Effects of a Duration of Play Rule Change and Training Periodization Strategies on Game Physical Outputs and Fitness in Elite Female Hockey Players

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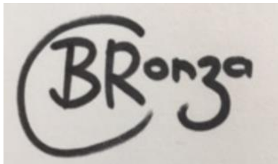
Attestation of Authorship

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 (except where explicitly defined), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of university or institution of higher learning.



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Intellectual Property Rights

Ethical Approval

Ethical approval for the studies undertaken in this thesis was granted from Auckland University of Technology's Ethics Committee (AUTEC) on 21st November 2014 Ethics Application Number: 14/323.

Abstract

Background: Preparing athletes for the demands of international competition is optimised when the game demands are known, which in turn allows for optimal periodization strategies to be implemented. Few studies have investigated the game demands of elite female hockey, especially since recent rule changes have been implemented. Likewise, identification of periodization strategies for effective aerobic development in hockey players is lacking and addressing this may prove valuable in optimising performance both in training and in competition. ***Aims:*** The aims of this thesis were to determine 1) the effect of a recent FIH rule change (from 2 x 35 min halves to 4 x 15 min quarters) on elite player physical outputs (study one), and 2) the effects of two different SSG periodization strategies on aerobic fitness in elite female hockey players (study two). ***Methods:*** In study one comparisons of game outputs derived from GPS analysis of 170 match files were made between international games before ('old') and after ('new') the implementation of a FIH rule change. Player GPS running data was categorized into generic velocity bands reflecting the percent of the total distance covered (low, 0–0.6 km/hr; moderate, 6.1–15.0 km/hr; high-intensity, 15.1–29.5 km/hr) and individual velocity bands based on each player's maximum aerobic speed (MAS: low, <70%MAS; moderate, 70-100% MAS; and high-intensity, >100% MAS) categories, as well as total work rate (m/min). In study two, twelve, elite female hockey players participated in two separate 5 week periodized SSG training interventions. The first employed a "short to long" periodized SSG training approach (Block 1), which was followed by an international tournament, then a second 5 week "long to short" SSG training (Block 2) was implemented. Block 1 "short to long" was periodised over the 5-week training block from small to medium pitch 4 v 4 SSGs to larger full pitch 11 v 11 games at the end of the block. Block 2 was periodised in a "long to short" manner, which involved a 2-week full pitch 11 v 11 tournament simulation progressing to a small to medium pitch 4 v 4 SSG's at the end of the block. Pre and post assessments of MAS and 5,10 and 40m linear speed were performed for both Block 1 and 2***. Results:*** In Study One differences in running outputs between ‘old’ and ‘new’ game formats were only statistically significant in the Low Generic (11.4 ± 29%, $p=0.002$), Low MAS velocity bands (8.08 ± 26%, $p=0.012$), and the average work rate (-3.25 ± 11%, $p=0.003$) for games following the ‘new’ format. There were no differences between ‘old’ and ‘new’ format for any moderate or high-intensity work bands ($P>0.05$). In study two there was a *small* training effect of Block 1 on MAS from pre to post testing with MAS improving by 2.0 ± 2.8 % (ES = -0.3, $P>0.05$). Similar effects were observed for Block 2 with *small* (1.4 ±1.98 %, ES=-0.21, $P>0.05$) improvements in MAS pre to post testing. There was no significant difference in MAS between Block 1 and Block 2 for the between block pre-post differences ($P>0.05$)**.** The 5, 10 & 40m speed for Block 1 only showed a *trivial* training effect. The 40m speed showed the largest change improving by -0.9 ± 3.9 % (ES = 0.49, $P>0.05$). The speed measures in Block 2 showed similar *trivial* training effects across the three speed distances, with the greatest percent difference in 5m speed showing an improvement (0.8 ± 2.0%; ES = 0.19, $P>0.05$). ***Conclusion:*** The changes in physical outputs indicate players spend more time in the low velocity bands with a small decrease in work rate from the ‘old’ to ‘new’ format. These changes indicate that the rule change had minimal physical effect as similar outputs were seen in the higher velocity zones which have a greater physical cost for players in international matches. In addition, findings of study two revealed that the training intervention improved the players MAS pre to post testing in Block 2, which would indicate that the long to short SSG training intervention had a small positive effect on aerobic system development during an in-season training intervention in elite women hockey players.

Chapter One: Introduction

1.1 Background

Rule changes in team sport are very common with often the intent to improve player performance and enjoyment, attracting spectators and athletes to the sport, attending to commercial pressure, adapting the sport to children's needs and interests and preventing injuries. Elite team sports may be required to adapt to new rules, changes to tournament structures and playing schedules, with success often being defined by how quickly teams adapt to these changes, then implement them efficiently into their training cycles to ensure optimal performance in competition. (Arias et al., 2011).

Hockey is an international team sport that has been progressive in refining the sport, with the implementation of many rule changes over the past ten years as the sport continues to progress from amateur to a professional era. These changes have included the change of playing surface from grass to a synthetic surface (Malhotra, Ghosh, & Khanna, 1983), modernized sticks (Allen, Foster, Carré, & Choppin, 2012), and rule alterations such as the self-start (Tromp & Holmes, 2011). The most recent major change has seen the match duration and format change from two thirty-five-minute halves with a ten-minute half time, into four fifteen-minute quarters with two, two-minute rest periods, and one ten-minute half time (FIH, 2014). It is possible that these changes have impacted on game physical demands, recovery and consequently may alter a team's tactics both technically and physically. However, little research has been conducted describing and quantifying potential differences between previous (old) and current (new) game formats and how these might impact periodization of training and coach decision making. Understanding the potential effects of these changes and how it impacts on the game technically, tactically and physically is a key part of optimally preparing teams for game demands, especially at the elite level.

Elite level competition in hockey requires athletes to have a high level of aerobic and anaerobic capacity, strength & power (Reily & Borrie, 1992). Furthermore, matches are often moderate to high in total distance, have repeated bursts of high intensity activity (Gabbett, 2010), and requires frequent changes of direction and game tempo. Matches are typically played in close proximity, with limited time to recover between games, and requiring athletes to maintain game intensity across a tournament (Abbott, 2016, Jennings et al., 2012a). Furthermore, the high player work rate and high intensity running required is often performed in a semi crouched position, while having to execute high technical demands of stick and ball control. Quantification of the physical outputs of team sport athletes during matches and training is important to ensure all players are optimally prepared for the rigors of competition.

To help quantify and monitor the physical outputs of team sport athletes time motion analysis (TMA) technology such as global positioning systems (GPS) has proved to be a useful performance and monitoring tool (Bloomfield, Polman, & O'Donoghue, 2007). This technology has assisted teams to adapt, individualise, periodize and implement training, playing and recovery systems in the daily training environment that will best allow their athletes to be physically prepared and express these qualities when it matters most, in international competition. The use of GPS also helps to reduce the risk of implementing insufficient and optimal training stimulus and misaligned recovery strategies which can lead to maladaptation, overtraining and not effectively preparing athletes for the demands of competition. To provide an optimal training stimulus once the demands of competition are known through TMA, coaches, sport scientists and strength and conditioners can accurately focus on preparing team sport athletes for the demands of the competition and to improve the physical qualities of the athletes. Based on the identified physical demands and characteristics of team sport competition and the importance of having a high level of aerobic fitness, it is clear that a significant portion of the conditioning programmes of team sport players including hockey, should focus on improving their ability to repeatedly perform high-intensity exercise and optimise their ability to recover from these bouts (Stone and Kilding, 2009).

High levels of aerobic conditioning in elite team sport plays a significant part in allowing players to repeatedly perform high-intensity activity, which places further significance of implementing a well-planned and periodized aerobic conditioning stimulus through the season. It has been shown that a high VO_{2peak} is moderately related to repeat sprint ability in hockey, rugby union and soccer players, as well as endurance-trained and untrained populations (Bishop et al., 2004, McMahon & Wenger, 1998). This suggests that the body's ability to deliver and use oxygen, both during and between high-intensity sprints, is important (Bogdanis et al., 1996). Furthermore, also in soccer, previous studies have demonstrated that players with a higher aerobic power cover greater distance during a soccer game (Bangsbo, 1994). Overall, a high VO_{2peak} will likely serve to reduce the metabolic disturbances resulting from anaerobic metabolism (Stone & Kilding, 2009). However, it should be acknowledged the limitations of VO_{2peak} and repeated sprint ability (RSA) in elite athlete populations that studies showing that VO_{2peak} is a poor indicator of the fitness status of team sport athletes (Edwards et al., 2003), and does not relate to performance in either short-term (Bishop et al., 2003) or prolonged intermittent exercise tests among professional players (Bangsbo and Lindquist, 1992), nor does it determine the total amount of running distance covered during a game (Krustrup et al., 2005). Ultimately, however, players who are aerobically well trained are likely able to maintain their work rates/power output towards the end of a game compared with those with poorer aerobic fitness (Stone and Kilding, 2009).

To improve aerobic fitness qualities in team sport athletes a number of methods have been proposed, with research to date suggesting the most effective methods to improve aerobic fitness in team sport athletes are traditional aerobic conditioning, classic aerobic conditioning, and sport specific conditioning. One popular sport specific method used in team sport environments to help deliver optimal training stimulus which develops players technical, tactical and physical qualities simultaneously is the use of small sided games (SSG). SSG's have become very popular in team sports for preparing athletes at all ages, levels of experience, or skill levels for the demands of the game within the context of the sport (Owen et al., 2004, Reilly, 2004). As well as these benefits they also have the potential to increase many physical qualities, such as aerobic and anaerobic capacities of team sport athletes and provide valuable preparation for the specific demands of formal team sports games (Gabbett & Mulvey, 2008), as well improving the variability of learning and ensuring an optimal level of unpredictability for developing decision making and creativity (Alison & Thorpe, 1997). Moreover, they are related to high motivational and engagement levels of players (Smith 2010, Ryan & Deci, 2000), increased ball involvement and could be considered a more effective use of training time which enables the coach, sport scientist, and players to focus on eliciting specific outcomes needed to improve demands of the game (Owen et al., 2012). However, the impact of SSG's is variable and dependent on factors such as pitch area, player number, coach encouragement, continuous or intervals, work to rest ratio's, rule modifications, game structure, ball availability and for some team sports the use of goals and/or goalkeepers (Hill Hass, 2011). Many of these variables that can be controlled by the coach may influence the exercise intensity during SSGs which in turn effects the amount of aerobic and anaerobic stimulus players may receive. Thus, complicating the art of programme planning, prescription and implementation into the dynamic training environment of team sport.

With regards to acute responses to SSGs, Rampinini et al (2009) examined effects of player number, field dimension and coach encouragement on the exercise intensity of SSG in soccer, designed specifically for aerobic conditioning. They found that the factor that had the greatest impact on the physiological response to SSG's was encouragement, followed by player numbers and field dimensions. In an earlier study they also found increasing the pitch area by 20% across a variety of SSG formats (3 vs 3 to 6 vs 6), resulted in the percentage of maximum HR (%HR_{max}) and blood lactate concentration being higher during SSG's played on a large pitch, than on a medium-sized or small pitch. RPE was also higher on medium and large pitch sizes compared with small pitches (Rampinini et al., 2007). Similarly, a study involving youth soccer players examined the acute physiological and perceptual responses and time-motion characteristics during three variations of SSGs (2 vs 2, 4 vs 4 and 6 vs 6) with a constant ratio of player number to pitch area applied to each SSG variation. The main findings were, as the number of players in the SSG teams decreased, when the relative pitch area per player remained constant, the overall physiological and perceptual responses increased, and the largest game format (6 vs 6) was associated with a greater range of distances travelled at speeds greater than 18 km/h. In contrast, the 4 vs 4 format, compared with the 2 vs 2, was characterized by significantly longer (average and maximal) effort durations and distances for speeds greater than 18km/h (Hill-Hass, 2009). This is an important consideration for SSG prescription, as to improve aerobic fitness in team sport, athletes need to maximise the amount of time above 100% maximum aerobic speed (MAS), with most elite male teams having a maximum aerobic speed of 15 -18km/hr and elite female athletes 14.5-16.5km/hr, the more the design of the SSG allows players to spend above these speeds the greater the opportunity to develop aerobic fitness qualities (Baker, 2015).

In training coaches quite often modify playing rules in SSGs to achieve greater exercise intensity or develop specific technical and tactical skills. Of the few studies that have investigated these effects on intensity most research was completed in soccer and found an increase in %HR$_{max}$ (Sassi et al., 2004, Mallo & Navaro, 2008) and blood lactate concentration (Aroso et al., 2004) due to rule changes. Another modification is the use of goalkeepers and at present, the influence of goalkeepers on exercise intensity in SSGs is not clear. Of the two studies found in soccer, Mallo and Navarro (2008) reported a significant decrease in %HR$_{max}$ total distance and time spent in high intensity running, in 3 vs 3 SSGs with goalkeepers. In contrast Dellal et al (2008) reported a 12% increase in heart rate response in 8 v 8 SSGs with goalkeepers. This shows further research is needed in team sport codes with goalkeepers to determine the influence on physiological and technical/tactical demands in SSGs.

Changing the duration and work to rest ratios in SSG’s is another popular method to alter exercise intensity, with most studies using an interval training method. Although most studies examining SSGs have prescribed the SSG bouts using intervals with short rests (e.g. 90sec-2min), some recent studies have used continuous SSG formats of differing duration (e.g. 10-30 minutes). Unfortunately, previous studies have not used consistent work to rest ratios and there is a large variation in the length, duration, and number of work bouts and rest intervals amongst studies, which makes comparison difficult (Hill-Haas, 2011).

There is no doubt that sport-specific aerobic conditioning can induce positive changes in aerobic fitness (and technique under physical load), however, in most studies, evidence of the impact of sport-specific aerobic conditioning on subsequent game performance is lacking. Sport-specific conditioning methods have been demonstrated to promote increases in VO_{2peak}; however, little research to date has addressed the subsequent effects on game performance. The effectiveness of sport-specific conditioning appears to be influenced by the skill level of the athlete, where those with a lower skill level may not be able to maintain the skill or drill at a suitable intensity to promote the desired aerobic adaptations. Current fitness must also be considered. Players with already high levels of fitness may easily achieve the desired physical load during SSG's and thus not achieve a training effect. Skill and fitness related issues can be overcome by manipulating conditions such as player numbers, field dimensions, game rules and coach encouragement: smaller playing numbers, larger playing areas and coach encouragement tend to increase the metabolic loading of SSG's. When traditional and sport-specific conditioning approaches are compared, results are equivocal. Both approaches promote similar increases in aerobic fitness and sport performance when training intensity and volume are constant. The most important benefit of performing sport specific conditioning is that it allows for both aerobic fitness and game skills to be developed simultaneously.

Regardless of the research examining game demands, rule changes and optimal periodization strategies in team sport, there remains a real lack of quality research conducted in the real-world setting of elite level team sport and hockey. The available research looking at player's physical outputs in relationship to rule changes for elite women's hockey is scarce. With only one study examining the effect of the 2009, free-hit rule on the game (Tromp & Holmes, 2011) and to the authors knowledge only one other study existing on the effects of the 2015 rule changes on women's hockey (Abbott 2016). This lack of research warrants further investigation to give coaches and trainers alike reassurance and clarity of the current physical profile and game outputs that ensure optimal periodization and training strategies to effectively prepare athletes for the demands of competition.

As well as a lack of quality research into the effect of current rule change in hockey, the current recommendations in optimal periodization of SSG's training interventions are based off only a few studies mainly in youth and elite soccer, rugby league and rugby union with studies typically employing only 2 interventions per week, and given the high training frequency of most team sport athletes it highlights opportunities for further interventions to be planned into the training week to optimise physical preparation of athletes.

With optimal periodization at the elite level being a holistic and multiannual process, where team sports look to prepare athletes to achieve peak performance across weekly competitions or for pinnacle tournaments. To achieve these goals, the fundamental principles and models of periodization, need to be understood to facilitate the structuring of the training and competition into various phases, periods and cycles. To further understand why different periodization models may have different training effects, researchers have identified various periodization strategies that are designed to align to the outcome required. These strategies differ both in terms of competitions, their number and structure and the content of the training process in various micro and mesocycles (Lyakh et al., 2016).

The first strategy, aligns the training process and team goals at achieving the best result in the pinnacle competition of the season. All other competitions are of secondary importance and participation in them serves as means of preparation and monitoring of the effectiveness of the training process and to prepare for the pinnacle event. The positive training effects of this periodization strategy, as viewed by Platonov (2013), allows the players to achieve the best individual results in the main competition in 60 – 70% or in some situations in up to 90% of cases. The second periodization strategy combines effective preparation for competition (in various disciplines) conducted over a long period of time (8-10 months) with the preparation for the participation in the main competition of the year. This strategy is characteristic for elite players. The challenges of this strategy are how to optimally combine workouts (in 4–7 macrocycles) with the specific character of the games and their competition schedule in terms of annual periodization. The third strategy is, according to Platonov (2013), may be the most useful for athletes practicing team sport games. This periodization strategy has the players participating in week to week competition throughout the year including which may fall between 50 and 70 competition game and playoff matches. The main concern of this strategy constitutes the optimal balance between work and rest as well as variability in training loads (volume and intensity) (Lyakh et al., 2016).

Therefore, optimal periodization may be considered both an art and science as coaches and sport scientists continue to balance the optimal proportion of training and competition in an ever-increasing competitive professional environment of modern sport at the elite level. It raises questions whether an optimal periodization strategy exists as often none of the above-mentioned periodization strategies may be used in its entirety. This may be due to the competition schedule and established priority of the team, resulting in the combination of different strategies (Platonov, 2013, Suslow, 2002). Furthermore, the annual competition schedule of most team sport games at the elite level does not allow for an optimal proportion of training sessions and competitions to participate in. As a result, instead of planned adaptation, players may experience the effects of de-conditioning across the most important physical pillars needed for success in team sports (Platonov, 2013, Suslow, 2002).

With these considerations in mind, research examining optimal SSG periodization within hockey, within a typical training week and across training cycles is warranted, particularly given the popularity, positive training effects and identified limitations of using SSG's to elicit development across technical tactical and physical domains and the current lack of comprehensive research done in this sport. The influence of SSG's on physical performance, game related outputs and optimal periodization strategies is yet to be fully established, with future research examining the impact of these variables in a high intensity intermittent sport such as hockey would be of particular benefit.

1.2 Study aims

To assist with being better physically prepared for international competition, the objective of this thesis is to clarify the effects of recent rule changes on the physical outputs of female players during elite hockey competition and, thereafter, explore optimal SSG periodization strategies to develop aerobic fitness.

The aims of thesis are therefore to:

1. Determine the effect of a recent FIH rule change (from 2 x 35 min halves to 4 x 15 min quarters) on elite player physical outputs.

2. Determine the effects of two different SSG periodization strategies on aerobic fitness in elite female hockey players.

1.3 Study hypothesis

1. It is hypothesized that the new FIH rules has affected the physical outputs of hockey players during international matches. Specifically, the new game format

will increase high intensity running actions resulting from the additional rest periods and a decrease in absolute game time.

2. The long to short SSG periodization approach will be successful in improving players physical profile.

1.4 Thesis organization

This Master's thesis is intended to examine the effects of a rule change on game physical outputs and the effects of two different five-week small SSG strategies on fitness in elite female hockey players.

This thesis adheres to pathway two, as classified by the Auckland University of Technology post-graduate thesis structure guidelines (AUT post-graduate handbook 2017). The sections in this thesis include an introduction, literature review, two studies, conclusion, and appendix.

Specifically, Chapter One includes the introduction, which provides context and presents an overview of the thesis.

Chapter Two incorporates a literature review that is split into two main parts with part A, introducing the reader to the concept of monitoring of game demands and Part B focusing on conditioning approaches to improve aerobic fitness in team sport. Part A of the literature review firstly focuses on an examination of the rule changes and changes to physical outputs in team sport and specific to hockey. Then, monitoring of physical outputs are investigated with specific reference to time motion analysis and GPS in team sport and how GPS is used to assess match play, positional differences and variability in match outputs in hockey. Part B of the literature review firstly focuses on general conditioning strategies used in team sport, then secondly investigates specific training strategies used in team sport, specifically looking at SSG's and the variables that affect this type of training. This is followed by comparing SSG's to interval training and the limitations and how SSG's are structured and prescribed within the team sport context.

Finally, directions for future research are discussed in reference to the implementation of using game outputs to prescribe optimal training stimulus, and to further develop our understanding of the different periodization strategies of SSGs training for the development of physiological, technical skill and tactical proficiency.

Chapter Three presents the first study of this thesis; the effects of a rule change on game physical outputs in elite female hockey players.

Chapter Four presents the second study of this thesis; an experimental study examining the effects of SSG's periodization strategies on fitness in elite female hockey players. The two studies presented in this thesis have been prepared specifically for publication in peer-reviewed journals, and thus have been formatted in consideration of word limits. All citations in this work have been presented in American Psychological Association (APA) referencing and are collated in Chapter Six at the end of the thesis.

Finally, Chapter Five incorporates an overall discussion and conclusion, evaluating the findings of both studies 1 and 2, including practical applications of the findings from the research completed, as well as limitations and areas for future research**.**

1.5 Significance of thesis

The performance potential of elite athletes is enhanced through the precise execution of each training session, as each contributes to the overall accumulated physiological response.

Therefore, having the advantage of profiling the physical outputs of athletes in international competition leads to informed decision making, maximising an athlete's adaptive response to each training session, and ultimately preparing the athlete and team for success in international competition.

Given the small margin between success and failure in elite sport, the effective periodization and programming of this training stimuli is crucial in achieving the optimal adaptive outcome, and maximising the gains needed in tactical, technical and physiological proficiencies of each athlete to ensure team success in international competition. However, the optimal periodization strategies to help achieve these gains in team sport and in particular hockey is unclear and yet to be defined. Therefore, this thesis seeks to contribute to the literature profiling game outputs under the current match format and rules of hockey, which informs the design and implementation of optimal periodization strategies. Furthermore, the currently limited body of knowledge regarding the optimal periodization strategies in hockey is added too, with an objective of defining different periodization interventions that impact performance, and informing coaches, and sport scientists how to optimally prepare their team for success in international competition.

