparingly as a way to give top players a short break before resuming play. This may enhance the variability of playing time within each position and further research may need to differentiate between starting players and bench players when reporting on physical outputs in hockey.

As mentioned earlier, a reduction in playing time for athletes may lead to an increase in physical effort when on the pitch whilst also increasing skill performance as players are playing with less fatigue (Lythe & Kilding, 2013), which may further alter physical outputs of hockey and the variability of such outputs. Finally, teams with good squad depth may be able to increase the speed or intensity of play by using players evenly (Jennings et al., 2012a) resulting in increased recovery time on the bench and the potential for higher exertion when on pitch as discussed for athletes with lower playing time. Previous rule changes in field hockey such as allowing rolling unlimited substitutions resulted in increased relative distance and tempo of the game (Lythe & Kilding, 2011). In the only other major sport which has undergone significant rule changes based on playing time (AFL) a reduction of 20min in game in 1994, alongside other rule changes, increased professionalism and tactical enhancements has substantially increased the pace of the game and the amount of running especially the volume of high intensity running (Gray & Jenkins, 2010).

A comparison of 'old' vs 'new' format of hockey would be needed before the findings of this research could be widely used to enhance training performance. This research may provide a great tool for further research to use similar methods with the 'new' game format, which may or may not alter the speed of the game and also the variability of match to match performance. Generating likely worthwhile change values of the 'new' format of hockey would be appropriate so that training interventions can be made effectively. With the rule changes in hockey, further research may be required with a focus on the demands of the 'new' international hockey game with respect to heart rate analysis, sRPE and GPS metrics.

Practical Implications

The present study revealed a significant difference in mean physical outputs between positions (Table 4) in international male hockey players. Strikers have the highest work rate but also the lowest playing time, whilst midfielders have a greater work rate than defenders over the same playing time. Strikers and defenders have similar amounts of high speed running whilst defenders have significantly less than strikers and midfielders. Strikers also have higher amounts relative moderate speed running than both midfielders and defenders. Training plans across the positions need to be tailored with these metrics in mind to the specific needs of each position in order to best reflect the demands of international field hockey. However, due to the range of variability that exists in the physical outputs of international hockey players, regardless of position (Table 5), rank, result or score margin (Figures 4-6, A-C), caution needs to be taken in applying the physical outputs directly into a training setting, as prescription of mean outputs may largely underestimate the actual physical outputs.

Using a likely worthwhile change in mean values may be an appropriate method of integrating GPS-derived physical outputs into an international hockey training schedule. With the high variability of high speed physical outputs (Table 5) a very large change (~30-50%) in mean values would need to be elicited to produce a likely worthwhile change, so using high speed metrics in the integration of GPS outputs to training needs to be used with caution. Rather, the use of a low variability metric such as TRD / work rate (expressed as metres per min) may deem a practical method of applying the likely worthwhile change value into a training program. A ~10% change in mean values for TRD would see a likely worthwhile change across all positions in hockey and is more achievable than a ~30-50% increase in high speed running distance. Coaches and practitioners should focus on creating drills or small sided games in training with a ~10% higher

TRD which may provide a good training intervention that specifically enhances an athletes ability to cope with the demands of international hockey.

Finally, whilst this thesis has shown a method of analysing the variability and work rates of international hockey, recent rule changes may mean the data is outdated compared to the ‘new’ game. It would be recommended that analysis of a large data set based off of the ‘new’ format of hockey applies similar protocols to this thesis to analyse the degree of variability in international hockey whilst also establishing the physical outputs of the ‘new’ format of international hockey. Using situational variables such as climate, tactical differences and with pacing strategies in mind may also further reduce the variability of within player variability from match to match.

Conclusion

In summary, GPS analysis of international matches has revealed that hockey is a high-intensity team sport, during which player work rate often reaches the highest levels recorded for team sports. However, differences exist between positions, with strikers producing work rates of 130m/min, midfielders 131m/min and defenders 119.2m/min. Variation also occurs in the breakdown of these metrics in relative speed bands between positions. Therefore, it is recommended that training for each position be individualised. When situational variances such as rank, result, score margin are considered, the mean outputs are influenced, mostly with respect to moderate and high speed distances. However, caution is needed when analysing the data due to the significant between (3.7 to 42.5%) and within-player (4.7 to 39.3%) variability that exists for some metrics, especially moderate and high speed metrics. Knowledge of the variability in hockey with respect to the smallest worthwhile change in physical outputs can be used to estimate what would be considered a likely substantial change. In this regard, for the least variable metrics, a ~10% greater relative distance in a given match or training exercise would be considered as a *likely* substantial difference and this may be an appropriate method of applying the results of this study into interpreting match demands and training practices of international hockey players.