Chapter 2: Literature Review

Part A: Monitoring of game demands in male and female hockey: A historical perspective

2.1. Purpose of the review

The purpose of this review is to the look at the historical and current research that involves game demands with a focus on hockey, performed when hockey was played in 2 halves, through to current game demands based on 4 quarters. The review is structured in 4 sections. Firstly, monitoring of game demands in male and female hockey will be discussed, highlighting the history and evolution of what monitoring tools have been used in assess game demands. Secondly, highlighting the reliability and variability of physical outputs and monitoring tools utilised in current research. The third section, will discuss the difference seen in game demands, due to positional differences, in the male and female hockey. Finally, the effect rule changes have had a game demands in team sport in general and in hockey will be discussed.

2.2 Existing literature in elite female and male hockey

In looking at sports research, across all publications, it can be acknowledged that hockey is an under researched sport in comparisons to other team sports and one that as the sport steps into the professional era will hopefully change. This is evidenced by Podgórski and Pawlak (2011) publication on "A Half Century of Scientific Research in Field Hockey" where the purpose of the research was to examine research in hockey from 1960-2010. They examined research articles from all areas covering the fields of biochemistry, physiology, sport injuries, psychology and game tactics. The outcome of this review revealed only 208 studies out of 7459 citations were directly related to hockey exclusively, with a vast majority of scientific studies merely using hockey as a reference point in comparison to other team sports. The number of citations in hockey identified in this review was 7459, which in comparison to other team sports such as soccer (258,943) football (1,025,038), AFL, netball, ice Hockey (229,143), basketball (570,309), rugby, lacrosse (22,700) and cricket (182,759) is very small. This highlights an opportunity for further research in this area to restore balance to the overall scientific pool of research in team sports, as Podgórski and Pawlak (2011) identified most of the research comes from 5 English speaking countries of NZ, Canada, Australia UK & USA, despite the sport being popular in Asian and European and South American countries. They were also able to show there was an increasing trend in published articles in hockey post the 2004 Athens Olympics, with 3929 published post 2004 and only 2801 published from 1960-2003. They also concluded from this review that the varying diversity of topics hinders an effective comparison of findings, especially considering that most of the studies focused on only a few selected aspects of the sport and were chiefly small sample studies, nor were they repeated to access validity and reliability of findings.

The first and perhaps most detailed insight into the modern game at the elite female level was provided by Gabbett (2010) who performed a GPS analysis of elite women hockey players during training and competition. Specifically, game demands of 14 elite female hockey players (who were in the Queensland Academy of Sport hockey squad or in the Australian national squad), across 32 matches of the Australian Hockey League were reviewed using GPS sampling at 5Hz. Data was categorized into movement velocity bands, low-intensity (0–1 ms^2), moderate-intensity (1–3 ms^2 and 3–5 ms^2), and high-intensity (5–7 ms^2). Players covered 6.6 km with a range of 3.4–9.5 km over the course of the match. Midfielders spent more time and covered greater distances in high-intensity running than strikers and defenders. The number of high-velocity and high acceleration efforts over the course of a match was greater in midfielders. In their research Macutkiewicz and Sutherland (2011) showed using GPS to evaluate activity profiles of elite women hockey players during match play of 13 international matches that the mean total distance covered was 5541 (+ 1144 m) in 48 (+ 4 min). This varied according to playing position with defenders having a mean playing time of 56 (+ 11 min), midfielders: 50 (+ 10 min) & forwards: 38 (+ 7 min). In total, 55.5 + 6.3% of match time was spent performing low-intensity exercise either standing: 5.8 + 2.7% or walking: 49.7 + 5.6%. Moderate-intensity exercise accounted for 38.1 + 5.0% either jogging: 25.8 + 3.5%; running: 12.3 + 2.9% of player match-time, with the remainder made up of high-intensity exercise, which is fast running: 4.9 + 1.4% and sprinting 1.5 + 0.6%. Forwards spent more time performing moderate- (41.4%) and high-intensity (7.7%) exercise than defenders and midfield players. This was among the first studies to use a GPS to assess the game demands of elite female hockey players and show that these characteristics differ according to playing position, which the authors attributed to defenders involved in 0–1 substitutions each half compared with 1–2 and 2–3 substitutions each half for midfielders and forwards respectively.

Johnston et al (2004) only reported the findings from single measurements on 15 elite male hockey players in the Scottish National League. One player was filmed per match for 15 weeks consisting of five defenders, five midfielders and five attackers. Using the video footage, activities were subjectively categorized as standing, walking, jogging, striding and sprinting to establish work to rest ratios and profiles of match play. Players spent most of time stationary (4.0%) or engaged in low intensity activity (walking 50.9%, jogging 29.6%) with only a small portion of the match in high intensity activity (cruising 10.1%, sprinting 4.7%). Mean HR was 155 ± 12 b.min-1 and players spent 64% of match time above 75% of HR_{max}. The mean ratio of high intensity (cruising and sprinting) to low intensity (standing, walking, jogging) activity was 1:5.7 ± 0.6 with minimal positional differences. Players performed 30 ± 6 sprints with an average sprint duration of 5.7 seconds (Johnston et al., 2004). This is the first published study to describe the temporal characteristics of hockey and although the calibre of the matches was only moderate, the information provides a useful categorisation of the time spent in different locomotion categories. The finding that the overwhelming proportion of time was spent either stationary, walking or jogging suggests that the game consists of short bursts of high intensity work superimposed onto an aerobic framework. The additional finding that players on average performed 30 sprints of 5.7 seconds per match indicates that the ability to perform and recover rapidly from high intensity activity is a key physical quality for elite hockey players.

Findings from a higher level of competition were reported by Spencer et al (2004) who used video analysis to monitor the activities of the Australian Men's team during an international match. While watching video playback the researchers subjectively identified and placed player motions into categories of standing, walking, jogging, striding and sprinting using the locomotion criteria of Bangsbo et al (1991). The mean match time of each player was 48 minutes with only three players being involved for the entire 70-minute duration. Low intensity activities of standing walking and jogging accounted for approximately 94% of match time (7.4% standing, 46.5% walking, 40.5% jogging). Only 5.6% of match time was spent performing high intensity running which compares favourably with the findings of Boyle et al (1994) and suggests little difference between the proportion of time spent in intensity categories at international level as compared to elite domestic level. Notable position differences were reported with respect to high intensity activity with inside forwards and strikers performing more sprints than fullbacks and halfbacks. The motions of all players were grouped into a team motion category and the flow of this motion was assessed during 5-minute periods throughout the match. It was reported that as a half progressed there were increases in the amount of standing and walking that occurred. For example, compared with the initial 5-minute period in the second half, the subsequent 30 minutes saw a significant increase in percent time spent walking and standing and a significant decrease in percent time jogging. Mean sprint duration was 1.8 seconds with an average of 30 ± 12 sprints per player. Although the number of sprints recorded per player per game is identical to that reported by Johnston et al (2004) the sprint duration is substantially lower (1.8s v 5.7s) which is likely due to different criteria used to log the start time of the sprint. Using typical speed testing data from an elite population, an average sprint of 5.7s suggests a distance of 40-50m per effort. Such a sprint duration is rare during hockey match play (Lythe & Kilding, 2011) with average sprint durations of 1-3 seconds being much more typical of time-motion studies of team sports so the findings of Spencer et al (2004) seem to be more realistic.

Paun et al (2008) monitored six players over four practice matches each during preparations for the Australian Hockey League. Average total distance covered by players during their time on the pitch was 6419 ± 838m. Players spent 89% of match time engaged in low or moderate intensity activity (standing, walking and jogging) with the remaining 11% in high intensity activity. An average of 36 ± 9 sprints was performed per player per match with a mean duration and distance of 2.5 ± 1.7s and 12.4 ± 9.9m. Studies indicate that elite male hockey has a relatively low overall match intensity with 80-90% of game time being spent performing low intensity movements. However, there are approximately 850 motion changes and 30 sprints of two seconds duration performed by each player during a game. Even though recent data from Spencer et al (2004) (1 match x 14 players), Spencer et al (2005) (3 matches x 10 players) and Paun et al (2008) (4 matches x 6 players) has provided useful insight into the physical demands of elite hockey at elite domestic and international level, there is still a need for further comprehensive data that covers all playing positions, over multiple matches at a high level of competition.

In elite men's hockey Lythe and Kilding (2011) showed using a variety of performance analysis methods that the average total distance covered during 70 minutes was 8160 ± 428m of which 479 ± 108m (6.1%) was performed at speeds greater than 19km/hr. Within this high intensity distance were 34 ± 12 sprints per player with an average duration of 3.3s. Average match HR was 85.3 ± 2.9% HR_{max} and average peak HR was 96.3 ± 2.7% HR_{max}. Distance covered decreased by 6.2% between the 1st and 2nd halves and there was a trend of decreasing distance in both halves when total distance was broken into five-minute time periods.

Jennings et al (2012) investigated the influence of multiple games on exercise intensity during a world class hockey tournament using 15 Australian International Male Squad members. With the specific aim to determine if the mean match intensity changed throughout a tournament, specifically high-speed running; and additionally, if playing position influences movement output across the tournament. Using GPS technology, the researchers looked at total distance (TD), low speed activity (LSA; 0.10-4.17 m·s-1) and high speed running distance (HSR; >4.17 m·s-1). Differences in movement demands (TD, LSA, HSR) between positions and matches were assessed using the effect size and percent difference ± 90% confidence intervals. Two levels of comparison were made. Firstly, data from subsequent matches were compared back to match 1 and secondly, data from each match compared to a tournament average (TA). The results showed that in all matches, when compared back to game 1, midfielders performed less HSR distance. However, the amount of HSR did not decrease as the tournament progressed. When compared to the TA, defenders showed more variation in each match. All positions showed lower movement outputs when the team won by a large margin. During these matches the mean total distance covered for strikers, defenders and midfielders were 9819m, 10160m and 9453, low speed running 7405m, 7363m and 7686m, and high speed running 2189m, 2554m and 1734m respectively.

Research investigating whether time on pitch or full game GPS analysis procedures are best for analysis of elite hockey showed that the mean total distance using 16 Scottish international male players over 8 international and euro hockey games was 5189m with a range from 5661-5976m in 48 min (46-51min). The mean metres per min (m/min) was 124m/min with a range of 120-128m/min (White & MacFarlane, 2013).

2.3 Rule changes and changes to physical outputs in team sport

Rule changes in team sport are very common with often the intent to improve player performance and enjoyment, attracting spectators and athletes to the sport, attending to commercial pressure, adapting the sport to children's needs and interests and preventing injuries (Arias et al., 2011). As Arias et al (2011) stated in their review of rule modifications in sport, 'Modifications in a sport should be analysed after a reflective process before they are finally introduced. In this process, the following aspects should be considered:(a) establishing the goals; (b) respecting the basic rules that are not recommended to be modified; (c) knowing the players' and coaches' opinions; (d) knowing how the modification interferes with a wide range of variables; (e) elaborating useful proposals that serve the organizations; (f) using more than one type of data; (g) modifying rules of internal logic and, preferably, functional rules and (h) following some basic stages in the process. The basic stages to follow in the study of rule modification are: (a) structural and functional analysis of the sport, (b) descriptive analysis of game action and other complementary data, (c) identification of the deficiencies of the game and establishment of the goals pursued by the modifications,(d) game modification, (e) descriptive analysis of game action and other complementary data with the modified rules and (f) optimization of the modifications and/or inclusion of other modifications if the goals are not achieved. They also found that 80% of the studies did not report the outcome of the previous modifications they analysed. More than half of the studies (60%) achieved the proposed goals. Nearly two-thirds (63.83%) analysed the effect of rule modification on game actions occurring during the game or through a test. Most of the studies (91.5%) did not consult the participants. The majority of the studies (74.46%) examined the effect of rule modification without any knowledge of a previous analysis or without any previous analysis, and 74.47% studied rule modification related to internal logic. The authors concluded that the reviewed literature seems to reflect awareness that it is necessary to modify rules to achieve certain goals, but few empirical studies report valid arguments on which the process is based. Furthermore, the studies consulted provide conflicting results about the same modifications. Despite underlining that rule modifications should be carried out based on scientific knowledge, there is a lack of studies that analyse the appropriate modifications to change rules. This makes it more difficult for people in charge of sports competitions to propose suitable rule modifications.

2.3.1 Current rules of hockey

Hockey is a global international sport with over 72 international teams on the FIH world ranking list for women and 85 for men. It is played between two teams of eleven players, made up of ten field players, and one goalkeeper per team (Mitchell-Taverner, 2005). The purpose of the game is to score a round ball, that has a circumference between 224 and 235 mm, and a weight between 156 and 163 grams into the oppositions goal measuring 3.66 meters wide by 2.14 meters high goal (FIH, 2014). The game is played, at international level, on 91.4 meters by 55 meter artificial water-based turf (Abbott, 2016).

There are certain characteristics of hockey that make it unique, which need to be taken into account when evaluating hockey research (Hodun, Clarke, De Ste Croix, & Hughes, 2016). These include players body positions due to the use of sticks (Reilly & Borrie, 1992; Wdowski & Gittoes, 2013), rolling substitutions (Tromp & Holmes, 2011), penalty corners (Vinson et al., 2013), and the drag flick (de Subijana et al., 2011; Laird & Sutherland, 2003, Abbott, 2016). Hockey is an invasion style game, like 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). There is a scoring zone at each end of the field. The zone is a "D" shape 28 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. 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 soccer 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 Hockey World Cup and Olympics which currently consist of 12 teams in each gender category for Olympics and 16 teams for the World Cup, both tournaments are on a four-yearly cycle. 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 championships. On top 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 a full international calendar, it is common for countries in the top 10 in the world to be playing 30-50 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.

2.3.2 Rule changes in hockey

The Federation of International Hockey (FIH) has continued to transform the game of hockey to make the game more enjoyable for players, officials, spectators and television audiences, with some rule changes having more impact than others. The FIH Rules Committee regularly reviews all the rules of hockey considering information and observations from a wide variety of sources including national hockey associations, players, coaches, officials, media and spectators together with match and competition reports, video analysis, rules trials and tournament regulations which vary the rules. Ideas which have already been trialled with the FIH Rules Committee’s approval in local or limited circumstances are especially valuable. Rules changes can then be based on practical experience (FIH, 2017).

The rules of hockey apply to all levels of the game and are effective from 1 January of each year at international level. It is important to note that national associations have discretion to decide the date of their implementation at national level. Additionally, national associations may apply to FIH to opt out of particular rules at levels below their top domestic leagues and/or for particular age groups, should they so wish.

A limited number of variations in the playing conditions through regulation will continue to exist in top level international matches played at FIH tournaments. These include the countdown clock for penalty corners and the current use of 4 x 15 minute quarters, which require additional technical table equipment and resources. Similarly, video umpire will only be used at FIH tournaments where the contracted full television coverage and facilities enable a viable system (FIH, 2017).

Some rules brought in by the FIH have had greater effects on the game that others. In 1970 the introduction of artificial turfs changes the pace and style of the game (Spencer et al., 2004). In 1975 FIH implemented a common set of rules for men and women, in 1992 unlimited substitutions were allowed, in 1998 the off sides rule was removed from the game, in 2009 self-pass rule was implemented, and most recently in 2015 the time parameters of the game were changed (FIH, 2014). The physical demands and nature of hockey are now in transition due to the current rule change with international hockey matches, now being played in four 15-minute quarters. In addition to decreasing the game time from 70 minutes to 60 minutes, clock stoppages have been introduced. The game clock is stopped during corners, and a countdown clock, independent from the game clock, of 40 seconds is started. The offensive team has 40 seconds to complete the awarded corner. The game clock is also stopped after a goal is scored. The clock is stopped, and a 40 second countdown clock independent of the game clock is started, this gives the team scoring team time to celebrate. The rule change therefore has a direct effect on the official game time, but with the ability to stop the clock, the actual length of each match may vary. For example, if three corners occurred in the first quarter of a game the official game time is 15 minutes. However, the length of play would be 17 minutes (Abbott, 2016). International players, coaches, and sport scientists have recognized the impact of the game formatting rule change on substitution tactics, and game intensity

2.4 Monitoring of physical outputs in team sports

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

2.4.1 Time Motion Analysis

Time motion analysis is used in team sports to track player movements, and create player action profiles (Gabbett, 2010; Jennings et al., 2012a; Macutkiewicz & Sunderland, 2011; Spencer et al., 2004, Vescovi & Frayne, 2015; White & MacFarlane, 2014; Wyldea et al., 2014) which can in turn be used to inform training and periodization to ensure players are optimally prepared for competition. Time motion analysis can be divided into 2 main categories: 1) video-based time motion analysis, either manually or through computer analysis, and 2) GPS analysis. Both systems are a way of quantifying the physical profiles and external load of athletes in training and in competition which allow coaches, sport scientists and strength and conditioners to see accurate data of what their athletes are being put through in terms of physical loading and locomotion (Edgecomb & Norton, 2006).

Further benefits to this involve the development of more effective training programs for the athletes specific to their sport (Casamichana & Castellano, 2010; Edgecomb & Norton, 2006), the ability to 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).The main differences between the two different systems are how the data is collected and analysed with both systems being able to differentiate and 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).

Early studies involving time motion analysis utilized video cameras, and only captured the data from a single player (Carling, Bloomfield, Nelsen, & Reilly, 2008). This labour-intensive analysis made it very challenging to use in the team environment due to the time taken to analyse athlete and team performance. However, this method was reliable for examining movements of individual players (Duthie, Pyne, & Hooper, 2003). Video based TMA can also be a useful tool to help measure physical outputs of players during field-based sporting events (Bloomfield et al., 2007; Rienzi, Drust, Reilly, Carter, & Martin, 2000) and is beneficial for sport specific analysis of the teams and individuals technical and tactical performance during competition. With the introduction of high level computer analysis systems, this has now reduced the time-intensive nature of video analysis (Gray & Jenkins, 2010, Abbott, 2016). 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). However, the systems are expensive, require costly stadium-based instillation, and require intensive calibrations.

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 more expensive to run and operate than the GPS devices (Di Salvo et al., 2006). However, until recently, some sports such as soccer 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 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 Fédération Internationale de Football Association (FIFA) have allowed the use of GPS monitoring systems to be used at the referee's discretion.

With the ever-evolving rules in field sports, performance analysis, the player action profiles provided by GPS can be a helpful tool in assessing the effects of different rules. Recently sporting GPS technology and combined GPS and accelerometer systems have become popular in training and match quantification. The relatively inexpensive, and portable GPS technology has allowed performance tracking to be used by a greater number of field sports**.** Thus, GPS has been applied extensively in team sports such as soccer, cricket, hockey, rugby union and league**.** There is extensive information on the activity profile of athletes from field sports in the literature stemming from GPS, it specifically allows for the movement patterns such as total distance covered by players and distance in velocity bands and time on the pitch to be assess and analyzed. Global positioning systems have also been applied to detect fatigue in matches, identify periods of most intense play, different activity profiles by position, competition level, and sport (Aughey, 2011).

2.4.2 GPS history

GPS is a satellite navigation network that provides location and time information of tracking devices. The first suggestion that GPS could be used to assess the physical activity of humans followed some 40 years later and was initially developed for military purposes, this system now has much wider application, including its use in athlete tracking and load quantification (Larsson 2003). GPS has been refined over time to reduce errors and available for everyday use in the technology field and since then we have seen a rapid uptake of GPS technology are now commonly used in individual and team-sports at all levels (Aughey, 2011, Malone et al., 2017).

Current GPS technology uses satellites to construct the geographical location and movements of a receiver, which allows for the tracking of individual players. A few satellites, with a minimum of four are required to determine the position of the GPS receiver trigonometrically. With the advances in technology GPS units are typically lighter, smaller and more affordable for the general public and sporting teams, and constructed to withstand heat, moisture, and sporting collisions. Current GPS units are compact and easily worn in specially designed harnesses, or slots sown in the jersey between the shoulder blades and upper part of the back. GPS units and their associated computer analysis software has provided the sport scientist and strength and conditioning coaches the ability to collect and analyse data relevant to the performance of athletes in training and competition. With the demand for GPS technology and the continued growth in professional sports world wide for male and female, the technology has now been fitted with triaxle accelerometers, gyroscopes and magnetometers which are collectively termed micro electrical mechanical systems (MEMS) (Abbott, 2016). Thus, GPS and MEMS technology provides practitioners with a wide array of data that can be used to assess athlete physical loading and activity profile (Coutts & Duffield, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010b, Rampinini et al., 2007, Malone et al., 2017).

In team sport the use of GPS technology has helped to overcome a lot of the limitations of video-based TMA and allows coaches and sports scientists to evaluate and compare player's movements in real time or retrospectively post team trainings or competitive games. With the continued development, affordability and portability of the GPS it allows for ever increasing accurate data to be collected in many outdoor settings. Indeed, recent GPS research has focused on validity and reliability and integrating GPS data with the physical capacity or fitness test score of athletes, game-specific tasks, or tactical or strategic information (Malone et al., 2017). To collect data indoors using GPS technology, this is currently limited to using the MEMS data as GPS devices rely on a series of satellites in order to determine where it is physically located. The signals from the satellites are attenuated and scattered by roofs, walls and other objects.

2.4.3 GPS metrics validity & reliability: team sports

With the number of peer-reviewed GPS research publications increasing exponentially since the first paper using GPS technology in sport was produced in 2001, addressing the use of GPS and MEMS for load monitoring, injury risk and neuromuscular fatigue, there is a need to understand how this data is derived to ensure its validity and reliability and how it should be reported (Malone et al., 2017).

The first attempts to validate GPS for field sport applications were made in 2006. While GPS has been validated for applications for several team sports, some doubts continue to exist on the appropriateness of GPS for measuring short high-velocity movements (Aughey 2011, Rampinini et al., 2014). With the advancements in technology continually improving, through developments in microprocessors, data processing, and software, there is a need for researchers to conduct independent validity and reliability studies as each device or update is released from the commercial suppliers. In acknowledging this need, due to the time taken to release such studies, GPS devices are often used in sport before essential independent information on measurement precision is available.

As Scott et al (2016), has shown in his review collating all studies that have tested either the validity or reliability or both of GPS devices in a team sport setting, with a focus on measurements of distance, speed, velocities, and accelerations across all sampling rates and accelerometers, player/body load and impacts in accelerometer-integrated GPS devices. It appears that both the measurement precision, validity and reliability of GPS devices has improved. The literature reviewed suggesting that all GPS units, regardless of sampling rate, are capable of tracking athlete's distance during team sport movements with adequate intra unit reliability. One hertz and 5Hz GPS units have limitations in their reporting of distance during high-intensity running, velocity measures, and short linear running particularly those involving changes of direction, although these limitations seem to be overcome during measures recorded during team sport movements. Ten Hertz GPS devices seem the most valid and reliable to date across linear and team sport simulated running, overcoming many limitations of earlier models, whereas the increase to 15Hz GPS devices have had no additional benefit (Johnson et al., 2014). In saying this there is a need to conduct further testing using true higher sampling GPS devices for further clarification of validity and reliability. As Malone et al (2017) recently stated "It must be noted that sampling rate alone will not improve the quality of GPS data, as factors such as the chipset processor used and position of the device on the body can also influence the output".

Currently, there are several manufacturers of GPS devices offering a variety of sampling rates, chip sets, filtering methods, and data-processing algorithms. Given differences in data processing, it is essential for the users and researchers of these products that the measurement of validity and reliability for each is determined and that users are aware of the many factors that influence the data obtained and collected from GPS devices and how the data is reported. An example of this is GPS velocity and distance being calculated from Doppler-shift or positional differentiation methods (Malone et al., 2017). Another example is the accuracy of positional information to determine the distance between multiple units is different to the accuracy of a unit to measure distance alone. Accordingly, measures of velocity and distance require validation independently and in combination with an example being distance covered at certain velocities.

In establishing the validity of GPS units for team sports, the following components must be considered, these include accurate gold-standard comparison measures for total distance, velocity of movement, limitations within the GPS units, such as establishing exact starting times of movements (Aughey, 2011a). As Aguiar et al (2015), and Gonçalves et al (2014) showed studies have used latitude and longitude measures to determine the distance between devices and subsequently athletes, hence the measure of position also requires specific validation. The challenge that researchers face is using validation studies that have used the same GPS brand/model specific to that used in their own research as well as reporting on same metrics (ie, range of speeds, distance etc.) examined in practice.

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). Also, the 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) with little difference seen between 10 and 15Hz Units (Johnston et al., 2014) but further research is needed in this area.

As Akenhead et al (2014) stated regarding validity of GPS, no global position statement on accuracy and validity of the GPS used in team sports can be given due to such constraints as different manufacturers, sampling frequencies, exercise tasks and statistical analysis variants. In assessing the validity of velocity, it is important to acknowledge the way in which this has been assessed and researched and the limitations of these methods. Some studies have used simple field-based research designs using human subjects with the velocity assessed against a known distance, whereas others have used timing gates to assess velocity (Coutts et al., 2010, Waldron et al., 2011) with the limitation of this is that velocity is determined by a limited number of sampling points.

In the context of team sport where assessing movements that involve constant changes in velocity acceleration and decelerations, then using a Laveg laser or radar gun may provide a more sensitive measure of velocity. However, many of these studies have investigated reliability and validity using linear running movements without any changes in direction. (Castellano et al., 2011, Varley et al., 2012, Nagahara et al., 2017), which is a limitation that needs to be acknowledged. As these studies provided a thorough assessment of velocity, acceleration, and deceleration compared with high-sampling criterion measures, the limitations were that they did not assess using sport-specific movements involving changes in direction. In acknowledging this limitation other researchers have employed sport-specific movement circuits, to assess velocity (Coutts et al., 2010, Jennings et al., 2010, Johnston et al., 2014, Petersen et al., 2009, Vickery et al., 2014), however most of these studies are limited in the criterion measures used to evaluate velocity (eg, timing gates, Stanley et al., 2013, and Gray et al., 2010) and the synchronization protocols are not well documented.

Inter-unit reliability and using different GPS models is another consideration for the user to consider when using GPS in the team sport setting as high error rates have been reported (Coutts & Duffied, 2010, Castellano et al., 2011, and Waldron, 2011). The practical limitation of this is using data collected from athletes wearing the same or different GPS units over a season or longitudinal period, which will make meaningful interpretation of the data difficult. Therefore, where possible sport scientists within team sports need to assign a specific GPS to each athlete that is consistent for within-athlete longitudinal monitoring. It is worth noting that the extent of the interference between 2 or more devices during testing has yet to be fully explored.

In summary high error rates have been reported for interunit reliability across various GPS models which makes meaningful interpretation of the data difficult. While interunit reliability information is available for distance it is difficult to determine for velocity. Future research could determine interunit reliability through the use mechanical devices that allow exact velocity and distance to be replicated (Malone et al., 2017).

Validation is typically required with every new GPS device release or upgrade and following any changes to data processing which may occur after firmware or software updates. Therefore, generalizations on the accuracy and validity of any technology or method should not be made, and conclusions of research studies should be always specific to the hardware and software versions employed and the sporting context (Cardinale and Varley, 2017).

2.5 Application of GPS technology to assess match play in hockey and GPS profiling of players

As previously mentioned hockey is not an extensively researched sport from a physical output using GPS or physical conditioning perspective and has limited research in the elite female populations. Of the limited studies that have studied the physiological demands of hockey, it has shown that elite male hockey players cover 4.5-9.5km per game (Jennings et al., 2012a, Lythe & Kilding, 2011, Spencer et al., 2004, White & MacFarlane, 2014), with an average playing time of 51min per player. With players typically averaging 130m/min confirming that the game is a fast-paced, aerobically demanding team sport (Lythe & Kilding, 2011). However, it must be acknowledged that this research was all completed prior to the hockey changing from halves to quarters in 2015.

From, the available velocity band data and research it suggests that there are considerable amounts of high and moderate speed running in elite men's hockey regardless of the zones bands used for analysis (Jennings et al., 2012a, Jennings, Cormack, Coutts, & Aughey, 2012b, Lythe and Kilding, 2011, Macutkiewicz & Sunderland, 2011, White and McFarlane, 2014). 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).

In the Australian Hockey League (AHL) players covered 6.6km ranging from 3.4-9.2 km over the course of a match. Midfielders spent more time and covered greater distances in high-intensity running than strikers and defenders. The number of high-velocity and high acceleration efforts over the course of a match was greater in midfielders. with players spending 97.3% of total match play in low- to moderate intensity activities. However, low-intensity periods were interspersed with frequent bouts of high-acceleration and high-velocity movement activities. Players can 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).

Abbott (2016) showed using the team action profiles of the US Women's national hockey team that players covered a 16.8% of the total distance in zone 5 (fast run 4.19-5.27 m/s) and zone 6 (sprint >5.27 m/s). This is higher than previously reported 6.1%, for men's by Lythe and Kilding (2011) and 6.4% for women's by Macutkiewicz and Sunderland (2011) under the same velocity zone definitions. The available data verifies that hockey is a fast-paced team game covering moderate to high amounts of total distance. 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).

2.5.1 Positional Differences

Several studies (Dwyer 2012, Gabbett 2010, Jennings et al., 2012, Johnston, 2012) have reported that defenders cover less distance at higher intensity than forwards and midfielders, which show that because of the central holding roles in defence that it can have a direct effect on their physical outputs. However, this may be dependent on tactics and substitutions employed, and level of opposition played. Gabbett (2010) has taken these observations a step further by recommending position-specific conditioning be implemented in team trainings based on some of the reported differences between positions. However, as Abbott (2016) stated, 'the percent difference in high intensity velocity zones and variation in significance between zones should be considered to justify the need for position specific conditioning'**.** Further research needs to be done in this area before additional position-specific high intensity training is prescribed by the various player positions of defender's, forwards, midfielders and screens**.** Abbott (2016) was able to show in her research with the US women's national team that the average and maximum effort distance covered by the team in the higher velocity zones showed an average effort is between 13 and 16 meters, and max effort ranging from 40 and 50 meters. This supports Spencer et al (2004) finding in their research that short-duration, high-intensity efforts replicating match requirements should be used during training**.** In the research conducted by Abbott (2016) on the US national team 'the positional differences showed defenders covered less relative percent distance in zones 5 and 6 when compared to forwards and midfielders and went on the further state that the percent difference covered in velocity zones 5 and 6 is not great enough to justify positional specific conditioning,' which is in contrast to the research of Gabbett (2010). However, with rule changes, specific demands of the games played and level of opposition this may influence the results seen in both research papers.

In elite male hockey from GPS studies to date, positional differences among the physical output metrics have been reported. Specifically, Jennings et al (2012b) reported that when the game was played in halves 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 is normalised to a full game**.** When the data is 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) This was attributed 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). As the researchers mentioned this reflects 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**.** When looking at mean work rate, defenders covered 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).

The data from Jennings et al (2012b) showed the large variation in positional differences from one major international tournament this highlights the need to 1) monitor players according to position and positional averages rather than team averages and 2) consider providing different conditioning stimulus to athletes across positional layers. In saying this it's important to put the data in the context of the situation as every team employs different tactics according to opposition faced, uses rotations of players differently, and tournament to tournament loading will also vary depending on team schedule which impacts recovery and ability to physically output, as well as environmental considerations such as heat and humidity**.** To use the data to inform training, it would be also important to work out the positional requirements of the team and each individual athlete that you are working with for total distance, minutes played, meters per minute and high speed running metres to ensure accurate feedback and optimal periodization and loading leading into pinnacle events.

2.5.2 Variability in GPS match outputs

While it’s important to understand positional differences with your team it is also important to understand what may cause the variability in match outputs (Kempton et al., 2015). Some of the possible causes of the variability in physical match outputs in team sports including, heat, travel, result, score line, rank of the opposition, team 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 et al., 2010; Mohr et al., 2012; Spencer et al., 2005). Therefore, considering the influence a number of these factors may have on match physical outputs this may help to explain why literature on team sports variability shows moderate to high levels of variability within physical outputs metrics (Kempton et al., 2015, McLaren et al., 2015).

To effectively use training to prepare players for pinnacle events its key that coaches, sport scientists and strength and conditioners understand what key physical, technical, and tactical trends has on performance as this may help guide programming and periodization (Aughey, 2011a, Neville, Rowlands, Wixted, & James, 2012) as well as recovery protocols and injury prevention / tracking (Cummins et al., 2013; Dupont et al., 2010) and how to best prepare athletes according to the ranking of the opposition (Hewitt et al., 2014).

Due to the fact that situational variables can have an affect both on the match physical outputs and the variability of these outputs (Bradley & Noakes, 2013) it’s an important consideration for coaches on how they use their players throughout the season and within the early stages of tournaments to ensure players are at their best during the final series or in the playoff matches.

As seen 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 is a consideration for organizers in how they schedule & structure the transition from regular season/pool matches to finals or playoff matches, to ensure players can push themselves closer to maximal capacity each game, due to more recovery time between games which may enhance the level of play, and the end product that the spectator experiences.

There is conflicting evidence in hockey on the effect that recovery time has on multiple games played over a short period of time. 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). More research needs to be done in this area to help optimally prepare athletes for tournament demands in hockey.

2.6 Summary

The goal of this review chapter was to provide a theoretical basis for the experimental chapters of this thesis. It provided an overview of the existing game demands in hockey literature considering evolving rule changes over the years. The GPS literature conducted on hockey was explored with reference to player position, age and standard/level of play, both in games and practice. The validity and reliability of GPS systems when assessing movement demands of team sports are influenced by several factors: GPS sampling frequency, speed, distance, and path of movements, which must be taken into consideration when examining previous research and planning future research. The various GPS outputs from modern day systems such as total distance, distance per minute, distance and time in velocity zones, time on pitch, change of direction, acceleration, and deceleration provide valuable information to the conditioning coach.

Part B: Conditioning approaches to improve aerobic fitness in team sport

2.7 Purpose of the review

The purpose of this review is to the look at the historical and current research that involves conditioning approaches to improve aerobic fitness with a focus on team sport and hockey. The review is structured in 3 sections. Firstly, conditioning strategies used in team sport will be discussed, highlighting the general and specific conditioning strategies that have been used to improve conditioning in team sport athletes with a specific focus on aerobic conditioning. Secondly, highlighting SSG training with a focus on how its prescribed and structured within a team sport context in the current research. The third section focusing on future progressions and final conclusions.

2.8 Conditioning strategies used in team sport

2.8.1 General training strategies used in team sport

Team sports require a high level of aerobic fitness, which enable athletes to display a high level of athletic ability. This includes the ability to maintain work rates, generate and maintain power (McMahon & Wenger, 1998) during repeated high intensity sprints (Bishop et al., 2004) and recover optimally between bouts of high intensity running (Stone & Kilding, 2009). Research to date would suggest that to elicit these adaptions, the most effective methods to improve aerobic fitness in team sport athletes are traditional aerobic conditioning, classic aerobic conditioning, sport specific conditioning, and a combination of traditional and sport specific (Stone & Kilding, 2009).

Traditional aerobic conditioning, uses running based drills which are continuous or intermittent, done in a straight line, which involve minimal COD and no skill component.

This popular form of aerobic conditioning is based on the principle that improvements in VO_{2peak} occur when a high percentage of VO_{2peak} is elicited during exercise (Wenger & Bell, 1986) and that it can deliver a training stimulus that is greater than what can tolerated in a single bout of continuous exercise. The benefits of this approach is that it's simple and effective, with research showing improvements in aerobic fitness over a 4-10 week period, and importantly an increase in total distance covered and sprints performed during a match (Helgerud et al., 2001, Dupont et al., 2004).

The prescription of traditional interval training in team sport is based on manipulating three key variables: work interval intensity and duration, recovery interval intensity and duration, and total work. These variables generate a large range of interval training prescriptions designed primarily to stress the aerobic and/or anaerobic pathways. One method using these principles is using high intensity intermittent methods based upon athlete's individual Maximum Aerobic Speed (MAS) score to form the fundamental basis of training to improve aerobic fitness qualities, especially in the preparation period.

The research shows that the amount of time spent at or above the 100% MAS appears to be the critical factor for improving aerobic power (Berthoin et al., 1995, Buchheit, 2008, Tabata et al., 1996, Wong et al., 2010). Research has shown that performing a number of short intervals at greater than 100% MAS was a more effective method of building aerobic power than the more traditional long slow distance (LSD) training (Tabata et al., 1996) or attempting to train only one interval continuously at 100% MAS. Specifically, an intensity of 120% MAS was determined to be the best single speed for short intervals that are followed by a short passive rest interval, based upon the fact that this intensity allowed the greatest supra-maximal training effect, in comparison to 90, 100, and 140% MAS (Dupont et al., 2002). One of the most effective methods involved intervals of 120% MAS for 15-30 seconds followed by an equal interval of passive rest, continuing for 5-10 minutes. Tabata et al., (1996) also found that at 170% VO_2max for 20 seconds followed by 10 seconds passive rest, for 4-minutes produced excellent changes in aerobic and anaerobic power, producing more effective results that LSD training sessions of 60-minutes at 70% MAS. However, the high-intensity group improved VO_2max by 14% compared to 10% in the low intensity group across the six weeks. The high intensity group also showed an improvement of 28% in anaerobic performance while the low intensity group was unchanged. Given the greater results in a shorter time, it was considered that the high intensity training was much more effective with this type of training now known as the Tabata method (Baker, 2015). However, it must be acknowledged that the limitation of the study were the subjects used for this research were not team sport athletes and the protocol was not running but cycling based.

With most of the recent research showing high intensity intervals of 15-30 sec or greater, interspersed with 10-30 seconds of either low intensity active recovery at 40-70% MAS or passive rest, for 4-10 minutes and repeated for 2 or more sets, greatly enhances aerobic power and capacity. Research has shown that training at or above 100% MAS is the key intensity factor and how long you spent there was the driving volume parameter under-pinning improvements in aerobic power.

High-intensity MAS interval training using intensities of 100% MAS to develop the ability to sustain high intensity efforts or intervals at 120% MAS or greater, to develop higher levels of MAS or to enhance the ability to repeat high intensity efforts increasingly used in the training of field sport athletes (Baker, 2011, Castagna et al., 2010, Billat and Koralsztein 1996, Buchheit 2008, Tabata et al.,1996, Wong et al., 2010).

More recently, Gallo et al (2014) reported that for every 5 seconds that AFL players were behind their team-mates in a 2 km time trial measure of MAS, they reported field tactical training sessions one full RPE point higher. So while other tests such as yoyo intermittent recovery test 2 (Krustrup et al., 2006) may have been shown to be predictors of AFL (McClellan & Lovell 2013) and soccer (Castagna et al., 2009) playing performance which may be due it assessing the anaerobic and the aerobic system, the simple measure of MAS may be associated with an athlete’s ability to tolerate the training loads associated with professional field sports. Therefore, the measure of MAS should not be seen only as a direct correlate of field sport performance, but also a determinant of the ability to perform the large and physically demanding training loads that are required for success in professional field sports (Baker, 2015).

Baker (2015) was also able to show that to compete at the elite level in most team sports, a well-developed aerobic energy system and subsequently, high MAS is required. Clear differences were seen across many team sports, between those participating in the highest levels and leagues and the sub-elite levels irrespective of gender. An example of this specific to hockey, illustrates that for female hockey in Australia, 4.23 m/s appears to be the level of developmental or sub-elite players, whereas a MAS of >4.4 m/s has been recorded for the elite national team, which included Olympic gold medallists. The same trends were found in the Norwegian male and female soccer data (Haugen et al., 2014).

While the use of MAS training is not the only approach to improve aerobic and anaerobic fitness qualities, a second method is that is popular within a team sport context is High Intensity Interval Training (HIIT). This method is an effective means of improving cardiorespiratory and metabolic function and therefore the physical performance of athletes (Billat, 2001, Laursen and Jenkins, 2002). HIIT involves the use of repeated short-to-long bouts of high-intensity exercise interspersed with recovery periods. For team and racquet sport players, the inclusion of sprints and all-out efforts into HIIT programmes has also been shown to be an effective practice for developing metabolic (O_2 and anaerobic) and neuromuscular systems (Bishop et al., 2011, Iaia and Bangsbo, 2010). These particularly intense forms of HIIT include repeated-sprint training (RST); sprints lasting from 3 to 7 s, interspersed with recovery periods (lasting generally less than 60 s) or sprint interval training (SIT; 30 s all-out efforts interspersed with 2–4 min passive recovery periods).

It is believed that an optimal stimulus to elicit both maximal cardiovascular and peripheral adaptations is one where athletes spend at least several minutes per session in their 'red zone,' which means reaching at least 90% of their maximal oxygen uptake (VO_2max) (Buchheit & Laursen, 2013). This is of interest to sport scientists working within team sport as it helps to characterize training protocols that allow athletes to maintain long periods of time above 90 % of VO_2max (T@ _VO2max).

Additionally, for team sport athletes training a variety of metabolic and neuromuscular systems simultaneously, the physiological strain associated with a given HIIT session needs to be considered in relation to the demands of other physical and technical/tactical sessions to maximize a given training stimulus and minimize injury risk (Buchheit & Laursen, 2013). However, the ability of the coach and sport scientist to understand the physiological responses to various HIIT formats may assist with selection of the most appropriate HIIT session to apply within the training week to get the optimal training response.

Classic team sport conditioning, uses an approach integrating strength, power, speed and aerobic conditioning components to prepare athletes for the demands of the sport (Hoffman et al.,1996). Research has shown that aerobic capacity can be maintained and increased from classic team sport training and competition (Gabbett, 2004, Gabbett, 2005). Further research has shown the aerobic capacity of team sport players typically increases in the preseason then decreases during the competitive season when using the classic team sport approach (Krustrup et al., 2003, Tavino et al., 1995). Increases in predicted VO_{2peak} during a rugby league season, when using a progressively overloaded training programme involving specific skill, speed, muscular power, agility and endurance training exercises, twice per week has also been found (Gabbett, 2004). Furthermore, Gabbett was able to show in junior and senior rugby league players an increase in aerobic fitness by between 5.1% and 8.6% over a 14-week pre-season training period. Despite having lower training loads, junior rugby league players exhibited greater adaptations in predicted relative VO_{2peak} than senior rugby league players (8.6% vs 5.1%, respectively). Bogdanis et al (2007) found similar results using a classic conditioning approach in the off season in adolescent basketball players which found improvements in VO_{2peak} (4.9%), and individual technical skill performance (15-25%).

Therefore, further research is needed to determine the importance of aerobic conditioning during the in-season and how this best fit within a coaching framework that requires a balance of technical, tactical and physical during this period. This also highlights how aerobic conditioning may be underrated in some sports due to the thought that technical and skill-based components are more important during the competitive season and where anaerobic conditioning is prioritised due to high intensity activities associated to game winning actions (Stone & Kilding, 2009). However, a lack of focus on aerobic conditioning will influence the ability to repeatedly perform, and recover from, high-intensity actions, so the absence of aerobic conditioning during the competitive season, regardless of the sport, may not be best practice to optimize the consistent performances and conditioning of athletes during the season. Future studies need to show coaches of various team sports how the different components of the game can be worked on simultaneously, such as aerobic endurance and technical and tactical execution.

While traditional and classic team sport conditioning can improve the aerobic fitness of team sport athletes, the greater use of sport specific aerobic conditioning also referred to as skill-based conditioning games (Gabbett, 2006) or game-based training (Gabbett, 2009) is increasingly being implemented by professional team sport across a variety of codes. This mostly involves use of small sided conditioning games (SSG), dribbling track/circuits, and skill-based drills, which incorporate movements and skills specific to the sport built into a physical frame work (Meir et al., 2001, Hill-Hass et al., 2011).

The potential benefits of performing sport-specific conditioning is that training will transfer better into the athletes' competitive environment given that the training stimulus simulates the specific movement patterns and physiological demands of the sport. Furthermore, skill-based conditioning games provide an opportunity to develop decision-making and problem-solving skills, under stressful physical loads, (Gabbett, 2001). It is possible that team sport players may respond better psychologically, in terms of motivation, to sport-specific physical conditioning approaches, rather than nonspecific traditional, continuous or interval-based conditioning (Stone & Kilding, 2009). In considering these factors, there is a growing body of research investigating the efficacy of various sport-specific methods to develop aerobic endurance across a variety of team sport codes (Gabbett, 2006, Hoff, 2002), with majority of research done in the sport of soccer.