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APPENDIX 1

Participant Information Sheet

Participant Information Sheet

21 October 2014

Physical outputs of training and match play in elite hockey.

Hi, my name is Scott Logan and I would like to invite you to participate in my post-graduate research at AUT University which aims to advance the understanding of; and training of, the physical outputs of playing hockey at the elite level.

Please read this information and decide whether or not you would like to be involved in the project. You don't have to be involved, and you can stop being involved in the project at any time without any negative effects for yourself.

What is the purpose of this research?

The use of global positioning system (GPS) and accelerometer technology is wide spread across elite team sport athletes to monitor game and training loads and to assist with prescribing training. With advances in technology and software, capturing a wider range of metrics is possible. This thesis will explore how best to represent and interpret GPS and accelerometer data in elite hockey, with respect to the effects of different types of training, as well as determine how game factors such as game format, opposition rank, tournament schedule and positional factors influence player physical outputs at the elite level.

The results of the study may also be published in scientific journals but you will remain anonymous and your name will not appear in any papers seen by others.

This research is being conducted as a masters thesis. At the conclusion of the study, the researcher will attain a Masters in Sport and Exercise. This research could also potentially lead to commercial benefit for the researcher.

What will happen in this research?

You are already required to partake in all Black Sticks Hockey commitments including tournaments and match play (selection dependant), hockey training sessions and strength and conditioning sessions and fitness assessments, as per the Black Sticks calendar and your player contract with Hockey New Zealand. During games and training, you are already familiar with wearing heart rate and GPS units to track your movement and exertion. For this research project, you don't need to do anything else other than complete the above training/games/assessments while wearing a HR monitor and GPS unit. This research simply involves me looking at this data more closely and formally comparing and analysing game and training data as part of a research project to improve knowledge of the game.

What are the discomforts and risks?

There are no risks other than those you typically experience during hockey training and matches such as contact and non-contact injuries.

What are the benefits from this project?

A closer more formal inspection of data collected will hopefully enhanced our knowledge of the demands of hockey games and training at the elite level, making training more specific to each of positional requirements which will help improve individual and team performance.

How will my privacy be protected?

All data collected from training sessions, matches and fitness testing will remain confidential. The only people who will see the results are the team's coaches, the researcher (Scott Logan) and the thesis supervisors (Dr Andrew Kilding).

Some of the data collected during this study may be published in a scientific paper on behalf of AUT (Auckland University of Technology), however all participants shall remain anonymous.

The data collected from the study will be kept only by the researcher on a secure laptop and external hard drive. The data will be kept indefinitely and may be used again for similar studies. If the data is used again for studies outside of this particular research, you will be again asked to give your explicit permission to use data attaining to you. There will be no discrimination if you wish to not be involved in this study or possible future studies.

What opportunity do I have to consider this invitation?

Please take your time to decide if you would like to do the project. If you are happy to participate, fill in the consent form and return it back to me at the start of a training session

Thank you for taking the time to read this information.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Andrew Kilding, Andrew.kilding@aut.ac.nz, Ph. 921 999 ext. 7056

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz*, 921 9999 ext. 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Scott Logan, High Performance Sport New Zealand, SPRINZ School of Sport and Recreation, AUT University, scott.logan@hpsnz.org.nz

Project Supervisor Contact Details:

Assoc. Prof. Andrew Kilding, SPRINZ, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph. 921 9999 ext. 7056, Andrew.kilding@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *21 October 2014*, AUTEC Reference number *14/323*.

APPENDIX 2

Consent Form

Consent to Participation in Research

Project Title:	*The physical outputs of training and match play in elite Hockey*
Project Supervisors:	*Assoc. Prof Andy Kilding,*
Researcher:	*Scott Logan*

- I have read and understood the information provided about this research project (Information Sheet dated 19 October, 2014).

  Yes/No

- I have had an opportunity to ask questions and to have them answered. **Yes/N o**

- I understand that the data collected from the testing sessions, training sessions and matches will be made available to the team coach and named researchers only

  Yes/No

- I give permission and understand that the team coach will receive the results of the studies in the aim to further guide future training protocols.