2.8.2 Small sided games in team sport

High-intensity, intermittent team sports require athletes to have well developed physiological capacities such as speed, muscular strength and power, agility, and maximal aerobic power (Reilly and Gilbourne, 2003). While these physical qualities are important for team sports athletes, they also require well-developed technical skill and decision-making ability and demonstrating these qualities under high levels of pressure and fatigue (Gabbett et al., 2009).

Studies of team-sport athletes have shown higher skilled players to have superior athletic qualities of speed, muscular power, and maximal aerobic power than their lower skilled team mates (Gabbett et al., 2009, Gabbett and Georgieff, 2007). Within the team-sport environment, significant expert-novice differences have been demonstrated in pattern recognition (Williams et al., 2006), decision-making (Jackson et al., 2006), dual task performance (Smith et al., 1992), and anticipation (Gabbett et al., 2007). Given the importance of developing these athletic and skill qualities to enhance team-sport performance, coaches, sport scientists and strength and conditioners are constantly looking to find the right balance in training to elicit the most effective methods of developing these attributes in their athletes (Gabbett, 2009).

To find this balance, SSGs are increasingly being used to improve the skill and physical fitness of team-sport athletes (Gamble, 2004, Sassi, 2004, Gabbett, 2009). These are in the format of modified games played on reduced pitch areas, often using adapted rules and involving a smaller number of players than traditional games. To highlight how SSG's have potential to improve the physical fitness of team sport athletes across various team sports such as soccer, rugby league and rugby, several studies have compared the physiological demands of SSG based training to the demands in competition reporting similar HR responses (152 beats.min^{-1} vs. 155 beats.min^{-1}) and blood lactate concentrations (5.2 mmol.L^{-1} vs. 5.2 mmol.L^{-1}) between competition and training (Gabbett 2009).

SSG training may also offer an acceptable substitute for aerobic interval training to maintain fitness during the competitive season (Reilly and White, 2004). When SSG was compared to the effectiveness of 6 weeks of aerobic interval training and SSG training on improvements in muscular power, agility, skill, anaerobic capacity, and maximal aerobic power in professional academy soccer players Reilly and White (2004) found there were no significant differences between groups for any of the performance tests following training (Reilly and White, 2004). Sassi et al (2004) was also able to show the effectiveness of using SSG training when they compared the heart rate (HR) and blood lactate responses to SSG training and interval running without the ball in elite soccer players, and reported SSG training offered a physiological training stimulus that was similar (and, in some cases, exceeded) interval running without the ball.

Furthermore, other researchers have also found positive training effects on physical fitness as shown by Rampinini et al (2007) when examining the effects of player numbers, field dimensions and coach encouragement on the exercise intensity of SSG's, designed specifically for aerobic conditioning and showed the performance measures following the training period of increased, with the group mean for the yo-yo IRT improving by 7.4% and for the yo-yo endurance test, by 44.3%. Gamble (2004) also reported significant improvements in aerobic fitness following a 9-week pre-season training period that consisted entirely of SSG based training in elite rugby union players.

Although the studies above highlight how SSG's have the potential to improve physical fitness in team sport athletes, it must be noted that replicating game intensity in SSG training may not be enough to induce reasonable improvements in aerobic function (Wenger & Bell, 1986). This is highlighted by Wenger and Bell (1986) research showing frequencies as low as 2 per week can result in improvements in less fit subjects but when aerobic power exceeds 50 ml/kg/min, exercise frequency of at least 3 times per week is required. As the levels of initial fitness improve, the change in aerobic power decreases regardless of the intensity, frequency or duration of exercise. Furthermore, although the acute physiological load of an SSG session can be manipulated by changing the technical rules (Dellal et al., 2011), the number of players and pitch size (Rampinini et al., 2007), the overall load cannot be precisely standardized. Within-player responses to SSG are highly variable (poor reproducibility for blood lactate (coefficient of variation (CV): 15–30 %) and high-intensity running responses (CV: 30–50 %) (Hill-Haas et al., 2007, Hill Hass et al., 2008), and the between-player variability in the (cardiovascular) responses is higher than more specific run-based HIIT (Hill-Hass, 2011). During an SSG in handball, average VO_2 was shown to be inversely related to VO_{2max} (Buchheit et al., 2009) suggesting a possible ceiling effect for VO_{2max} development in fitter players (Buchheit and Laursen, 2013).

2.8.3 Variables affecting small sided games intensity

Direct supervision and coaching of exercise sessions have been shown to improve adherence to an exercise programme, increase training intensity and increase performance measures in a variety of training modes (Coutts et al., 2004, Mazzetti et al., 2000). In soccer, active, consistent coach encouragement has also been suggested to have an influence on training intensity (Rampinini et al., 2007, Sampaio et al., 2007) and therefore influencing development of aerobic fitness. Specifically, Rampinini et al, (2009) examined the effects of player numbers, field dimensions and coach encouragement on the exercise intensity of SSG's, designed specifically for aerobic conditioning. They found that the factor that had the greatest impact on the physiological response to SSG was encouragement, followed by player numbers and field dimensions. In an earlier study they also found increasing the pitch area by 20% across a variety of SSG formats (3 vs 3 to 6 vs 6) increased the physiological response of athletes. Both the percentage of maximum HR (%HR_{max}) and blood lactate concentration were higher during SSGs played on a large pitch than on a medium-sized or small pitch. RPE was also higher on medium and large pitch sizes compared with small pitches (Rampinini et al., 2007).

When manipulating player numbers despite some methodological concerns such as very short game duration and differing work to rest ratios, most studies have shown that SSGs containing smaller numbers of players elicit greater HR, blood lactate and perceptual responses (Williams & Owen, 2007, Sampaio et al., 2007). Research conducted in soccer has shown that a concurrent increase in player number and relative pitch area per player in SSGs elicits lower exercise intensity. The observed reduction in SSG intensity may have been due to either the independent effects of increasing the number of players or the inability of the additional players to cover more of the available pitch area (Hill-Haas, 2011).

Hill Hass, (2009) examined the acute physiological and perceptual responses and time-motion characteristics involving youth soccer players during three variations of SSGs (2 vs 2, 4 vs 4 and 6 vs 6) with a constant ratio of player number to pitch area applied to each SSG variation. The main findings were, as the number of players in the SSG teams decreased, when the relative pitch area per player remained constant, the overall physiological and perceptual responses increased, and the largest game format (6 vs 6) was associated with a greater range of distances travelled at speeds greater than 18 km/h. In contrast, the 4 vs 4 format, compared with the 2 vs 2, was characterized by significantly longer (average and maximal) effort durations and distances for speeds greater than 18km/h (Hill-Hass, 2009).

This is an important consideration for SSG prescription, as to improve aerobic fitness in team sport, athletes need to maximise the amount of time above 100% MAS, with most elite male teams having a maximum aerobic speed of 15 -18km/hr and elite female athletes 14.5-16.5km/hr, the more the design of the SSG allows players to spend above these speeds the greater the opportunity to develop aerobic fitness qualities (Baker, 2015).

2.8.3.2 Continuous or interval based stimulus

Research looking at whether interval and continuous methods are the most effective method of developing in season aerobic fitness qualities using SSG's has shown that both training regimens could be used during a season for match-specific aerobic conditioning with neither appearing to offer significant advantage over the other, but were unlikely to provide a sufficient stimulus overload for fully developing maximal oxygen consumption (Hill-Haas et al., 2008, Fanchini et al., 2010).

2.8.3.3 Work to rest ratio

Changing the duration and work to rest ratios in SSG's is another popular method to alter exercise intensity, with most studies using an interval training method. Although most studies examining SSGs have prescribed the SSG bouts using intervals with short rests (Balsom et al., 1999., Aroso et al., 2004) some recent studies have used continuous SSG formats of differing duration (e.g. 10-30 minutes) (Hill-Haas et al., 2008, Dellal et al., 2008). Unfortunately, previous studies have not used consistent work to rest ratios and there is a large variation in the length, duration, and number of work bouts and rest intervals amongst studies, which makes comparison difficult (Hill-Haas, 2011).

2.8.2.4 Rule modifications and the use of goalkeepers

In training coaches quite often modify playing rules in SSGs to achieve greater exercise intensity or develop specific technical and tactical skills. Of the few studies that have investigated these effects on intensity most were done in soccer and found an increase in $\%HR_{max}$ (Sassi et al., 2004) and blood lactate concentration (Aroso et al., 2004) due to rule changes. Another modification is the use of goalkeepers and at present, the influence of goalkeepers on exercise intensity in SSGs is not clear. Of the two studies found in soccer, Mallo and Navarro (2008) reported a significant decrease in $\%HR_{max}$ total distance and time spent in high intensity running, in 3 vs 3 SSGs with goalkeepers. In contrast Dellal et al (2008) reported a 12% increase in HR response in 8 vs 8 SSGs with goalkeepers. This shows further research is needed in team sport codes with goalkeepers to determine the influence on physiological and technical/tactical demands in SSGs.

2.8.4 Comparing small sided games with interval running

While it is important to quantify the acute responses to a given training stimulus, the training response following a sustained period of exposure will most likely reveal the efficacy of a new training approach. In this regard, studies have compared SSG-based training and interval running on physical fitness and playing performance in team-sport athletes to ascertain if SSG are at least equitable to traditional/classic methods in terms of fitness development. [Gabbett, 2006, Impellizzeri et al., 2006).

Reilly and White (2004) examined the use of SSGs as a conditioning stimulus and comparing it directly with traditional forms of fitness training. Using a parallel matched group design they recruited 18 professional youth soccer from an English Premier League football club, and players were allocated to a SSGs group or an aerobic interval training group. Players completed the training twice per week, as part of their normal training, over a 6-week period during the competitive season. The SSGs involved 5 vs 5 games, played in intervals of 6 x 4 minutes, interspersed with 3-minute active recovery at 50-60% HR_{max}. The interval running duration was matched with the SSGs, with a target intensity of 85-90% HR_{max} (active recovery of 3 minutes at 50-60% HR_{max}). All physiological performance measures, including counter movement jumps, 10-30 metre sprints, 6x30 second anaerobic shuttle test, the agility T-test and the multi-stage fitness test, demonstrated similar changes during the study. Therefore, based on these results the authors concluded that both SSGs and interval training are equally effective for maintaining in-season aerobic and anaerobic fitness in elite youth soccer. However, one of the limitations was the HR responses to each type of training were not reported, making it difficult to determine if both groups received a similar internal training load during the study period. A further limitation of this study was that there was little detail of the periodization and prescription of the SSGs training. For example, the game format was restricted to 5 vs 5 for all sessions, and no detail relating to pitch area, rules or coach encouragement was provided.

In addition to this study, Impellizzeri et al, (2006) investigated the effects of specific (SSG's) vs. generic (running) aerobic interval training on physical fitness and objective measures of match performance in soccer using 29 junior players from 2 professional Italian soccer clubs, that were randomly assigned to each group also using a parallel matched-group design. The 12-week training intervention spanned over 4 weeks of the pre-season and 8 weeks of the competitive season in which the players completed two sessions per week designed to improve aerobic fitness. The training consisted of 4 x 4min at 90-95% of maximum heart rate with 3min active recovery at 60-70% HR_{max}. The SSGs training involved a mix of SSGs, including 3 vs 3, 4 vs 4 and 5 vs 5 players. Both the duration and training intensity were matched between the groups, with testing done at the start, after 4 weeks of pre-season and after 8 weeks of training during the regular season. Maximum oxygen consumption, lactate threshold, running economy at lactate threshold, soccer-specific endurance (measured via Ekblom's circuit test), and indices of physical performance during soccer matches (total distance covered, and time spent standing, walking and running) were measured. The authors reported significant improvement in aerobic fitness and match performance in both groups after the first 4 weeks of preseason. However, they found no significant differences between groups for any of the measured variables, including the soccer-specific tests which suggests that both SSG's and traditional running based intervals are equally effective ways of periodizing aerobic interval training in junior soccer players. Notably, the improvements in $VO2_{peak}$ for generic running group and SSGs for the in-season phase of the study were also very similar to the earlier study of Reilly and White (0.8% and 0.7%, and 0.3% and 0.2%, respectively).

Further studies in soccer have compared the physiological responses between soccer specific SSG training drills and generic interval training with again many of these studies confirming results mentioned in earlier studies, that the exercise intensity achieved during SSGs are similar to generic fitness training drills of similar duration (Sassi et al., 2004, Dellal et al., 2008). An example of this is Sassi et al (2004) study comparing the acute physiological responses of two formats of 4 vs 4 and 8 vs 8 SSGs with interval running (4 x 1000 metre repeats, separated by 150 seconds of recovery), using 11 elite professional players from a Spanish first division football club. Although there was no systematic manipulation of pitch area, game format (player number) or rule modifications in this study, the SSG formats elicited a greater %HRmax response compared with the interval running (91% vs 85%HRmax).

Dellal et al, (2008) compared the heart rate response of short-duration (5 to 30-second efforts) high-intensity interval running with a variety of SSG formats, using ten elite soccer players from a French first division football club. In contrast to the previous study by Sassi (2004), only the 2 vs 2 with no goalkeepers, and 8 vs 8 including goalkeepers SSG formats generated similar heart rate responses compared with the short-duration interval running protocols. The 1 vs 1 with no goalkeepers and 4 vs 4 including goalkeeper's formats generated the lowest HR responses of both the SSGs and interval running combined. The results of these studies demonstrate that the smaller-format SSGs played on a relatively large pitch area, can elicit similar intensities to both long duration interval running (Sassi et al., 2004) and short-duration high-intensity interval protocols (Dellal et al., 2008) which needs to be considered in how SSG are periodized within the training week. However, it appears that the variability in exercise stimulus is greater in SSGs compared with generic interval training which may be due to the unstructured and unpredictable nature of the movement demands in SSGs (Hill-Hass, 2011).

Furthermore, Gabbett (2006) compared SSG training and traditional conditioning activities for improving speed, agility, muscular power, and maximal aerobic power in rugby league players. Sixty-nine sub elite players performed either a skill-based conditioning game or a traditional conditioning programme 2 x weekly over a 9 week in-season programme which was performed over 2 competitive seasons. SSG training induced a significant improvement ($p < 0.05$) in 10m, 20m, and 40m speed, muscular power, and maximal aerobic power, whereas traditional conditioning activities improved 10m speed and maximal aerobic power only. Interestingly, as well as reporting physical metrics, analysis of game-based statistics revealed that both groups won six of eight matches played during the training period, but on average the game-based training group scored more points in attack and had a greater points differential than the traditional game-based group. While, this was only a short observation time-frame with limited games, this suggests that SSG training offers potential as an effective method of conditioning for team sport athletes that result in comparable (or greater) improvements in physical fitness and game performance than traditional conditioning activities.

While these studies have demonstrated that SSG training and traditional conditioning programs may result in similar improvements in physical fitness, the optimum balance and how to periodize traditional and SSG training remains unclear. It is also unclear whether it is a combination of SSG training and traditional conditioning that results in greater aerobic and physiological adaptations than either SSG training or traditional conditioning in isolation, and whether the research (that has been predominantly performed on elite athletes) can be directly applied to non-elite population.

Further research investigating the training performance and dose response relationships of SSG training and traditional conditioning activities are needed as some researchers have found significant improvements in physical fitness with SSG based training of short duration (e.g., 4 bouts of 4 minutes) (Impellizzeri et al., 2006), while others have found improvements in physical qualities when using longer duration (3 bouts of 12-15 minutes) games (Gabbett, 2006). With limited research done across team sports and none in hockey this presents a great opportunity for researchers to provide practical research that coaches sport scientists and strength and conditioners can use and apply to improve athlete's physical qualities and improve performance.

2.8.5 Limitations of small sided games

Research identifying limitations of SSG's have suggested advantages and disadvantages of training based on subjective evidence (Bishop, 2008, Gabbett, 2001, Gabbett, 2003). Although SSG's has been shown to provide a specific training stimulus that generally, replicates the overall demands of team-sport competition, research also suggests that it may not always meet the high-intensity, repeated-sprint demands of competition (Gabbett & Mulvey, 2008, Gabbett, 2009), and may have a potential limitation in providing a sufficient stimulus to elicit a greater cardiovascular load needed to develop aerobic qualities (Hoff and Helgerud, 2004). In consideration of this, the rules/structure of SSG's could be manipulated to create fewer stops in player movement to create a greater cardiovascular load (Stone & Kilding, 2009).

Despite the promising outcomes from acute (short) and chronic (long) SSG studies Hill-Hass (2011), in his review of SSG's in soccer, was able to identify the following limitations which need to be considered before SSG's can be applied in the team sport training environment. These limitations include (i) the ceiling effect in achieving high exercise intensities for highly fit or skilled players (Buchheit et al., 2009, Hoff and Helgerud, 2004), (ii) the ability to replicate the demands of the most intense periods of match play (Hoff and Helgerud, 2004, Gabbett, 2008), (iii) the requirement of a high level of technical and tactical proficiency to achieve appropriate exercise intensity (Castagna et al., 2004), (iv) the risk of contact injuries during training (Little, 2009) and (v) and the availability of enough coaches to control and monitor this type of training (Hill-Hass, 2011). Once these limitations are acknowledged and considered by coaches and sport scientists, this will enable optimal periodization strategies to be implemented into the weekly training environment, leading to improved training practices.

Prior knowledge of these potential limitations can be used when planning and delivering SSG's in the team sport environment and to optimise the effectiveness of this mode of training for developing both physical attributes and technical and tactical proficiency. For optimal use of SSGs training to improve aerobic fitness, it is suggested that a systematic approach to manipulating SSG prescriptive variables is adopted, with an emphasis on careful structuring, control and real-time monitoring to ensure what intensities are desired and achieved, and what other supplementary training may be required.

2.9 Structuring and prescribing SSG training

2.9.1 Periodization and integrating high intensity aerobic training with sport training and SSG

Within the team sport literature there are limited studies that have specifically considered the periodization of combining high intensity aerobic training with SSG's (Baker, 2015). It must be acknowledged that the recommendations are based on practical experience rather than research based, which is a limitation that needs to be taken into consideration in how this information can be applied in team sport. This presents good research opportunities to be explored to ensure optimal strategies are employed to produce performance gains.

An example of a SSG micro cycle during the competitive period of the season, is detailed by Baker (2015) showing some practical examples from the field, of how the implementation of high-intensity aerobic energy system and SSG conditioning could be combined. Baker suggested that once a team sport athlete has attained an adequate level of aerobic fitness and MAS or in the specific preparation phase or competitive periods of the sport season when skill and tactical training takes precedence, then the alternating sets of 4-8 minute sets of the interval based MAS aerobic training with 3-8 mins of small-sided games is an effective conditioning/maintenance and sports skill development tool for field sport athletes (Table 2.3).

Table 2.3 - An example of the integration of high-intensity conditioning with small-sided games, skills and tactical training during the specific preparation phase for field sports.

Time Allocation	Drill	Objective
0-6min	Movement preparation drills	Prepare the body for training
7-15min	Running technique drills	Reinforce running mechanics and the intensity of the latter warm up
15-17min	Drink break and rest	
17-27min	Skills and small group tactics	Breaking into smaller groups familiarization with the skills, tactics and drills that are the focus of the session in a non-fatigued state before the main portion of the session
27-30min	Drink break and rest	
30-35min	Tabata 120% MAS x 20:10 x 10	Induce Fatigue and maintain fitness levels
35-42min	Small sided conditioning games	Reinforce the skills and tactics that are the focus of the session in fatigued competitive situations
42-45min	Stationary drills	Practice basic stationary skills proficiency on a fatigued state
45-48min	Drink break and rest	
48-55min	Eurofit @ 120% x 15:15 x 14	Induce fatigue and maintain MAS fitness levels
55-62min	Small sided conditioning games	Reinforce the skills and tactics that are the focus of the session in fatigued competitive situations
62-65min	Stationary drills	Practice basic stationary skills proficiency on a fatigued state
65-68min	Drink break and rest	
68-83min	Team tactical training	Practice broader team tactics with attention to skills and small group tactics reinforced earlier.
83-85min	Warm Down and Debrief	

2.9.2 Small sided games periodization in team sports

Periodization offers a framework for planned and systematic variation of training parameters with the goal of optimizing training adaptations specific to a particular sport (Gamble, 2006). In team sports, the typical model of periodization will include the following phases: general preparation, specific preparation, pre-competition, and competition (Dawson, 1996). With respect to periodisation of SSGs this relates to how a single session micro cycle is structured and progressed across several weeks of a training mesocycle.

A micro cycle is the shortest training cycle, typically lasting a week with the goal of facilitating a focused block of training. The mesocycle represents a specific block of training that is designed to accomplish a particular goal. Mesocycles are typically three or four weeks in length. Generally speaking, three or four micro cycles are tied together to form a mesocycle with two very common mesocycles consist of 21 and 28-day training blocks. The *macrocycle* is the longest of the three cycles and includes all four stages of a periodized training program (e.g., endurance, intensity, competition and recovery). Because macrocycles incorporate all 52 weeks of a team or athletes annual plan, they provide the conditioning coach with a complete view of the team's training regimen and allow the coach or sport scientist to facilitate long-range planning. For example, peaking for a national championship event one year from now, you can mark that date on your calendar and work backward to create a program that allows you to peak at that time. You can use the same process to identify several major events throughout the year and develop a plan that facilitates multiple fitness peaks. Often, because of its length, changes to your macrocycle will often be made throughout the year (Lyakh et al., 2017).

A common problem for coaches and sport scientists is determining the appropriate training loads to prescribe during the competition phase of the season. Factors such as the quality of the opposition, the number of training days between matches and any travel associated with playing away games all influence the between match periodization of training loads (Kelly and Coutts, 2006). Indeed, Clemente (2014) acknowledged the gap in current research determining appropriate training loads and offered several theoretical considerations in his study of the periodization of small sided soccer games. The aims of the study were to review the general effects of SSG's in terms of physiological responses and develop some practical considerations to implement in training micro cycles to optimally prepare teams during a soccer season based on the team playing one or two competitive matches in a week. It was observed that changing the number of players, field dimensions, and task constraints can possibly induce different physiological responses. Thus, it was possible to determine that it may be possible to increase the HR responses, blood lactate concentration, and RPE by increasing the field dimensions, reducing the number of players, or playing without goalkeepers using small goals.

It was also determined that for a periodization based on SSG's, a potential effective method is to stabilize a standard microcycle, then change the type of SSG's being played (Table 2.4). Therefore, in a regular training session of 90 minutes, the specific exercises required to develop fitness could be replaced by specific periodized SSG's with well-defined tactical content, which in turn develop specific physical capabilities. By applying and monitoring the effects of this methodology, it may be possible to optimize the specificity of training and increase the contact of players with the fundamental tactical and technical concepts that are essential to improve the synchronization between teammates and increase the possibilities of playing optimally as a team, leading to improved performance and a greater chance of winning (Clemente, 2014).

Table 2.4: Recommendations for small sided game organization during a micro cycle

	Mon	Tues	Wed	Thur	Fri	Sat	Sun
Number of Players	Day Off	4 v 4, - 6 v 6	2 v 2 – 4 v 4	5 v 5 – 7 v 7	2 v 2 – 4 v 4	4 v 4, - 6 v 6	Game
Field Dimensions		Medium	Small	Large	Medium	Medium	
$\%HR_{max}$ RPE		60-75% Moderate	80-90% Maximal	>90% Stressful	>85% Maximal	60-75% Moderate	
Blood Lactate		3-6 mmol/L	7-10 mmol/L	6-12 mmol/L	6-8 mmol/L	3-6 mmol/L	
Repetitions		1-8	3-6	4-8	3-5	1-8	
Duration of Repetitions		6-15min	30s-3min	3-6min	20s – 2min	6-15min	
Sets		1-2	2-4	2-3	3-5	1-2	
Ratio: work/recovery		1:0.2	1:1 or 1:2	1:0.5 or 1:1	1:1 or 1:2	1:0.2	

RPE= rate of perceived exertion

Clemente also looked at the differences in micro cycle periodization approaches between Italian and English soccer sides and found that the highest volume is performed in the intermediate days between matches. In a week with only 1 match, the highest volume was performed on 2 consecutive days on the 4 and 3rd day prior to the match. Where the team had 2 matches, only 1 day was assigned to great having a high volume of workload. When comparing the main difference between the Italian and English periodization (for 1 match per week) from the examples provided by literature, the English team (case study) had a full rest day in the middle of the week. (Owen et al., 2009). In the Italian example of periodization, there is no rest day in the middle of the week but rather 2 days of tapering are used with low stimulation before the match. This is an example of how within a weekly micro cycle different loading approaches within team sport can be applied to optimally prepare teams for weekly competition.

In a study that investigated SSG periodization across a full mesocycle, Owen et al (2012) examined the effects of periodized SSG training intervention during a 4-week in-season break on the physical performance changes (i.e., speed, aerobic performance, and repeated sprint ability) within elite European soccer players. Fifteen, elite, male, professional players from a Scottish Premier League team participated in 7 separate SSG sessions (3 vs 3 plus goalkeepers) of which games lasted for a 3-minute duration for the selected number of games (ranged from 5 to 11) increasing over the intervention period. To examine the effects of the SSG intervention on physical performance changes, pre and post testing sessions took place over a 2-day period (day 1: anthropometry and repeated sprint ability [RSA] assessments; day 2: running economy [RE] and blood lactate assessments). Results showed that the 4-week SSG training intervention induced significant improvement in RSA as indicated by faster 10-m sprint time ($p < 0.05$, small effect), total sprint time ($p < 0.05$, medium effect), and smaller percentage decrement score ($p < 0.05$, medium effect). Furthermore, the SSGs also led to an improvement in running economy as indicated through significantly reduced VO_2 and heart rate at running speed 9, 11, and 14 km/hr (all $p < 0.05$, large effects). The authors were able to conclude that the periodised SSG training intervention could have a positive effect on both the anaerobic and aerobic system during the in-season break.

2.10 Future Progressions

Future research is required to further develop our understanding of the training stimulus provided by SSGs, and the influence of modifying SSG design variables has on the exercise intensity of SSG's training. In particular, assessing different periodization strategies of SSG's training for the development of physiological, technical skill and tactical proficiency are required to further refine programme design. In this regard, a number of interesting research questions include: 1) are larger SSG formats (e.g. 6 vs 6 through 11 v 11) more effectively used in early preseason training, while smaller game formats (e.g. 4 v 4 to 2 vs 2) be used just prior to the competitive season? 2) is the overall effectiveness of SSG's training improved when implemented as part of a traditional linear periodization approach, or is it better to implement these games using a 'block periodization model approach'? To the authors knowledge, no training study in hockey has investigated optimal SSG periodization strategies and interventions which provide practical solutions for coaches, sport scientists and strength and conditioners to consider and implement within their team context.

2.11 Conclusion

Despite the extensive use of SSGs in team sport training and preparation for competition, our understanding of their effectiveness as a training approach for developing physical, technical and tactical skills across team sports is far from complete. Research to date has improved our understanding of the physiological responses to SSG, how they compare to traditional training methods and how manipulating some of the key variables may affect SSGs intensity so that at least similar fitness and performance gains can be made to those achieved with traditional interval training methods. However, future studies are required to increase the understanding of the optimal periodization strategies of SSGs to elicit desirable changes in physical fitness of team sport athletes at the elite level, especially in the lead up to major events.

Chapter Three: Study One - Effects of a rule change on game physical outputs in elite female hockey players

3.1 Abstract

Purpose: The purpose of this study was to determine the effects of the 2015 International Hockey Federation (FIH) rule change on elite female players game physical outputs. ***Methods:*** Comparisons of game outputs derived from GPS analysis of 170 match files were made between international games before ('old') and after ('new') the implementation of the FIH rule change. Player GPS running data was categorized into generic velocity bands reflecting the percent of the total distance covered (low, 0–0.6 km/hr; moderate, 6.1–15.0 km/hr ; high-intensity, 15.1–29.5 km/hr and individual velocity bands based on each players maximum aerobic speed (MAS: low, <70%MAS; moderate, 70-100% MAS; and high-intensity, >100% MAS) categories, as well as total work rate (m/min). ***Results:*** Differences in running outputs between 'old' and 'new' game formats were only statistically significant in the Low Generic (11.4 ± 29 %, p=0.002), Low MAS velocity bands (8.08 ± 26%, p=0.012), and the average work rate (-3.25 ± 11%, p=0.003) for games following the 'new' rules. There were no differences between 'old' and 'new' game format for any moderate or high-intensity work bands (P>0.05). ***Conclusion:*** The changes in physical outputs indicate players spend more time in the low velocity bands with a small decrease in work rate from 'old' to 'new' game format. These changes indicate that the change in rules had minimal physical effect as similar outputs were seen in the higher velocity zones which have a greater physical cost for players in international matches.

3.2 Introduction

Hockey is a globally played intermittent team sport played at various levels ranging from amateur to professional. At the elite level the playing calendar is designed around 4 major international tournaments the Olympic Games, Hockey World Cup, World League Finals and Champions Trophy. Due to the structure of international tournaments, hockey demands a high level of physical conditioning, with matches played in close proximity with limited time to recover between games, high player work rate and high intensity running required. Game demands include moderate to high total distance, repeated bursts of high intensity (Gabbett, 2010), frequently change of direction and game tempo, the ability to maintain exercise intensity across a tournament (Abbott, 2016, Jennings et al., 2010), often performed in a semi-crouched position while having to execute high technical demands of hockey, ball control and distribution during match play.

Lythe & Kilding (2011) showed that in international male players that aside from fullbacks, the positional demands across the various positions were similar, with small but significant decrease in physical outputs from first to second halves (6.2 %). Furthermore, research has shown most of the match play is at low intensity 92-93% with the remaining 6-7% of play consisting of high intensity running and sprinting (Spencer, et al., 2004, MacLeod et al., 2007). The amount of high speed running above 19km/h typically is between 5-10% of the total distance covered in each game, and the average work rate typically between 120 and 140 metres per minute played (Jennings et al., 2012a, 2012b; Lythe & Kilding, 2011; White & MacFarlane, 2013).

Research in elite female hockey players has shown a reduced amount of high intensity activity performed in the second half, coupled with a significant decrease in average heart rate in the second half (174 ± 12 beats·min^{-1} vs. 169 ± 11 beats·min^{-1}; $p<0.01$), suggesting a manifestation of fatigue resulting in a decrease in physical performance (MacLeod et al., 2007). The influence of continuous and unlimited substitutions has shown that players cover a mean distance of 5541m in 48-52min of that 853m was spent high speed running and 232m sprinting. Differences in game demands were observed between positions, with the activity profile of forwards differing considerably from that of defenders and midfielders. Forwards spend a greater percentage of time performing moderate- and high-intensity exercise, such as running, fast running and sprinting, and less time walking. This is reflected in the High:Medium:Low (H:M:L) exercise ratios with forwards having less time to recover between moderate- and high-intensity bouts (1:6:7). Defenders recording the highest playing time and forwards the lowest which is because defenders where substituted less than midfielders and strikers and showing the influence that one of the rule changes of unlimited substitutions can have on the tactical use of players in different positions. The higher number of substitutions and thus reduced playing time for forwards suggests this allows them to perform more high-intensity exercise than the other positions (Macutkiewicz & Sunderland, 2011).

However, when interpreting these studies, it is important to acknowledge that the game of hockey has undergone several changes in rules in the last 25 years that may have affected the physical game demands, as well as how the game is played technically and tactically. These rule changes include the introduction of unlimited substitutions in 1992, removal of the offside rule in 1998, and most recently (2015) a change to the game duration and format from 2 x 35min halves to 4 x 15min quarters. Such changes are made for a variety of reasons which include improving player’s performance and safety, attracting players, speeding the game up, adapting the sport to children’s needs and interests, and improving the games as a spectacle for viewers and attending to commercial pressure (Arias et al., 2011). Furthermore, it must also be acknowledged that with the most recent rule change in 2015 that previous data may now not best represent the demands of hockey seen today, therefore the need to explore the differences in game demands from the ‘old’ to ‘new’ format of international hockey.

With regards to the most recent rule change, Abbott (2016) reported on positional and match action profiles of elite women’s hockey players in relationship to the 2015 FIH rule changes. The findings demonstrated that low intensity actions in zone 2 walking (0.19-1.68m/s) gradually increased, while the percent distance covered in zones 4 running and 5 fast running (3.08-5.27m/s) decreased when comparing 1st vs. 2nd, 1st vs. 3rd and 1st vs. 4th quarters. However, the limitation of this study is that it was done with one specific international team ranked 8th in FIH ranking collected over four tournaments matches, which included twenty-six games, which may elude to the results being specific to this population. To further validate the results seen in the Abbott (2016) study further research is needed with other international teams which will lead to further insight into game demands under the new format of hockey.

In other team sports that have altered match rules, it has been shown that game demands are affected. For example, in professional basketball, the rule modification of shortening the time allowed to attempt a field goal by 6 secs resulted in significant increases in maximal and submaximal oxygen consumption (Comery et al., 2008). Similarly, in professional rugby league, introduction of the 10m rule which increased the distance players had to retire from the tackle ball situation which increased the total distance covered for all players (Eaves et al., 2008). It is important for coaches and practitioners to understand how the game duration and format in hockey so that conditioning of players can be optimised. Therefore, the aim of this study was to determine effects of the FIH rule change on GPS-derived physical outputs in female elite hockey.

3.3 Methods

3.3.1 Participants

Nine elite women hockey players participated in the study. Participant characteristics are presented in Table 3.1. Players were categorised by playing position: Defence (n=3), Midfield (n=3) and Striker (n=3). When substitutions of players were made they were placed into the same field positions e.g. striker, but not always the same positional role due to the playing system of the team. Match analysis was carried out over 52 international matches over a 3-year period (2013-2015) resulting in a total of 170 sets of data. The data used for the ‘old’ rule data analysis was collected in a variety of international matches during February 2013 to June 2014, which were played in 2 x 35min halves. After the rule change was implemented by FIH in Sept 2014 games were 4 x 15min quarters. The ‘new’ rule data analysis was collected in Nov 2014 to April 2015. All matches were played on a water based, synthetic turf, in compliance with FIH field of play rules (FIH, 2014). Institutional ethics committee approval for the study was approved and each player gave informed consent for data to be used for research purposes.

Table 3.1 Participant Characteristics

Variable	Defender n =3	Midfield n = 3	Striker n = 3
Age (yr)	22.3 ± 1.7	24.0 ± 0.8	23.0 ± 1.6
Height (cm)	1.72 ± 0.02	1.70 ± 0.05	1.73 ± 0.07
Body mass (kg)	68.0 ± 1.41	60.0 ± 4.8	64.7 ± 9.2
International caps	80 ± 36	122 ± 58	88 ± 8

Data expressed as mean ± SD.

3.3.2 Match analysis

For each player, on field actions were recording using Catapult Minimax X S4 GPS (Catapult Innovations, Melbourne, Australia), which sample at 10Hz for the duration of the game. The GPS units were positioned between the scapular planes at T2–T6 of the spinal column and secured in place with a harness. Data from each GPS unit were downloaded to a laptop computer and analysed using commercially available software (Catapult Sports Sprint Software v.5.1.4). Playing time was calculated using the GPS data and checked against video analysis of playing time and substitutions made by the coaching staff. The GPS data was edited to only include time spent on the field of play, during the regulation game time. The time on the substitution bench, and the time during the 10-minute half time break (old and new game) and 2min quarters (new game) rest periods were not included in any calculations (White & MacFarlane, 2013).

3.3.3 Exercise intensity

Players' running outputs were categorised according to three generic and relative intensity bands: low, moderate and high intensity. The generic bands were defined as low (0–0.6 km/hr), moderate (6.1–15.0 km/h), and high-intensity (15.1–29.5 km/hr) velocity bands. These specific action profiles were originally adapted from definitions provided by Bangsbo and Lindquist (1992) for men's international soccer athletes and Lothian and Farrally (1992) for Women's National League hockey athletes. The player data for the relative categories were defined by a percentage of each player's maximum aerobic speed (MAS), assessed at the start of each block by running a maximum 1600m test performed on a 400m international athletics track. The players MAS was calculated by dividing the distance of the test (1600m) by each player's individual time. The data based on each individual MAS was then categorised into low (<70% MAS) moderate (70-100% MAS) and high (>100% MAS) data. For distances covered in generic and relative bands, the ratio of high to low-intensity (H:L) and high to medium to low intensity(H:M:L) exercise were calculated. Player work rate was assessed by using only time on pitch data as players perform multiple rotations during a match. The average player work rate for the match was then calculated. Total distance covered was considered relative to the total number of minutes played for each athlete (m/min), and total distance covered in each velocity zone (Low, Medium, High) was considered relative to the total distance covered in percentage to account for the difference in time on pitch.

3.3.4 Statistical analysis

Each individual athlete's data files for total distance, generic and relative intensity bands and work rate were separated into 'old' and 'new' game data files and analysed using microsoft excel. To provide an overall estimate of the team's game demands 'old' vs 'new', data obtained from all players regardless of position were averaged across those players to obtain the required data. Players data was not analysed and substituted into positional groupings due to the small number in each group (n=3 for each positional group of forward, midfielders and defenders). It is important to note that for these analyses, not all players played an equal number of minutes and in all the same international matches, and the 'new' match formatting caused variation between quarter lengths. Analysis of the outputs relative to game time allowed for comparisons for the teams pre to post rule change. All statistical procedures were performed with SPSS (IBM, New York, NY). Paired sample t tests were used to compare team full game data pre-rule change to the corresponding team full game data post rule change at the team level. Statistical significance was set at $p<0.05$, and all data were reported as mean ± SD.

3.4 Results

Table 3.2: Tournament Schedule and Outcomes

	Location	Date/Opponent/Result					
Argentina Test Series 1st	Rosario, Argentina	24/02/2013 ARG Lost 1-4	25/02/2013 ARG Drew 1-1	27/02/2013 ARG Won 4-1	1/03/2013 ARG Lost 0-1		
Four Nations Test Series 1st	Whangarei NZ	13/04/2013 USA Won 5-0	14/04/2013 KOREA Won 3-0	17/04/2013 ARG Drew 2-2	18/04/2014 USA Won 1-0	21/04/2014 ARG Lost 1-5	
Korea Test Series 2nd	Auckland NZ	28/03/2014 KOR Lost 3-4	29/03/2014 KOR Lost 3-4				
Six Nations Invitational Tournament 4th	Hawkes Bay, NZ	5/04/2014 KOR Won 3-1	6/04/2014 CHINA Lost 1-2	8/04/2014 ARG Lost 2-3	10/04/2014 JAPAN Won 3-2	12/04/2014 AUS Lost 2-4	
Hockey World Cup 5th	The Hague Holland	31/05/2014 BELGUIM Won 4-3	2/06/2014 KOR Lost 0-1	5/06/2014 HOLLAND Lost 0-2	7/06/2014 JAPAN Won 4-1	9/06/2014 AUS Drew 0-0	14/06/2014 CHINA Won 4-0
USA Test Series 2nd	Stratford NZ	26/10/2014 USA Lost 1-3					
Australian Test Series 2nd	Wellington NZ	15/11/2014 AUS Drew 2-2	16/11/2017 AUS Lost 2-3	18/11/2014 AUS Drew 3-3			
Argentina Test Series 2nd	San Luis Argentina	23/11/2014 ARG Lost 1-2	24/11/2014 ARG Lost 0-3				
Champions Trophy 4th	Mendoza Argentina	29/11/2014 JAPAN Won 2-1	30/11/2014 HOLLAND Drew 1-1	2/11/2014 CHINA Won 2-0	4/11/2014 ENG Won 3-1	6/11/2014 AUS Drew 1 -1	7/11/2014 HOLLAND Lost 1-2
Eight Nations Cup 2nd	Hawkes Bay, NZ	11/04/2015 JAPAN Drew 2-2	12/04/2015 ARG Won 3-2	14/04/2015 KOR Won 2-1	16/04/2016 INDIA Won 2-1	18/04/2015 KOR Won 4-0	19/04/2015 AUS Lost 2-3
World League Semi Final 4th	Antwerp Belgium	23/06/2015 INDIA Won 5-0	25/06/2015 AUS Won 2-0	30/06/2015 JAPAN Won 5-1	2/07/2015 KOR Drew 1-1	4/07/2015 AUS Lost 2-4	

3.4.1. Positional playing time and MAS

The playing time varied across player and positions (Table 3.3). Simple numerical comparisons revel that midfielders and defenders have the highest game time in both the ‘old and ‘new’ format, followed by strikers and defenders. Team and all position data on average had an increase in playing minutes from old to new format. Similarly, MAS varied across each player with the strikers showing the biggest increase from old to new format, with midfielders and defenders MAS on average remaining stable. Team MAS on average also showed an increase from old to new format.

Table 3.3 Positional Playing time and MAS for ‘old’ vs ‘new’ format

Player	MAS Old m/s	Mean Minutes Old	MAS New m/s	Mean Minutes New
Defender 1	4.35	36 ±1.21	4.4	44 ± 6.2
Defender 2	4.17	45 ± 4.3	4.2	48 ± 8.4
Defender 3	4.15	56 ± 7.4	4.2	62 ± 6.2
Defender Mean	4.2	46 ± 4.3	4.2	51 ± 6.9
Midfield 1	4.46	60 ± 4.3	4.5	61 ± 4.5
Midfield 2	4.11	44 ± 4.8	4.1	54 ± 4.9
Midfield 3	4.29	59 ± 4.3	4.4	59 ± 5.2
Midfield Mean	4.3	54 ± 4.7	4.3	58 ± 4.9
Striker 1	4.02	41± 5.9	4.1	49 ± 5.5
Striker 2	4.28	52 ± 8.4	4.4	53 ±5.8
Striker 3	4.29	50 ± 4.9	4.6	55 ± 6.1
Striker Mean	4.2	48 ± 6.4	4.4	52 ± 5.8
Team Mean	4.2	50 ± 5.0	4.3	54 ± 5.8

Data expressed as mean ± SD, m/s =metres per second

3.4.2 Total distance and generic intensity bands

The generic game outputs of old vs new format is presented in Table 3.4. The results showed only a small non-significant percent difference in total distance covered of 3.1% between the ‘old’ v ‘new’ formats of the game. While there was a significantly greater distance covered in the low generic intensity band during New (11.4%, p<0.00, Table 3.4.3), there were no significant differences in absolute distance covered for either the med or high generic intensity bands (0.52 and 0.84 % respectively, p>0.05).

3.4.3 Relative intensity bands and workrate

The relative game outputs of old v new format is presented in Table 3.4. The results showed a similar trend to the generic game outputs, with only the low MAS showing significance and a moderate percentage difference of 8.1%. Although there was a 9.9% decrease in high MAS from 'old' to 'new' format, this difference was not significant. Furthermore, the relative distance covered in medium was also not significant different. However, the average workrate was significantly different with a 3.3% difference decrease in average workrate from 123m/min in the old rules to 119m/min in the new format.

Table 3.4. Comparison of absolute running outputs during hockey before (Old) and after (New) the FIH rule change

	Old Game Mean ±SD	New Game Mean ±SD	Mean Difference Old Game v New Game	Percentage Difference	Significance P-value
Total Distance (m)	6142 ± 1208	6330 ± 877	-188 ± 1109	3.06 ± 19.1	0.46
Low Generic (m)	1484 ± 327	1653 ± 390	-169 ± 394	11.4 ± 28.9	0.00**
Med Generic (m)	3492 ± 680	3510 ± 490	-18 ± 723	0.52 ± 21	1.00
High Generic (m)	1177 ± 424	1167 ± 369	10 ± 482	0.84 ± 42.7	1.00
Low MAS (m)	3564 ± 712	3852 ± 718	-289. ± 823	8.08 ± 25.6	0.01*
Med MAS (m)	1673 ± 412	1653 ± 396	19 ± 471	-1.2 ± 27.4	1.00
High MAS (m)	902 ± 555	813 ± 335	89 ± 649	-9.86 ± 70.6	0.75
Mean Workrate m/min	123 ± 9.3	119 ± 10.8	4.8 ± 13	-3.25 ± 10.8	0.00**

m/min = metres per minute, m =metres
* p<0.05
** p<0.01

3.5 Discussion

Given the official game time and format in hockey has changed from 70 min in 2 halves, to 60min with 4 x 15min quarters, the purpose of this study was to investigate the effect of this rule change on running based outputs in elite women hockey players during games from international tournaments. The results from this study demonstrate that some differences in running outputs exist between the old and new format. Identifying the implications of how the rule change has impacted outputs would help to inform coaches of new game demands which can then be used to design effective conditioning programmes to help optimally prepare athletes for demands of the modern game.