  Yes/No

- I understand that the data collected from the testing sessions, training sessions and matches will be securely stored indefinitely and may be used for future studies only with my explicit permission for this to occur.

  Yes/No

- I understand that I may withdraw from this project at any time prior to completion of data collection, without being disadvantaged in any way.

  Yes/No

- I agree to allow the collected data to be used for research purposes, including a post-graduate thesis, conference and journal publications

  Yes/No

- I agree to take part in this research

  Yes/No

Participant signature:____

____

Participant Name: ____

____

Date: _______________

Project Supervisor Contact Details:

Assoc. Prof Andrew Kilding

Sports Performance Research Institute NZ

AUT University

AUT Millennium

17 Antares Place, Mairangi Bay, 0632

Ph.: 921 9999 ext. 7056 Email: *Andrew.kilding@aut.ac.nz*

Approved by the Auckland University of Technology Ethics Committee on 21 October 2014, Reference number 14/323

APPENDIX 3

Ethical Approval Letter

AUTEC
SECRETARIAT

21 October 2014

Andrew Kilding
Faculty of Health and Environmental Sciences

Dear Andrew

Re Ethics Application: **14/323 Physical outputs of training and match play in elite hockey.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 21 October 2017.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 21 October 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 21 October 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Scott Logan scott.logan.taylor@gmail.com

APPENDIX 4

Situational Variability of Strikers

Absolute Physical Outputs	1 to 5 CV	7 to 11 CV	>12 CV	Overall CV
TD (m)	17.86; ±6.21	10.83; ±9.83	12.14; ±3.87	17.61; ±3.89
LSD (m)	18.29; ±8.1	13.17; ±6.34	13.86; ±6.59	20.12; ±6.52
MSD (m)	33.14; ±13.6	20.5; ±16.04	19.14; ±11.94	27.81; ±14.23
HSD (m)	32; ±12.74	23.33; ±14.87	24.86; ±11.37	31.61; ±9.34
Relative Physical Outputs	1 to 5 CV	7 to 11 CV	>12 CV	Overall CV
TRD (m/min)	9.71; ±5.44	8.83; ±5.33	6.14; ±3.64	9.77; ±2.98
LSRD (m/min)	10.86; ±3.37	9.83; ±10.8	7.43; ±4.65	10.59; ±3.97
MSRD (m/min)	27.57; ±14.11	19; ±8.26	18; ±11.64	26.04; ±9.91
HSRD (m/min)	28; ±13.17	25.17; ±12.86	22.86; ±10.52	27.82; ±9.39
Absolute Physical Outputs	Win CV	Draw CV	Loss CV	Overall CV
TD (m)	12.17; ±4.08	14.46; ±5.81	20.17; ±9.09	17.61; ±3.89
LSD (m)	12.4; ±6.42	14.97; ±7.33	16.91; ±10.25	20.12; ±6.52
MSD (m)	19.63; ±12.24	26.99; ±9.04	40.17; ±20.61	27.81; ±14.23
HSD (m)	25.57; ±11.36	26.76; ±9.49	37.86; ±20.86	31.61; ±9.34
Relative Physical Outputs	Win CV	Draw CV	Loss CV	Overall CV
TRD (m/min)	5.94; ±3.38	11.29; ±3.91	10.91; ±6.39	9.77; ±2.98
LSRD (m/min)	7.81; ±4.35	9.77; ±8.58	12.3; ±4.09	10.59; ±3.97
MSRD (m/min)	17.97; ±10.87	23.44; ±11.41	31.76; ±19.78	26.04; ±9.91
HSRD (m/min)	21.99; ±10.01	27.41; ±9.26	32.9; ±16.54	27.82; ±9.39
Absolute Physical Outputs	Big win CV	Close game CV	Big Loss CV	Overall CV
TD (m)	12; ±3.92	13.38; ±4.19	20.43; ±9.47	17.61; ±3.89
LSD (m)	13; ±7.16	12.88; ±5.33	17.86; ±11.01	20.12; ±6.52
MSD (m)	20.43; ±12.56	23.13; ±9.2	40.71; ±21.03	27.81; ±14.23
HSD (m)	25.14; ±7.85	26.5; ±6.51	38.71; ±20.44	31.61; ±9.34
Relative Physical Outputs	Big win CV	Close game CV	Big Loss CV	Overall CV
TRD (m/min)	6; ±3.96	9.13; ±3.82	11.14; ±6.35	9.77; ±2.98
LSRD (m/min)	8.29; ±5.14	8.88; ±5.81	12.43; ±3.92	10.59; ±3.97
MSRD (m/min)	19.29; ±12.22	19.38; ±10.6	33; ±19.72	26.04; ±9.91
HSRD (m/min)	21.43; ±9.93	24.88 ; ±7.6	32.29; ±16.8	27.82; ±9.39

TD=Total distance; LSD=Low speed distance (<11km/h); MSD=Moderate speed distance (11.01-19km/h); HSD=High speed distance (>19.01km/h); TRD=Total relative distance (m/min); LSRD=Low speed relative distance (m/min); MSRD=Moderate speed relative distance (m/min); HSRD=High speed relative distance. Results displayed as Mean; ± 95% CL.

APPENDIX 5

Situational Variability of Midfielders

Absolute Physical Outputs	1 to 5 CV	7 to 11 CV	>12 CV	Overall CV
TD (m)	12; ±3.44	8.75; ±3.53	9; ±2.48	13.82; ±3.13
LSD (m)	9.50; ±1.59	7.75; ±3.28	8.6; ±2.57	15.51; ±3.52
MSD (m)	20.25; ±9.93	13.25; ±4.75	17.8; ±10.33	20.61; ±5.78
HSD (m)	32.75; ±17.01	24.25; ±17.83	28.8: ±16.6	38.19; ±16.19
Relative Physical Outputs	**1 to 5 CV**	**7 to 11 CV**	**>12 CV**	**Overall CV**
TRD (m/min)	6.75; ±5.26	4.75; ±2.39	7.4; ±4.44	8.42; ±2.78
LSRD (m/min)	5.25; ±2	3.25; ±2	3.8; ±1.04	6.07; ±3.03
MSRD (m/min)	16.75; ±10.82	9.5; ±7.18	18.2; ±12.49	20.46; ±8.05
HSRD (m/min)	30.75; ±17.3	22.5; ±17.55	29.2; ±19.02	39.31; ±15.59
Absolute Physical Outputs	**Win mean CV**	**Draw mean CV**	**Loss Mean CV**	**Overall mean CV**
TD (m)	8.94; ±1.17	10.58; ±4.65	14.4; ±4.57	13.82; ±3.13
LSD (m)	8.36; ±2.74	9.28; ±1.88	11.13; ±4.1	15.51; ±3.52
MSD (m)	17.9; ±8.09	15.83; ±8.74	23.37; ±11.73	20.61; ±5.78
HSD (m)	29.36; ±15.12	27; ±9.9	37.6; ±20.76	38.19; ±16.19
Relative Physical Outputs	**Win CV**	**Draw CV**	**Loss CV**	**Overall CV**
TRD (m/min)	8.3; ±3.45	4.98; ±2.97	7.83; ±6.54	8.42; ±2.78
LSRD (m/min)	4.72; ±0.57	4; ±2.84	3.65; ±3.03	6.07; ±3.03
MSRD (m/min)	18.12; ±12.06	12.23; ±6.31	18.68; ±18.55	20.46; ±8.05
HSRD (m/min)	29.58; ±17.42	24.45; ±9.4	35.28; ±18.13	39.31; ±15.59
Absolute Physical Outputs	**Big win CV**	**Close game CV**	**Big Loss CV**	**Overall CV**
TD (m)	10; ±1.76	9.25; ±3.98	15.5; ±4.95	13.82; ±3.13
LSD (m)	9; ±3.29	8.75; ±2	10.75; ±7.62	15.51; ±3.52
MSD (m)	19.6; ±8.08	14.75; ±4.18	26; ±14.47	20.61; ±5.78
HSD (m)	31; ±15.63	24.25; ±4.18	43.25; ±24.53	38.19; ±16.19
Relative Physical Outputs	**Big win CV**	**Close game CV**	**Big Loss CV**	**Overall CV**
TRD (m/min)	8.6; ±3.68	4.75; ±2	8.25; ±8.15	8.42; ±2.78
LSRD (m/min)	3.8; ±1.05	4.75; ±2	4; ±3.44	6.07; ±3.03
MSRD (m/min)	20; ±11.75	11.25; ±5.42	20; ±23.96	20.46; ±8.05
HSRD (m/min)	30.4; ±18.92	22.75; ±4.75	39.75; ±22.14	39.31; ±15.59

TD=Total distance; LSD=Low speed distance (<11km/h); MSD=Moderate speed distance (11.01-19km/h); HSD=High speed distance (>19.01km/h); TRD=Total relative distance (m/min); LSRD=Low speed relative distance (m/min); MSRD=Moderate speed relative distance (m/min); HSRD=High speed relative distance. Results displayed as Mean; ± 95% CL.