For a meaningful comparison, it is important to identify that the current data is representative of previously published literature. In the present study, under the 'old' format, the elite women hockey players covered a total distance on average of 6142 ± 1208m in international matches. This dataset is comparable with the total distances reported in other studies (Abbott 2016) where distances of 6118 ± 1094 and 5912 ± 1378 were seen in forwards and defenders of the US national women's hockey players respectively. However, it differs to research completed under the 'old' format with Gabbett (2010) finding of 6.6km and Macutkiewicz & Sutherland (2011) finding of 5541 ± 1144m. It must be acknowledged that Gabbetts research was conducted in a national tournament using a mix of international and regional representative players and Macutkiewicz & Sutherland (2011) using elite international women players. The differences seen could reflect the influence of the continuous substitution rule and how this is applied by different teams and different playing standards from national to international level.

In the present study, the mean playing time was 50 ± 5min (Table 3.3) which is similar to that reported by MacLeod et al. (2007) and Macutkiewicz & Sutherland (2011) (48±4min). Midfielders recorded the highest playing time (54 ± 4.7 min), forwards (48 ±6.4min) and defenders the lowest (46 ± 4.3 min). One explanation could be that the midfielders were all key players who had high fitness levels as shown by "Old' MAS scores and were involved in lower amount of rolling substitutions per game compared with a greater amount of substitutions used for defenders and forwards respectively. This data is considerably different to that reported by Abbott (2016) (Midfielders 41 ± 8.3, forwards 38.3 ± 1.3, Defenders 57.5 ± 11.4), and Macutkiewicz & Sutherland (2011) (Midfielders 50 ± 10min, forwards 38 ± 7min, Defenders 56 ± 11min) which could reflect the how different teams and coaches use different tactical systems, substitution strategies of the different positions, and how key players are used within the context of the unlimited substitution rule to best get performance outcomes during international matches.

Differences were also seen in the absolute ratios of High, Moderate & Low (H:M:L) intensity bands. In the present study the ratio of H:M:L under the 'old' format showed the elite women hockey players covered 24.2% at Low intensity (0-6km/hr), 56.9% at Moderate intensity (6-15km/hr) and 19.2% at High Intensity (>15km/hr). These differ from previous reported H:M:L ratios reported by Macutkiewicz and Sunderland (2011) of 55.5, 38.1 and 6.4% under the same velocity zone definitions. These different results may reflect that the game demands of different teams are specific to that team and athlete population which makes direct comparison difficult (Abbott, 2016). From this data it is also clear that international hockey players under the old format required a high level of aerobic fitness to cover the reported absolute distances and aid recovery from high-intensity efforts (Table 3.4).

To see what effect the ‘new’ rule change had on the absolute running-based metrics, an ‘old’ v ‘new’ format comparison of elite games of comparable level and competitiveness was implemented in the present study (Table 3.4). This revealed difference in some outputs. Specifically, there was a significant difference in low generic running outputs with an increase in running distance from 1484 ±327m to 1653 ± 390 from ‘old’ to ‘new’ format, which is a 11.4% increase. This increase may be a result of allowing players to maintain the percent distance covered in the high velocity zone, however there were no statistically significant changes in either of the moderate and high intensity zones when comparing ‘old’ to ‘new’ format. This leads to further consideration of what classification of velocity bands in research is used to accurately assess change at higher velocities which has a greater physical cost for players. The velocity bands used in Gabbett’s (2010) research using 0-1, 1-3, 3-5, 5-7 and >7m/s may capture the subtle changes in high intensity running that might be occurring at the higher end of this band of 5-7 and >7m/s or 18-25km/hr or greater than 25km/hr. This might show further subtle changes occurring at these higher velocities, which may explain the increase in low intensity running seen in this present study.

This revealed similar results to the absolute outputs with a statistical significant ($p<0.05$) difference between ‘old’ and ‘new’ in the Low MAS category (8.1%, Table 3.4). Consistent with absolute running outputs, no significant differences were found in the moderate and high MAS running outputs, though the -9.9% difference the High MAS is noteworthy.

The tactical strategies and playing system of NZ women’s national team is to play the game with high intensity and speed which is reflected in the mean workrate seen in this study (Table 3.4). The team produced a statistically significant difference ($p<0.05$) of 123 ±

9.3m/min under the 'old' format and 119 ± 10.8m/min under the 'new' format which was a percentage difference of -3.25%. The change in m/min is consistent with the findings of Abbott (2016) involving the USA Women's Hockey Team that produced a small change of 120.58 ± 10.25m/min under the old format and 118.16 ± 9.38 m/min after the rule change. However, it is important to note that the m/min data will be affected by team tactics, the number of substitutions made, and analysis methods used (Varley et al., 2014). Furthermore, under the "new' game, with 40 sec allocated for goals scored and penalty corners, the official time depends on the number awarded during the match. The total game time under the 'new' format is now dependant on how many goals and penalty corners are conceded by each team due to a 40 second clock stoppage to allow spectators and TV viewers an opportunity to see replays of the goals and corners. This will also likely influence the reported m/min as these stoppages were not omitted from analysis, which may further explain the lower m/min in both the present study and that seen in a previous study (Abbott 2016).

The routine uses of GPS data to categorize distance and time spent within established speed thresholds, from walking to sprinting efforts (Aughey, 2011), raises the question of whether absolute or relative speed bands should be used to define speed thresholds, and whether these need to be both team sport and gender specific. While speed zones have been established and frequently applied for male-dominated sports such as rugby league (Austin & Kelly, 2013), rugby union (Cunniffe, Proctor, Baker, & Davies 2009) and AFL (Mooney et al., 2011), using the same zones for female athletes may underestimate the physiological demands of the game. For lower intensity activities, the typical differences between male and female physiological capacities may not result in any practically significant differences in work rate. However, at higher intensities and speed thresholds, the differences in physiological capacities between genders, including lower aerobic fitness and absolute sprinting ability in females (Mujika, Santisteban, Impellizzeri, & Castagna, 2009), may lead to substantial differences in physiological cost at a given running speed (Clarke, 2015). Using average velocity distribution curves of movement patterns during games from a range of men's and women's team sports, Dwyer and Gabbett (2012) proposed lower speed thresholds for use in women's team sports. However, despite this, limited research has applied the use of lower GPS speed thresholds and addressed whether relative or absolute speed bands provide a more accurate analysis of GPS data in women's team sports. While some researches have used individualised physiologically defined thresholds for high-intensity running in rugby union (Da Lozzo & Pogliaghi, 2013), these are yet to be widely adopted within the sport. The benefits of using of individualised relative thresholds may permit a more accurate prescription of training programmes and further understanding of the game as they relate to the specific physiological demands of individual players by ensuring game demands particularly at higher intensities are not over or underestimated. This is seen in the present study where using speed bands that are absolute (high generic) and relative (high MAS) show large differences in high intensity distances covered, which in practical application may overestimate the high intensity running performed during an international match using generic bands. This may result in overtraining and sub-optimal training prescription to prepare athlete for the demands of competition.

Clarke (2015) showed that the use of individualised physiologically based thresholds for quantifying high intensity running in women's rugby sevens players may be superior to a fixed threshold applied across a group. Where distances were covered above an individually defined threshold for high-intensity running these correlated substantially with both players' aerobic fitness and high-speed running capacity. In contrast, distances covered by female players above the industry used (men's) threshold of $5\ m \cdot s{-1}$ correlated with maximum running speed only. This provides further evidence for researchers to consider the physiological differences between male and female athletes when establishing high-speed running thresholds for use in team sports and how relative speed bands such as MAS may be used to define running intensities. Further benefits of expressing game demands with individualised relative speed bands for high-intensity running is that it allows for accurate prescription of effective training as players differ in the speed at which they begin to run at high intensity. This will allow the coach and sport scientist to individualize conditioning based work and monitor provide specific training feedback that is specific to an individual's fitness levels. It must be acknowledged that while current GPS analysis software has the capacity to analyse data using players individualised relative thresholds, there is still limited research in this area (Cummins et al., 2013).

3.6 Conclusion

The rule change in hockey has had some impact on the running outputs of elite female players. Specifically, players spend more time in the low velocity bands with a decreased workrate from the 'old' to 'new' format of the game. These changes indicate the change in rules has had little physical effect, especially as no changes were seen in the higher velocity zones and total distance covered which have a greater physical cost for players in international matches. However, it is acknowledged that differences seen may be due to the change in tactical use of players, the introduction of time stoppages for goals and penalty corners and the systems employed by coaches due to the change in rules and game format.

Chapter Four: Study Two

Effects of small-sided games periodization strategies on fitness in elite female hockey players

4.1 Abstract

Purpose: The purpose of this study was to determine the effects of two different five-week SSG periodization strategies on aerobic fitness and speed in elite female hockey players**.** ***Methods:*** Twelve, elite, female hockey players (age 23 ± 1.6 years; height 1.72 ± 0.02cm; body mass 64.7 ± 9.2, 97 ± 36 International caps) participated in two separate 5 week periodized SSG training interventions. The first 5 weeks employed a long to short periodized SSG training intervention (Block 1), which was followed by an international tournament, then a second 5 week short to long SSG training (Block 2) was implemented. Pre and post both interventions, testing sessions took place to assess maximal aerobic speed and 5,10 and 40m linear speed**.** ***Results:*** There was a *small* training effect of Block 1 on MAS from pre to post testing with MAS improving from 4.45 ± 0.30 to 4.54 ± 0.30 m/s^2 (2.03 ± 2.81 % difference; ES = -0.3, p>0.05). Similar effects were observed for Block 2 with *small* (1.4 ±1.98 % difference, ES=-0.21, p>0.05) improvements in MAS pre to post testing of 4.58 ± 0.30 to 4.65 ± 0.33. There was no significant difference in MAS between Block 1 and Block 2 and for the between block pre-post differences (p>0.05)**.** The 5, 10 & 40m speed for Block 1 only showed a *trivial* training effect across the three different distance measures. The 40m speed showed the largest change improving from 5.94 ± 0.28 to 5.82 ± 0.21 sec pre to post testing (-0.91 ± 3.90 % difference; ES = 0.49, p>0.05). 10m speed also showed improvement from 1.90 ± 0.06 to 1.89 ± 0.06 pre to post testing (-0.21 ± 1.78 % difference; ES =

0.07, $p>0.05$). The speed measures in Block 2 showed similar *trivial* training effects across the three speed distances, with the greatest percent difference in the 5m speed showing an improvement from 1.11 ± 0.05 to 1.10 ± 0.05 sec (0.76 ± 2.01 % difference; ES = 0.19, $p>0.05$). The 10 and 40m speeds also showed a decrease in times from pre to post testing of 1.89 ± 0.07 to 1.88 ± 0.06 sec (-0.46 ± 1.46 % difference; ES = 0.15, $p>0.05$) and 5.82 ± 0.25 to 5.79 ± 0.21 sec respectively (-0.44 ± 1.53 % difference; ES = -0.44, $p>0.05$). ***Conclusion:*** The main findings revealed that the training intervention improved the players MAS pre to post in Block 2, which would indicate that the long to short SSG training intervention had a trivial but positive effect on aerobic system development during an in-season training intervention in elite women hockey players.

4.2 Introduction

It’s widely acknowledged that preparing athletes for elite sport is a holistic and multiannual process, where athlete and teams look to achieve peak performance at pinnacle events and tournaments. To achieve peak performance and success on the world stage its key that the fundamental principles of periodization are incorporated into the preparation and during the pinnacle event.

For team sports, periodization strategies will depend on the competition schedule and the established technical, tactical, physical and sport science priorities within each squad. With the professionalism and commercialization of elite sport, the periodization of team sport athletes and teams will often not allow for the implementation of ideal periodization model and strategies, finding balance between training and peaking for weekly competitions or pinnacle events. As a result, instead of planned adaptation, symptoms of de-adaptation can be observed in the functioning of most the important body systems (Platonov, 2013; Suslow, 2002).

This is the ongoing challenge for coaches, physiologists, strength and conditioners and sport scientists as there is currently no one way to optimally periodize these various components. It highlights how getting this right within the context of the team sport environment still has challenges of both art and science to ensure players are optimally prepared to play at their best when required within the context of their sport and ensure player welfare is maintained.

To develop technical tactical and physical qualities simultaneously the use of small sided games (SSG) has become very popular in team sports for preparing athletes at all ages, levels of experience, or skill levels for the demands of the game (Reilly and White, 2004). The main benefit of SSG is the possibilities they offer for developing physical, physiological, technical, and tactical performance qualities within the context of the sport (Fradua et al., 2013, Owen et al., 2004). As well as the potential to increase many physical qualities, SSG's can provide valuable preparation for the specific demands of formal team sports games (Gabbett & Mulvey, 2008), improving the variability of learning and ensuring an optimal level of unpredictability for developing decision making and creativity (Alison & Thorpe, 1997, Tan et al., 2012). Moreover, SSG's are closely related to the high motivational and engagement levels of players (Smith 2010, Ryan & Deci, 2000). SSG training also increases ball involvement and could be considered a more effective use of training time which enables the coach, sport scientist, and players to elicit specific outcomes needed to improve demands of the game (Owen et al., 2012). This highlights some of the advantages of this type of training periodization over generic training methods such as interval running training.

However, there are considerations that need to be taken into account such as manipulating the pitch size, number of games played, duration, coach encouragement, and technical restrictions as they all have been shown to alter the physical and technical demands associated with SSG interventions (Dellal & Hill Hass et al., 2011, Hill-Haas., et al., 2010, Rampinini et al., 2007).

The overload delivered by SSGs by themselves is also unpredictable and depends upon the structure and rules of the games, and this is less quantifiable without the use of GPS technology. Therefore, athletes below the elite level who do not have the technology available to monitor the overload may be better suited to using traditional conditioning methods such interval running, when the training objective is to develop greater MAS and fitness levels, before relying solely on small sided games to develop aerobic energy fitness.

Once a team sport athlete has attained adequate fitness levels in the specific or competitive periods of the season when skill and tactical training takes precedence, alternating periods of interval running conditioning drills with SSG's may be an effective way of periodizing players conditioning and sports skill development in team sport athletes (Baker, 2015).

Taking these considerations into account, researching and developing optimal SSG periodization strategies for team sports for practical application will have an impact on the how teams prepare for the demands of competition. Establishing clear guidelines will enable coaches to provide a more effective and efficient training environment enabling the development of tactical, technical and physical improvements prior to and during the competitive season.

Of the limited research addressing the development and implementation of optimal SSG periodization strategies which can be directly applied into team sport environments, Gamble, (2004) reported significant improvements in aerobic fitness following a 9-week pre-season training period that consisted entirely of SSG based conditioning games in elite rugby union players. Furthermore, Gabbett (2006) using skill-based conditioning games as an alternative to traditional conditioning during a training intervention implemented 2 x weekly over 9 weeks, showed significant improvements in 10,20 and 40-m speed, muscular power, and maximal aerobic power pre to post training intervention. Both of these studies show the potential for the application of using periodized SSG or skill-based conditioning games within the team sport environment to improve athlete's physical performance qualities. However, the lack of research also highlights an opportunity to explore effective strategies for implementing SSG training interventions and periodization models that are effective and be directly applied to the dynamic training environment of team sports.

Within the limited existing research, Owen et al (2012) is one of the few studies that has attempted to address SSG periodization experimentally in team sports by exploring the effects of a 4 week periodized SSG training intervention on physical performance (speed, aerobic performance, and repeated sprint ability) in professional male soccer players. The study revealed significant improvements in repeated sprint ability and running economy (RE). They were able to conclude that implementing a periodized 4-week SSG training intervention during the in-season break is capable of improving elite-level soccer players' physical fitness characteristics, in conjunction to technical and tactical elements of the game, within a relatively short period. However, further research is still required to examine if other optimal periodization strategies exist for SSG training in team sport players. Specifically, whether a short to long or long to short SSG periodization may be better than then other to improve physical characteristics of team sport athletes over the course of a 5-week mesocycle. The two different SSG training blocks are founded on a multi-targeted block periodization model that consists of three types of specialized blocks: *accumulation*, for developing basic motor and technical abilities (mostly aerobic and muscle strength abilities as well as basic technical skills); *transmutation*, for developing event-specific abilities (mostly anaerobic and/or aerobic-anaerobic abilities and more specialized technical skills), and *realization*, for maximal speed, event-specific tactics prior to the forthcoming trial or competition (Issurin, 2016). It was hypothesized that the long to short periodization would be superior to the short to long SSG periodization because this allows the development of the aerobic energy system before the anaerobic lactic (glycolytic) and anaerobic a-lactic (ATP-CP) energy system. This will help the athletes since the aerobic energy system plays an important role in recovery for both anaerobic energy systems to metabolise by-products and replenish fuel stores which may lead to superior ability to cope with the anaerobic SSG training used in the later weeks of the long to short SSG periodization.

Therefore, to further advance knowledge in the field of training periodization and to refine strategies to optimally utilise SSGs, the aim of the present study was to determine the effects of two different periodization models using SSG's and game-based drills on physical fitness and performance in elite female hockey players.

4.3 Methods

4.3.1 Experimental approach to the problem

To compare the effects of two different 5 week periodised SSG interventions in elite hockey players, an in-season design was adopted similar to that adopted by Owen et al (2012). During the 2015 international hockey season, 2 separate and different 5-week training mesocycles were prescribed separated by a period of 4 weeks, with international matches or tournaments occurring pre and post each mesocycle. The overall structured periodised training programme were strictly controlled at these specific stages of the season due to an agreed training structure and playing model which was implemented at the start of the year. The intention of the training interventions was to use as little generic conditioning as possible using the periodized SSGs to achieve the required high intensity work rates prepare players for international hockey.

4.3.2 Participants

Twelve elite female international field hockey players from NZ's National Hockey Team participated in this study. Written informed consent was received from players after a detailed explanation of the study aims, individual and team benefits, and potential risks involved with participation. During the study all players were on normal nutritional programming with no athletes required to undertake special nutritional interventions that would have had a negative impact on performance and training outcomes.

The training sessions implemented prior to the start of each 5-week training intervention were similar given the fact that they previous completed competing in international matches or tournaments. This was followed by 10-12 days of rest away from hockey training which involved 3 x strength sessions and 4 x MAS interval training per week, which was designed to maintain the athletes physical conditioning prior to the commencement of the training intervention and team periodization. During the build up to Block 1, prior to the team competing in an international tournament, the squad had come off a 6 week off season generic conditioning programme set by the sport science team with set goals and fitness targets to achieve prior to the commencement of national team training.

4.3.3 Testing battery

A battery of tests was conducted using standardised procedures before and after each periodized block. Players were familiar with all assessments and the timing of testing ensured that the players had no exposure to high intensity training at least 24 hours prior to the commencement of any of the testing sessions to minimise any influence of fatigue on test performance.

4.3.4 Anthropometrical profiling

The anthropometrical assessment included height, weight and summation of 8 skinfolds sites which included biceps, triceps, subscapular, iliac crest, supra-spinale, abdominal, mid-thigh, and calf. All measures were conducted in accordance with International Society for the Advancement of Kinanthropometry (ISAK) standard procedures at the start of the physical testing battery by an ISAK qualified practitioner**.**

4.3.5 Linear speed profiling

Prior to assessments of speed on an indoor Mondo surface, a standardized warm up was performed by each player. This involved 10 min of self-selected mobility, dynamic exercises and stride outs, and progressively faster practice runs at 60, 70, 80, 90% max effort. Thereafter, athletes were positioned in a stationary position 0.3 m back from the beam of the first timing light (Swift Performance Systems, Brisbane, Australia) and instructed to sprint maximally through the dual beam timing lights set 1m off the ground with gates set at 0, 5 10 and 40m. Athletes were instructed to start decelerating at 50m where a cone was placed to ensure maximal effort through to 40m. Three maximal effort sprints were recorded with the best time used for subsequent data analysis.

4.3.6 Maximum Aerobic Speed (MAS)

After a standardized warm up, which involved 2 laps of a 400m athletics track followed by 10 minutes of self-selected mobility and dynamic warm up exercises, players performed the Maximal Aerobic Speed (MAS) test (Berthon et al., 1997), which consisted of 4 laps or 1600m of an international 400m athletics track on a Mondo surface in dry conditions. The time trial format was selected as it is a simple, reliable and time efficient way to assess aerobic fitness qualities with a large number of athletes (Baker & Heaney, 2015, Berthon et al., 1997). Players were timed using a hand-held stopwatch with the time taken to complete the 1600m recorded. The distance covered and time taken were used to calculate each player's MAS before and after each intervention.

4.3.7 Small sided games intervention

All SSG were periodised as part of the national teams usual training and preparation for two key tournaments. The timing of the SSG's depended on the periodization for each session with the periodization plan shown in Tables 4.3 & 4.4. All games were played on an international sized hockey turf 91.4 x 55m, in a variety of conditions due to Block 1 taking place in late summer early autumn and Block 2 taking place in late autumn and the start of winter. Most of training sessions took place at 6pm at night except for the Saturday sessions which took place early morning at 8am. The SSG periodization model employed during this training study was adapted from Raymond Verheijen soccer specific SSG periodization model which is used and taught by FIFA and within elite football teams around the world (Verheijen, 2014).

Block 1: Short to long SSG training intervention

The SSG's intervention for Block 1 was periodised in a short to long manner as detailed in Table 4.2. This approach involved the SSG intervention progressing over the 5-week training block from small to medium pitch 4 v 4 SSGs to larger full pitch 11 v 11 games at the end of the block. In the context of this study short to long SSG periodization is using the small pitch 4 v 4 as short and long as the larger full pitch 11 v 11 games. Typically, the short small pitch SSG are defined by a short time frame of 3-5min, whereas the long full pitch games are defined by a time frame of 8-20min.

TABLE 4.2 Block 1 Short to long mesocycle periodization

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Week 0					Pretest	Rest Day	Rest Day
Week 1	Pretest + Strength S+RS+ SSG1+TT	Strength	S+SSG2+TT	S+TT	Strength	SSG 3+TT	Rest Day
Week 2	Speed + HI Intervals	Strength	RS+S+SSG4 +TT	S+SSG5+TT	Strength	SSG6 +TT	Rest Day
Week 3	Strength S + SSG7+TT	Strength	Strength S +SSG8+TT	S+TT	Strength	SSG9+TT	Rest Day
Week 4	Speed + HI Intervals	Strength	S+RS+SSG1 0+TT	S+TT	Strength	SSG11	Rest Day
Week 5	Strength TT+RS+S SG12 +TT	Strength	TT+SSG13+ TT	SSG14	Strength	TT+SSG15	Rest Day

S=Skills low to moderate intensity, RS=Repeated sprint drills high intensity, TT=Technical tactical low intensity, HI =High intensity, SSG1 =Small sided game 1 which corresponds to table 4.4

Block 2: Long to short SSG training intervention

The SSG's intervention for Block 2 was periodised in a long to short manner, which involved a 2-week full pitch 11 v 11 tournament simulation progressing to a small to medium pitch 4 v 4 SSG's at the end of the block (Table 4.2).

TABLE 4.3: Block 2 Long to Short full mesocycle periodization

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Week 0					Pretest	SSG 1	SSG 2
Week 1	Rest day	TT	Strength + TT	SSG 3	Strength	SSG 4	Rest Day
Week 2	Strength + TT	SSG5	Strength	SSG 6	Strength	SSG 7	Rest Day
Week 3	Recovery Session	Strength	S+RS+SSG8 +TT	S+SSG9 +TT	Strength	S+SSG10+TT	Rest Day
Week 4	Strength S+RS+ SSG11 +TT	Strength	S+SSG12+TT	S+SSG13 +TT	Strength	HI Interval session	Rest Day
Week 5	Post Test + Strength TT+RS+SSG14 +TT	Strength	S+SSG15+TT	S+SSG16 +TT	Strength	Club Hockey	Rest Day

S=Skills low to moderate intensity, RS=Repeated sprint drills high intensity, TT=Technical tactical low intensity, HI =High intensity, SSG1 =Small sided game 1 which corresponds to table 4.5

To ensure high intensity during the SSG's and continuity of play maintained, regardless of periodized approach or game format, balls were placed around the outside of the pitch and inside the goalkeeper's net and players instructed to play at match tempo with encouragement from the coach and support staff during each game. During each training block, each week had typically three SSG sessions, with one of these being a large pitch full field game to continue to develop the aerobic stimulus need to help develop quick recovery between hockey actions and develop optimal hockey fitness for international matches and tournaments (Table 4.3 & 4.4). For each player, on field actions were recording using Catapult Minimax X S4 GPS (Catapult Innovations, Melbourne, Australia), which sample at 10Hz for the duration of the training. The GPS units were positioned between the scapular planes at T2–T6 of the spinal column and secured in place with a harness. Data from each GPS unit were downloaded to a laptop computer and analysed using commercially available software (Catapult Sports Sprint Software v.5.1.4). Rating of perceived execution (sRPE) was used to monitor individual player intensity from each training session.

Table 4.3: Block 1 short to long week by week periodization detail

Block 1	Week1 SSG 1	Week1 SSG 2	Week1 SSG 3	Week2 SSG 4	Week2 SSG 5	Week2 SSG 6	Week3 SSG 7	Week3 SSG 8	Week3 SSG 9	Week4 SSG10	Week4 SSG11	Week5 SSG12	Week5 SSG13	Week5 SSG14	Week 5 SSG 15
Format	4v4	3v3, 4 v 4	8v8, 9v9	4v4, 4v5	4v4	4v4 & 11v11	7v7, 7 v 8	4v4	11v11	9v9	11v11	11v11	11v11	11v11	11v11
Duration	3min	3min	15min	4min	6min	3min & 15min	5min	15min	8min	15min	10min	15min	15min	15min	10min
Rest	2min Active	2min Active	2min Pass	2min Activ e	2min Active	2min Active	2min Pass	2min Pass	2min Pass	2min Active	2min Passive	2min Active	2min Active	2min Active	2min Active
Reps	6	8	4	7	4	6 & 2	6	8	4	6	4	4	3	4	5
Total SSG Duration	18min	24min	60min	28min	24min	18 & 30	30min	40min	60min	48min	60min	40min	45min	60min	50min
Pitch Size L x W (m)	35x55	36x25	92x55	35x55	46x55	46x55 92x55	73x55	20-40 x 60	92x55	92x55	92x55	92x55	92x55	92x55	92x55
Average Player RPE	8	8.2	893	6.1	6.9	7.1	8	7.3	8.1	8.5	7.1	8.5	5.1	8.1	4.8
Training Load	756	984	996	732	828	852	960	876	972	1020	852	1020	612	972	504

Pass = Passive, SSG 1 = Small Sided Games session 1 this corresponds to details in table 4.2, L=length, W=Width, m = metres

Table 4.4: Block 2 long to short week by week periodization detail

Block 2	Week0 SSG 1	Week0 SSG 2	Week1 SSG 3	Week1 SSG 4	Week2 SSG 5	Week2 SSG 6	Week2 SSG 7	Week2 SSG 8	Week3 SSG 9	Week3 SSG10	Week3 SSG11	Week4 SSG12	Week4 SSG13	Week4 SSG14	Week 5 SSG 15	Week 5 SSG 16	Week 5 SSG 17
Format	11v11	11v11	11v11	11v11	11v11	11v11	11v11	11v11	5v5	10v10	4v4 8v 8	4v4	11v10	10v 10	4 v 4 5 v 5	10 v10	4 v 4
Duration	15min	15min	15min	15min	15min	15min	15min	15min	4min	7min	5min 8min	4min	15min	8min	4min	2 x15min 1 x 18min	4min 9min
Rest	2min Pass	2min Pass	2min Pass	2min Pass	2min Pass	2min Pass	2min Pass	2min Pass	1min Active	2min Active	2min Active	1min Active	3min Pass	1min Active	1min Pass	2min Pass	1min pass
Reps	4	4	4	4	4	4	4	4	6	5	7/2	7	3	6	8	3	8/2
Total SSG Duration	60min	60min	60min	60min	60min	60min	60min	60min	24min	35min	46min	28min	45min	48min	32min	48min	50min
Pitch Size L x W (m)	92x55	92x55	92x55	92x55	92x55	92x55	92x55	92x55	46x 55	92x55	23x55 22 x46	32x55	92x55	92x55	22-45x55	70x55	55x22 92 x 55
Average Player RPE	6.7	6.8	7.4	7.0	5	7.1	5	7.1	6.9	7.2	6.9	8	7.4	8.0	8.5	7.1	8.8
Training Load	804	816	888	840	450	852	600	852	828	864	828	960	888	960	1020	852	1056

Pass = Passive, SSG 1 = Small Sided Games session 1 this corresponds to details in table 4.3, L=length, W=Width, m = metres

4.3.8 Statistical analysis

All statistical procedures were performed with SPSS (IBM, New York, NY). Data is presented as means ± SD. Paired sample t tests were used to compare testing results pre to post after Block 1 and Block 2 and between the end of Block 1 and the start of Block 2. Statistical significance was set at $p<0.05$, and all data were reported as mean ± SD and 95% confidence interval. Cohen's d effect sizes (d) were determined as trivial <0. 2, small 0.2-

0.6, moderate 0.61-1.20, large 1.21-2.00 and very large 2.01-4.0 (Hopkins, Marshall, Batterham, & Hanin, 2009).

4.4 Results

4.4.1 MAS

There was a *small* training effect of Block 1 on MAS from pre to post testing with MAS improving from 4.45 ± 0.30 to 4.54 ± 0.30 m/s^2 (2.03 ± 2.81 % difference; ES = -0.3, Table 4.5 , p>0.05). A significant effect was observed for Block 2 with *small* (1.4 ±1.98 % difference, ES=-0.21, p=0.00) pre to post improvements in MAS (4.58 ± 0.30 to 4.65 ± 0.33). There was no significant difference in MAS between Block 1 and Block 2 for the between block pre-post differences (p>0.05) (Table 4.6).

4.4.2 5,10 and 40m speed

The 5, 10 & 40m speed for Block 1 only showed a *trivial* training effect across the three different distance measures. The 40m speed showed no significant difference pre to post testing (-0.91 ± 3.90 % difference; ES = 0.49, p>0.05). 10m speed also showed no significant difference but did show an improvement from 1.90 ± 0.06 to 1.89 ± 0.06 pre to post testing (-0.21 ± 1.78 % difference; ES = 0.07, p>0.05). There was little change in the 5m speed during Block 1 (-0.07 ± 2.73 % difference; ES = -0.01, p>0.05) (Table 4.5).

The speed measures in Block 2 showed similar *trivial* training effects across the three speed distances, with the greatest percent difference in the 5m speed showing an improvement from 1.11 ± 0.05 to 1.10 ± 0.05 sec (0.76 ± 2.01 % difference; ES = 0.19, p>0.05). The 10 and 40m speeds also showed a decrease in times from pre to post testing of 1.89 ± 0.07 to 1.88 ± 0.06 sec (-0.46 ± 1.46 % difference; ES = 0.15, p>0.05) and 5.82 ± 0.25 to 5.79 ±

0.21 sec respectively (-0.44 ± 1.53 % difference; ES = -0.44, p>0.05). There was no significant difference in speed measures across 5,10 and 40m between Block 1 and Block 2 for the between block pre-post differences (p>0.05) (Table 4.6).

Table 4.5 Effects of SSG training intervention on fitness and speed pre and post Block 1 and Block 2

	Block 1 Pre RC	Block 2 Post RC	Block 1 95% CI	Block 1Effect size/magnitude	Block 1 % Difference	Significance P-value
MAS 1600m m/s	4.45 ± 0.30	4.54 ±0.30	-0.16 - 0.02	- 0.30/small	2.03 ± 2.81	0.18
5m Speed (sec)	1.12 ± 0.04	1.12 ± 0.05	-0.02- 0.02	-0.01/trivial	0.07 ± 2.73	0.93
10m Speed (sec)	1.90 ± 0.06	1.89 ± 0.06	-0.02 0.02	0.07/trivial	-0.21 ± 1.78	0.66
40m Speed (sec)	5.94 ± 0.28	5.82 ± 0.21	-0.02-0.26	0.49/small	-0.91 ±3.80	0.09

Data expressed as mean ± SD. Pre RC = Pre-Rule Change, Post RC = Post Rule Change, m/s = metres per second, sec = seconds

	Block 2 Pre RC	Block 2 Post RC	Block 2 95% CI	Block 2 Effect size/magnitude	Block 2 % Difference	Significance P-value
MAS 1600m m/s	4.58 ± 0.30	4.65 ± 0.33	-0.12 -0.01	-0.21/small	1.4 ± 1.98	0.02*
5m Speed (sec)	1.11 ± 0.05	1.10 ± 0.05	-0.00- 0.02	0.19/trivial	0.76 ± 2.01	0.17
10m Speed (sec)	1.89 ± 0.07	1.88 ± 0.06	-0.00 -0.02	0.15/trivial	-0.46 ± 1.41	0.21
40m Speed (sec)	5.82 ± 0.25	5.79 ± 0.21	-0.02- 0.08	0.13/trivial	-0.44 ± 1.53	0.26

***** p<0.05
Data expressed as mean ± SD. Pre RC = Pre-Rule Change, Post RC = Post Rule Change, m/s = metres per second, sec = seconds

Table 4.6 Effects of SSG training intervention on fitness and speed between Block 1 and 2

	Block 1 Post test	Block 2 Pre Test	B1 Post – B2 Pre 95% CI	B1 Post – B2 Pre % Difference	Significance P-Value
MAS 1600m m/s	4.54 ± 0.30	4.58 ±0.30	0.04 -0.013	0.88	0.34
5m Speed (sec)	1.12 ± 0.05	1.11 ±0.05	0.00-0.00	-0.89	0.48
10m Speed (sec)	1.89 ± 0.06	1.89± 0.07	0.01-0.02	0.00	0.84
40m Speed (sec)	5.82 ± 0.21	5.82 ±0.25	0.03-0.06	0.00	0.91

Data expressed as mean ± SD, B1 = Block 1, B2= Block 2, m/s = metres per second, sec = seconds

4.5 Discussion

The aim of the present study was to determine the effect of two different 5-week SSG training interventions on physical fitness and speed measures in elite, adult international hockey players during the international season. The main findings revealed that the training intervention improved the players MAS pre to post in Block 2, which would indicate that the long to short SSG training intervention had a small significant positive effect on aerobic system development.

With aerobic system development during a season a priority for most team sport athletes (Reilly & White, 2004), the findings of this study demonstrate using different periodised SSG training interventions may develop and maintain aerobic fitness qualities when periodised alongside the development of the technical and tactical requirements of the sport during the competitive season. It is well-documented that the greatest training benefits occur when the training stimulus simulates the movement patterns, physiological demands and decision-making characteristics of the sport (Rushall et al., 1990). This is a positive for coaches and athletes knowing they can improve game awareness, technical and tactical understanding while improving skill and fitness levels.

In the present study, MAS was increased by 2 and 1.5% following Block 1 and Block 2 respectively, though this was only significant for Block 2. Although the training effect was small (Table 4.5), equivalent to increasing the players MAS by 0.2-0.3 km/h, small gains could still have a positive effect on performance as research has shown that a superior aerobic system facilitates the ability to recover from intense bouts of repeated sprint efforts, is correlated with higher repeated sprint ability and is a critical component of team success in team sports (Bishop et al., 2004, Baker, 2015).

The findings from the present study add to the emerging amount of research that identifies SSG periodization as an alternative training modality to generic interval running which can improve the physical fitness characteristics in elite team sport athletes (Reilly & White, 2004). Due to team sports requiring intense efforts at unpredictable times, some researchers and coaches advocate SSG's as a better alternative to traditional conditioning due to the "unpredictability" of games and the fact that games also develop sports skills and game sense. While there is no other research investigating SSG periodization in hockey, research done in other team sports have shown improvement in YoYo Intermittent Recovery Test performance over 7 weeks (Hill Haas et al., 2010), and 3% improvement in running economy over 12 weeks implementing SSG training interventions in youth soccer players (Impellizzeri et al., 2006). The limitations of SSG's is that the overload delivered by games by themselves is also unpredictable and depends upon the structure and rules of the games etc (Baker, 2015).

Using traditional conditioning methods to develop greater MAS and fitness levels, before relying on SSG's to develop aerobic energy fitness has also been recommended (Baker, 2015). This generic way of conditioning does not offer the same enjoyment, motivation and ability to develop the random and unorthodox movement patterns within the context of the sport associated with SSG training interventions, hence further limiting the comparisons between to the two modalities (Hill-Haas et al., 2009). The answer could be a combined and integrated approach using both generic MAS conditioning with SSG or skill and tactical training.

The present study also revealed that the training intervention improved the player's acceleration and speed (Table 4.6) with Block 2 showing improvements across all speed measures of 5,10 and 40m (0.76 ± 2.01, -0.46 ± 1.41, -0.44 ± 1.53%). Although these improvements were deemed *trivial* these changes are consistent with Owen et al (2012) findings of a *small* change in 10m sprint times during a 4 week in season break. However, due to a lack a research pertaining to the effects of SSG on physical parameters other than maximal aerobic capacity further research is needed to address whether SSG can actually improve speed performance in elite team sport athletes (Owen et al., 2012). Another explanation for the slightly greater improvement in speed in Block 2 is that players were now well into there in season periodization of consistent strength and conditioning and speed training, whereas in Block 1 players were coming off a preseason training block where strength and speed were being introduced following off season. However, potentially the gains seen in Block 1 could have been larger than those see in Block 2 since the athletes were coming off a lower baseline. Furthermore, it is difficult to identify to what extend the SSG intervention improved speed qualities due to the fact within the overall periodization of both blocks hockey specific repeated sprint drills and 3 x a week strength training was implemented, which may have influenced the *trivial* speed results seen.

Comparing the results from the present study to other SSG periodization studies the variation in pitch dimensions, number of players, game rules, coach encouragement, weekly periodisation of the SSG and the differences in research methodologies (Hill Haas et al., 2011) need to be considered when assessing the differences seen. Therefore, optimal periodization of SSG within the elite and sub elite levels of team sport need further research and validation, to continue to understand how different periodization strategies can change individual and team's physical fitness levels.

With both Block 1 and 2 using different versions of a periodized multi-targeted block structure model, which uses sequencing of specialized blocks mesocycles, intended to develop specific targeted abilities within each block, it was hypothesized that Block 2 long to short would be more effective. This is supported by results seen in table 4.6 with greater significant differences seen from pre to post testing in Block 2. This may be because the present study was conducted during the early (Block 1) to mid phase (Block 2) of the season and with the results of Block 2 potentially being affected by the physical preparation done in Block 1, which can be seen in the table 4.6 where athletes came in at greater aerobic fitness levels (0.88 % difference). Physiologically, with athletes having a greater aerobic and speed base created by the progressive overload of generic fitness prior to the start of Block 1 (off season), and the hockey specific fitness and speed development developing from the conditioning in Block 1, this could further explain the superior results seen in Block 2.

Furthermore, with the short to long periodization implemented in Block 1 starting with 2 weeks focusing on the development of the Anaerobic A-Lactic (ATP-CP) energy system then progressing to a week focused on Anaerobic Lactic (Glycolytic) energy system, then 2 weeks focusing on aerobic system development players may have still been adapting to the progressive overload implemented through the mesocycle. This post testing which occurred immediately at the end of this phase may have been too early for athletes to express the potential changes in physical qualities gained through the SSG intervention. Furthermore, with player's strength qualities being re-established following the off season and building through Block 1 this may have further affected the results seen, however this was not measured during this study which is a limitation that must be acknowledged. Also knowing that the athletes were required to peak for a pinnacle tournament post Block 2, these results are to be expected but make it difficult to compare the two different SSG training interventions.

Further considerations that make comparisons between the two periodization designs difficult is that it was the intention to have a short to long SSG periodization in Block 1, then reverse this model in Block 2 with a long to short design. However, with a pinnacle tournament at the end of Block 2, changes had to be made to the SSG periodization due to the team needing more of a tactical focus, resulting in more 11v 11 full field games periodized into the training week at towards the end of the training intervention (Table 4.5).

The lack of control group also effects the findings as it could be argued that the small gains seen in fitness and speed may be affected by the strength session in the gym, and technical, tactical parts of the training during the intervention period. As most of the skill and tactical training is undertaken at long slow distance type of speeds and heart rates, involving cardiovascular stimulation at the lower end of the "polarity spectrum", which will have an effect in combination with the SSG and repeated sprint drills on overall aerobic system development. However, it is worth noting that repeated sprint hockey drills and MAS conditioning were also used within the periodization at times, which may have influenced results, however the experimental SSG's were the predominant high intensity stimulus.

4.6 Conclusion

In conclusion, the periodization of SSG's may have a positive effect on aerobic system development in elite female hockey players. These findings could potentially provide valuable information to coaches and sport scientists for the design and implementation of a playing model using SSGs and game-based drills as part of a periodised programme to optimise training time, optimally physically prepare athletes physically to play hockey and ensure players receive the right balance of technical tactical & physical demands during training.

Chapter Five: Discussion and conclusion

5.1 Summary of findings

Preparing athletes for the demands of international competition is maximised when the athlete and game demands are known and profiled, which in turn allows for optimal periodization strategies to be implemented. The importance of ensuring these strategies and programming are effective within a training block allows for optimal athlete adaptation to take place. The objective of this thesis was to 1) extend the current knowledge of a rule change on physical running outputs of elite players during competition and 2) to determine if an optimal SSG periodization strategies exists with respect to enhancing aerobic fitness in elite female hockey players.

The literature review in this thesis revealed only one study in hockey that has investigated the 2015 FIH rule change and the effects on physical outputs during competition (Abbott, 2016). With the limited research looking at this change, further studies were needed to validate the results seen in Abbotts study to see if the results and findings were population specific to this research. This validates the need for further research in this area to confirm or provide further context to the findings, then coaches and sport scientists may have greater confidence to apply learnings within their team sport environment. Furthermore the limitations identified within the Abbotts study of 1) investigating recovery protocols used during the 2min quarter and 10min half time to reduce the reduction of m/min and percent distance covered in the low and medium speed bands, 2) removing the 40 second running clock during corners, and goals in the GPS analysis to allow for a better understand of the quarter system, 3) standardizing the time in each quarter to allow for a more accurate analysis of players workrate as expressed by m/min 4) examining the current definition of speed and velocity bands used in team sport specifically within female team sport, all warrant further investigation and research to assess impact on international matches and how athletes are optimally prepared.

Additionally, despite several studies reporting on the acute and chronic effects of SSG in team sport players, few studies have examined the impact of varying the periodization model when prescribing SSGs (Owen et al., 2012, Clemente et al., 2014), with no research done on this aspect in hockey. Further research in the area is warranted as better understanding of the effects of a rule change on player physical outputs and how varying the periodization of SSGs influences aerobic fitness development could help to refine team preparation for international competitions.

Considering the limitations identified in the literature, chapter three investigated the effects of FIH changing the match format in international hockey from 2 x 35 min halves to 4 x 15min quarters on athlete physical outputs. This study revealed that changes in physical outputs occurred but only at the lower velocity ranges where an increase in distance spent in these ranges and the average player work rate decreasing after the rule change. This is consistent with Abbott et al (2016) in a similar elite female population. Conversely, the results presented in chapter three do not support our hypothesis that the implementation of these new rules allowed athletes the ability to produce and maintain more high intensity actions, resulting from the additional rest periods and a decrease in game time. Rather our results indicate athletes were spending more time running at low or medium speeds and covered less metres per minute on average showing a decrease in work rate after the rule change with similar match times.

The greater amount of time spent in these lower velocity ranges may be due to the effect of the team still adapting to the new tactical approach employed by coaches after the rule change. Also, the influence of the actual game time depending on the number of corners and goals awarded during the game, which may affect the metres per min as these changes may be due to the varying durations in quarter length which can range from 15-24min. This could also account for increases in low intensity actions due to the 40 sec clock stoppages for penalty corners and field goals which were not taken out in the GPS analysis after the rule change. The increases seen in low intensity actions in the 'new' format of the game could also be due to the ability to recover from high-intensity actions, however in this study significant increases in high intensity actions were not seen in the new format.