APPENDIX 6

Situational Variability of Defenders

Absolute Physical Outputs	1 to 5 CV	7 to 11 CV	>12 CV	Overall CV
TD (m)	11.33; ±5.58	16; ±13.29	12.57; ±4.95	13.82; ±3.13
LSD (m)	11; ±6.4	21.83; ±14.34	13.86; ±2.89	15.51; ±3.52
MSD (m)	21; ±13.97	13.83; ±7.87	23.29; ±6.05	20.61; ±5.78
HSD (m)	30.83; ±10.69	25.33; ±21.33	43.71; ±19.74	38.19; ±16.19
Relative Physical Outputs	1 to 5 CV	7 to 11 CV	>12 CV	Overall CV
TRD (m/min)	8.33; ±6.04	9.67; ±6.18	8.29; ±2.65	8.42; ±2.78
LSRD (m/min)	6.33; ±2.87	7.83; ±8.72	4.57; ±2.72	6.07; ±3.03
MSRD (m/min)	21.83; ±12.86	18.5; ±12.27	24.43; ±7.58	20.46; ±8.05
HSRD (m/min)	28.83; ±10.94	26.83; ±13.05	45.57; ±23.42	39.31; ±15.59
Absolute Physical Outputs	Win CV	Draw CV	Loss CV	Overall CV
TD (m)	12.91; ±3.18	15.92; ±11.55	12.3; ±4.78	13.82; ±3.13
LSD (m)	13.86; ±2.15	18.68; ±13.02	18.48; ±3.19	15.51; ±3.52
MSD (m)	20.1; ±5.3	18.58; ±6.82	18.26; ±4.7	20.61; ±5.78
HSD (m)	35.27; ±18.52	22; ±13.15	38.36; ±15.51	38.19; ±16.19
Relative Physical Outputs	Win CV	Draw CV	Loss CV	Overall CV
TRD (m/min)	6.99; ±2.78	9.7; ±5.35	10.88; ±6.85	8.42; ±2.78
LSRD (m/min)	4.26; ±1.8	7.26; ±10.87	7.14; ±3.74	6.07; ±3.03
MSRD (m/min)	18.2; ±8.74	19.68; ±7.46	27.22; ±13.27	20.46; ±8.05
HSRD (m/min)	36.68; ±15.77	21.98; ±5.85	39.68; ±38.42	39.31; ±15.59
Absolute Physical Outputs	Big win CV	Close game CV	Big Loss CV	Overall CV
TD (m)	12; ±4.94	15.5; ±7.56	10.4; ±1.88	13.82; ±3.13
LSD (m)	13.38; ±3.48	17.17; ±7.89	14.6; ±0.68	15.51; ±3.52
MSD (m)	21; ±5.49	20.33; ±11.28	14.2; 9.51	20.61; ±5.78
HSD (m)	37.62; ±20.27	30.83; ±10.73	36.6; ±7.58	38.19; ±16.19
Relative Physical Outputs	Big win CV	Close game CV	Big Loss CV	Overall CV
TRD (m/min)	7.25; ±2.67	8.33; ±1.59	8.8; ±8.11	8.42; ±2.78
LSRD (m/min)	4; ±2.32	6.67; ±5.42	7.8; ±3.97	6.07; ±3.03
MSRD (m/min)	19.63; ±9.31	19.33; ±10.64	21.8; ±15.09	20.46; ±8.05
HSRD (m/min)	38.63; ±18.61	31.5; ±14.54	35; ±28.22	39.31; ±15.59

TD=Total distance; LSD=Low speed distance (<11km/h); MSD=Moderate speed distance (11.01-19km/h); HSD=High speed distance (>19.01km/h); TRD=Total relative distance (m/min); LSRD=Low speed relative distance (m/min); MSRD=Moderate speed relative distance (m/min); HSRD=High speed relative distance. Results displayed as Mean; ± 95% CL.