The effects of SSG's periodization strategies on elite female hockey players were presented in chapter four, with the aim to investigate the influence of two different five week SSG periodization strategies on improving aerobic fitness and speed qualities and to provide insight into possible periodization strategies which can be used in hockey to prepare athletes for the demands of the new international competition game format. The main findings of the study revealed that varying the periodization strategy of SSG training had no significant impact of MAS for the short-to-long periodization, but having a significant, but small effect on the long to short periodization indicating a shift in aerobic system development during the competitive season. This finding is consistent with the Owen et al (2012) results showing a positive change in running economy as indicated through significantly reduced VO_2 and HR at running speed 9, 11, and 14 km/hr and repeated sprint ability after a four-week SSG training intervention in elite European soccer players. Furthermore, the results revealed the training interventions improved the players overall speed in acceleration and top speed measures of 5, 10m and 40m respectively pre to post in both 5-week blocks. Although these results were deemed *trivial* it could indicate that the two different training interventions had a positive effect on speed development. These improvements are consistent with Owen et al (2012) findings of a *small* change in 10m sprint times during a 4 week in season break.

With the results from Block 2 successful in improving players physical profile from pre to post testing this may add further support for the use of SSG's as an option to develop elite team sport athlete's physical qualities when periodised alongside the development of the technical and tactical requirements of the sport during the competitive season. The positive results seen in Block 2 may be due the periodization being based on planned progressive overload where the athletes develop the aerobic system first allowing improvements in the athlete's ability to produce more ATP in week 1 and 2, then progressing to developing the Anaerobic Lactic (Glycolytic) Energy System in 3, which was also scheduled as a lighter training week to allow adaption form previous week, before the focus in the last 2 weeks progressed to developing Anaerobic A-Lactic (ATP-CP) Energy System, while maintained adaptations from the previous week with selected aerobic system development. Therefore, further research may help decide whether this system is applicable to other team sports to improve athlete's physical profiles during the competitive season and adds to the discussion as to whether sport scientists and strength and conditioners use additional generic running to elicit optimal changes to athlete's physical profile.

To effectively impact elite team sport performance and success during competition, an accurate profile of the game demands during competition is required. This allows coaches and support staff to develop and implement optimal training stimuli to prepare the athletes for these demands and allow them to express their true athletic qualities during competition. In chapter three, it was demonstrated that the physical demands of an international match in hockey under the 'new' format and rules of the game to be a total distance of 6.3km, a generic high intensity distance of 1.1km above 15.1 km/hr, an individual high intensity distance of 813m above 110% of MAS, and an average player work rate of 119m/min, this data can now be used to inform future training interventions to enhance player physical fitness. By designing the training to elicit these match demands in SSG's or sport specific drills, coaches sport scientist and strength and conditioners can be confident they are preparing athletes for the demands of the competition. To successfully implement this strategy elite teams must have the monitoring technology to be able to successful profile the demands then use it during training to monitor training demands to ensure the optimal stimulus is being delivered to each athlete. With one of the major focus of the NZ's elite female national team to develop the physical qualities needed to maintain and repeat high intensity actions during international matches, the combination of development of a high aerobic and anaerobic capacities, player substitutions, tactical strategies and player's athletic ability allow these high intensity actions and high work rates to be expressed and repeated. The data from chapter three profiling the physical demands of the 'new' format also shows the variation in relative and absolute velocity zones confirms how important the development high aerobic and anaerobic capacities for international hockey is for success during international competition.

With the relative and absolute high intensity actions accounting for 13% and 18% of the total distance covered in the 'new' format, the intermittent nature of hockey, the necessity to repeat high-intensity actions throughout a game, and the ability to perform those actions being recognized as a key determinant of success (Bishop et al., 2003), further supports the need for optimal periodization strategies to be employed in the preparation phases leading into key tournaments. Likewise, with the variation of the percent of relative distance covered in various velocity zones in the new format of the game being low 60%, medium 26%, and high 13%, this again supports the need for a balanced periodization approach of aerobic and anaerobic conditioning and agrees with previous research that concluded hockey to be an aerobically demanding sport with frequent anaerobic efforts (Gabbett, 2010, Spencer et al., 2004). This is supported by Spencer et al (2004) identifying that sprinting efforts were not evenly distributed throughout a game and further research identifying that increasing an athlete's top speed may allow players to produce higher relative speeds during a match, while increasing athletes' aerobic capacity will allow for a higher critical speed to be maintained while recovering between intermitted bouts of high-intensity (Bishop et al., 2003, Bishop & Spencer, 2004, Vescovi, 2015).

Taking these considerations into account it would suggest an optimal periodization model for hockey needs to incorporate developing 1) high levels of aerobic fitness to maintain quick recovery between high intense periods of play, 2) high anaerobic capacity to ensure quick recovery between anaerobic efforts, 3) Ability to accelerate quickly off the mark and get up to top speeds efficiently and quickly which maximises sprinting, tackling, winning, 1 v 1 contests, turning and sprinting and, 4) develop repeated short sprinting ability which allows players to express the ability to maintain maximum explosive actions throughout a 60+ minute game and help achieve a higher work rate in the latter stages of the game. How these different components are developed in a periodised and structured way to develop players who can operate at highly advanced levels of play with less time and more pressure needs to be considered. Furthermore, developing 60min hockey players who can maintain more explosive actions with a high level of execution is the current challenge of coaches, sport scientists and strength and conditioners. This warrants further investigation in future research as this is the first study attempting to address these questions within elite hockey players.

While the acute and chronic effects of SSGs on aerobic fitness is well documented (Hill Hass 2011), the optimal periodization of aerobic training stimuli using SSG is poorly understood. The findings of study 2 of this thesis suggest that various block periodization models can be implemented to prepare athletes for the game demands of international hockey. The two different block periodization models used in study 2 using a progressive short to long (Block 1) and long to short (Block 2) approach provided mixed results in using SSG to develop player's aerobic fitness levels with block 2 showing a significant improvement. The results from these studies is a positive step forward to further understand how progressive SSG block periodisation models may be used to further inform coaches and sport scientists how these periodization frameworks may be successfully applied within the context of team sports. The periodization model used also show how it is possible to integrate technical tactical and physical development concurrently to ensure that the overall synergy of player development is maintained through an in-season training block, which is the ongoing challenges of elite team sport.

5.2 Limitations of the research

The current thesis was conducted utilising a highly-ranked international women's hockey squad. This provided a unique opportunity to gain insight into the physical outputs of high-calibre players during games and training as well as gaining insight into each player's fitness using standardised tests. However, while attempts were made to ensure the research maintained scientific rigour, it is acknowledged that there are occasions when this was not possible when dealing with elite athletes in their high-pressure and controlled training and game environment. The following section highlights the limitations to the thesis that should be considered when interpreting the findings:

1) With the official time of a field hockey game changing from 70 to 60 minutes under the new rule brought in 2015, and the newly implemented 40 sec clock stoppage for penalty corners and goals, this can drastically affect the game length. The official game clock is stopped on a corner, or after a goal, and an independent running clock of forty seconds begins. Once the forty seconds ends, the official game clock resumes. As a result, the quarter lengths can now range from 15 minutes to 24 minutes. The actual game time will depend on the number of corners and goals awarded during the game. For this reason, caution must be used when examining m/min as an indicator of workrate, because changes in m/min may be due to the varying durations in quarter length. To retain validity in study 1, corner and goal clock stoppages were not removed when calculating time on pitch for data collection. As a result, the observed increases in low intensity actions in the new format of the game could have been due to players moving slowly during the clock stoppage which would influence the reported m/min. Taking this into account match and quarter times under the new rules need to be standardised to 60 min and 15min each quarter by taking out these stoppages of play for penalty corner and goals when analysing the GPS data for each player.

2) Previous research has suggested that a large sample size is needed to provide true average action profiles for elite level athletes (Cummins, Orr, O'Connor, & West 2013). Due to the small sample size n = 9 for the first study and n = 12 for the second study, this can be considered a limitation to providing a valid analysis of the presented data. However, as aforementioned this study is one of only a few

on elite level hockey players and although it adds uncontrollable variability due to a variety of opposition, team tactics, injuries, and other environmental factors, it still adds value to the sport science research done in elite hockey.

3) As well as varying total match time, the playing time per player in hockey is not always equal across games and position due to substitutions/player rotations and tactical decisions (Table 3.4). Therefore, due to the fact that all GPS-derived metrics are influenced by playing time this is a noted limitation for study in chapter 3. These differences could skew the data set 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. To partially account for this, players who played less than 35 min (~70% of mean game time) were excluded from the current study data set. There may also be positional differences within the data set that are not accounted for as the data set is made up of 3 strikers 3 midfielders and 3 defenders, which did not allow for positional differences to be analysed due to the small sample size n=3 from each position, but together still adds value to the literature in elite female hockey.

4) The data set used to analyse the effects of the SSG intervention on fitness parameters in chapter 4 may have been affected by testing done after the second 5 week. SSG training intervention had to be done at the start of week 5 instead of once the whole intervention had been completed due to time and travel constraints with the team leaving to compete in a pinnacle tournament post this training block.

5) Unfortunately, there were no control groups in chapter 4. Furthermore, in chapter 4 the players were not at the same fitness levels at the end of Block 1 and at the start of block 2 which can be seen by the differences seen in Table 4.7. This may be due to the athlete's aerobic fitness improving through block 1 but has an effect on being able to compare the which block was superior than the other for improving aerobic fitness of the players involved. A control group would have been beneficial to account for this. Finally, the technical training implemented in both Block 1 and Block 2 may also have interfered with the aerobic and speed adaptations seen as this was not periodized to the extent that the SSG interventions were across both blocks of training.

5.3 Practical applications

Some of the implications, benefits and questions raised by changing the match format from 2 x 35min halves to 4 x 15min quarters and reducing the playing time of the match by 10 minutes is how teams use this rule change to tactically and physically enhance performance during international matches. One such implication of the rule change is that the reduction in playing time may lead to an increase in physical effort when on the pitch as players are not exposed to as higher volumes in international matches and tournaments. This needs further research to explore how the game has evolved since the new rule format was introduced. Furthermore, a reduction in playing time may also increase skill performance as players are now potentially playing with less fatigue (Lythe & Kilding, 2011), which may further alter physical outputs of hockey and the variability of such outputs. However, both the physical and skill performance of the athlete may be affected by the tactical approach of the team involved and how rolling substitutions are used and what systems coaches employ across with various playing positions in hockey.

With this being only the second study to profile the new format of the game, further research with a larger sample size is needed to accurately profile the physical outputs and game demands to continue to inform how athletes are best prepared for the demands of competition. Further research could also look at how teams use player rotations to enhance team performance. Due to the extra breaks at quarter time, defenders who typically may play higher minutes at a lower relative distance than midfielders and strikers (Abbott, 2016), may now be able to increase their playing time, increasing absolute physical output loads.

Furthermore, due to the increased stoppages in the game, teams 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 key players to recover enough to maintain physical outputs without needing an extra substitution. Hence, keeping key players on the pitch longer each quarter, and effectively using 'non starting players', whom may be used to give top players a short break before resuming play, therefore increasing demands on key players throughout a tournament and decreasing the playing time and demands of 'non starting players'. This may enhance the variability of playing time within positions and further research may need to differentiate between starting players and non-starting players when reporting on physical outputs in hockey. This can be seen in Table 3.4.2 where the players involved in the study who were all key players, their playing time increased from 'old' to the 'new' format. This may also help explain the increase in low intensity running seen under the 'new' format as players spend more time in the lower bands to adapt to the increased playing minutes (Table 3.4). This may be due to the players producing more high intensity efforts in the new format of the game, further research is needed to validate this view. This raises further questions about how to manage player loads through a tournament, firstly ensuring key players are not over loaded and able to be effectively recovery and have high outputs at the end of the tournament in key playoff matches, and secondly ensuring non starting players are not under loaded, and lose conditioning and fitness which may impact on tournaments and training post the tournament.

The present study demonstrates that implementing a SSG block periodization intervention, predominately using SSG's as the high intensity stimulus, can improve physical fitness characteristics of elite international hockey players during the in-season in preparation for pinnacle international tournaments. Specifically, the long to short periodization used in Block 2 successfully improved aerobic fitness and speed qualities from pre to post testing. With the improvements and results seen in Block 2 greater than Block 1. These results show that implementing a long to short periodized SSG block periodization using a playing model that develops technical, tactical and physical pillars concurrently can be successful in improving aerobic fitness and speed qualities of team sport athletes. These results may also provide ideas for periodization frameworks for coaches, sport scientists and strength and conditioners working in elite team sport to implement and apply across various sport to see if similar results are found and provide further validity to the results found within this study.

The ability to develop players physical profile throughout the season within a relatively short time period, while optimising training time using a playing model approach where players can develop technical and tactical elements of their games as well as continue to improve physical qualities, makes this SSG and player model approach very appealing to coaches, sport scientists and players alike.

Despite the potential advantages of implementing this sport-specific conditioning approach, coaches, sport scientists and strength and conditioners need to carefully consider that an over reliance on using just this method of training may mask specific weaknesses within a players physical profile, and will require the need to profile and standardise the physical outputs of various SSG's to ensure influential factors such as duration pitch size player number do not lead to under or over train players and avoid the training effects that come with both of these scenarios.

At the elite level where the use of technology such as GPS to quantify the optimal training load and intensities is common, care needs to be taken at the sub elite level where this technology is not used and available to prevent players from over reaching and over training, as players at either end of the athletic ability spectrum are at risk due to the demands of training exceeded the capacity of the players to cope with the training load.

To help provide a solution to this problem, data gathered from this study was used to profile various SSG's to help quantify intensities and load seen with various forms of SSG implemented during both 5 week SSG interventions, which may help coaches at the sub elite level know what type of training load and intensity they might expect from prescribing these different forms of SSG's within their weekly training periodization (Table 5.3). Care needs to be taken when using this data as subjects were highly trained and each week periodised to ensure to optimal loading and recovery was used to elicit the right amount of training stimulus.

At the elite level this information may help the coach and sport scientist choose which form of SSG best elicits high intensity running, max velocities and players work rates that are most reflective of that seen in international hockey and stimulate thought about how best to profile SSG and drill based training interventions within the context of their own high performance programme.

The various physical outputs from the different formats of the SSG’s show that for this population of elite athletes the large pitch 9 v 9 to 11 v 11 SSG’s elicit the high intensity metres typically seen in an international match. 4 v 4 SSG and 11 v 11 full pitch games were effective in eliciting players work rate seen in international hockey with 4 v 4 over a medium sized pitch eliciting the highest average work rate at 129 m/min. However, the overload delivered by games by themselves is also unpredictable and depends upon the structure and rules of the games etc, as seen by the range of high intensity metres and player workrate. Therefore, in the weekly periodization a combination of traditional conditioning methods such as MAS interval running and SSG’s to develop greater MAS and fitness levels may be a more practical and effective way to condition your athletes. Once a field sport athlete has attained an adequate MAS in the specific preparation phase or competitive periods of the season when skill and tactical training takes precedence, then the alternating sets of MAS interval running with SSG’s may be an effective conditioning and sports skill development tool for team sport athletes.

Table 5.3 Recommendations for SSG use to elicit high intensity running and player workloads reflective of international hockey

	RECOMMENDATIONS FOR SMALL SIDED GAME USE TO ELICIT HIGH INTENSITY RUNNING & PLAYER WORKLOADS REFLECTIVE OF INTERNATIONAL HOCKEY												
		PITCH DIMENSIONS	PITCH SIZE Length x Width	SSG DETAILS	REPETITIONS	DURATIONS OF REPETITIONS	REST	HIGH INTENSITY METRES Average Per Game	HIGH INTENSITY METRES RANGE Per Game	HIGH INTENSITY METRES TOTAL/RANGE	PLAYER WORKRATE	PLAYER WORKRATE RANGE	MAX VELOCITY Average Per Game/Range
B1	4 v 4 & 4 v 5	MEDUIM	35 X 55m	4 v 4 with 2 Goals with 1 GK, Rebound Game, so when you score you go back opposite way and retain possession	6	3min	2min Active Doing Basic Skills	11.8	0-71M	70m (21-197m)	112m/min	95-137m/min	18km/hr (15-22km/hr)
B1	3 v 4 & 4 v 4	MEDIUM	35 X 35m	4 v 4 with 2 Goals with 1 GK in circle Rebound Game, so when you score in goal with no GK you go back opposite way and retain possession. Game is played using the full circle then an angle sideline to other goal	8	3min	2min Active Doing Basic Skills	19.3	0-67m	151m (54-222m)	120.5m/min	103-149m/min	19km/hr (15-24km/hr)
B1	9 v 9	LARGE	92 X 55	Full Field 9 v 9 game with 2 Gk's	4	15min	2min Full Recovery	142.3	29-315m	570m (469-794m)	125m/min	106-142m/min	22.1km/hr
B1	4 v 4 & 4 v 5	MEDUIM	35 X 55m	4 v 4 with 2 Goals with 1 GK, Rebound Game, so when you score you go back opposite way and retain possession	7	4min	2min Active Doing Basic Skills	17.1	0-55m	130m (92-224m)	118m/min	113-123m/min	19.1km/hr (17-21km/hr)
B1	7 v 7 & 8 v 8	LARGE	75 X 55m	7 v 7/7 v 6 on 3/4 Pitch with 2 Gk's. Normal Rules	6	5min	2min Full Recovery	38	0-81m	227m (106-357m)	119m/min	110-126m/min	21km/hr (20-21.3km/hr)
B1	4 v 4	MEDIUM	75 x 40-20m	4 Teams 4 v 4 played in 2 channels over 3/4 pitch with 1 goalkeeper. Pitch Size: Angled Pitch over 3/4 pitch 40mto20m Width by 60m length 2 Goal game rebound game with 1 keeper in each game	8	5min	2min Full Recovery	46	0-105m	367m (128-520m)	129m/min	118-139m/min	21km/hr (18-23km/hr)
B1	11 v 11	LARGE	92 X 55	Full Field 11 v 11 game with 2 Gk's against u18 Boys	4	15min	2min for quarters then 10 min Half Time	55		424m (259-592m)	119m/min	110-132m/min	22km/hr (21-24km/hr)
B1	11 v 11	LARGE	92 X 55	Full Field 11 v 11 game with 2 Gk's against Mixed Female & u21 Boys	4	15min	2min for quarters then 10 min Half Time	62		481 (301-754m)	125m/min	119-132m/min	21km/hr (19-24km/hr)
B2	11 v 11	LARGE	92 X 55	Full Field 11 v 11 game with 2 Gk's against Mixed Female & u21 Boys	4	15min	2min for quarters then 10 min Half Time	52		557 (414-615)	129m/min	120-133m/min	22.1km/hr (20-23km/hr)
B2	11 v 11	LARGE	92 X 55	Full Field 11 v 11 game with 2 Gk's against u18 Boys	4	15min	2min for quarters then 10 min Half Time	63		481	125m/min	120-133m/min	21.3km/hr (19-24km/hr)

The high intensity range for this study was set at >110%MAS and with the most recent research showing that the amount of time spent at or above the 100% Maximal Aerobic Speed (MAS) appearing to be the critical factor for improving aerobic power (Baker, 2015), this is another useful tool for coaches and sport scientists to plan for to elicit optimal physical improvements in their players.

To further validate the use of a playing model approach, in addition to the results shown, pre to post testing during Block 1 and 2, there were 8 out of 15 and 6 out of 15 athletes who set personal bests in the MAS testing, which helps to show the link between optimal periodization strategies and performance. Also knowing that the true test of performance is how the team performs during international competition during build up and pinnacle tournaments, following both training blocks the team finished 2nd and 4th respectfully and qualifying a spot at the Rio Olympic games.

5.4 Future research

Future research is required to further develop our understanding of game demands at the elite level and the best training stimuli to enhance player game fitness. To the authors knowledge to date, there is no training studies that have investigated optimal SSG periodization strategies and interventions within hockey which provide practical solutions for coaches, sport scientists and strength and conditioners to consider and implement within their team context. The research within the context of this paper will look to help answer some of these questions and provide further clarity on how SSG periodization may be applied in hockey.

With regards to utilising SSGs as a conditioning tool for the development of physiological, technical skill and tactical proficiency, a number of interesting research questions are evident. Specifically, are larger SSG formats (e.g. 6 vs 6 through 11 v 11) more effectively used in early preseason training, while smaller game formats (e.g. 4 v 4 to 2 vs 2) be used just prior to the competitive season? Secondly, is the overall effectiveness of SSGs training improved when implemented as part of a traditional linear periodization approach or is it better to implement SSGs using a block periodization model approach (Issurin, 2010). In addition, a better understanding and quantification of the physiological demands of technical and tactical training sessions also requires further investigation as this is an important aspect of successful training in team sport athletes. Such sessions add to the overall loading on a player and raises the question of what is ‘missed’ during the technical/tactical sessions in relation to the accumulated training load completed at high intensities, such as during SSGs and other purposeful condition approaches. Once understood, this might enable optimal high-intensity prescription and loading which can be then be planned and periodized into the training week.

Comparing the effectiveness of SSGs and interval running suggest that both are equally effective in their ability to improve aerobic fitness, with future studies examining optimal periodization strategies for using the different types of training methods for developing sport specific physical qualities and validating what conditioning approach is superior to improve actual game performance is warranted.

Future research may further divide the players into positional groups to look further into whether different physical requirements are required according to position. This may identify inter-positional variances such as the defenders being subdivided into centre backs and the outside backs (right and left half), midfielders into centre and attacking midfielders and strikers into centre striker and wide strikers (left and right), which may add to the positional profiling of each team to ensure optimal training strategies are integrating into the player system of the team. This research may lead to coaches and sport scientists emphasizing the importance of individualizing conditioning programs and work on position specific drills to meet the specific demands of the different playing positions (Gabbett, 2010).

Another recommendation is using a greater data collection size looking at match demands using elite men's and women's hockey teams which would allow for a more in-depth sport analysis. To further assist with this analysis the creation of hockey standard velocity zone definitions would allow for between study comparisons and comparisons of varying levels, and ages of athletes. The ability to compare velocity zones between research studies will help inform the development of long-term athlete development pathways which are specific to hockey. This concept was explored using elite women's rugby seven's players and results showed that expressing game movement patterns with an individualised velocity zones and thresholds for high-intensity running allows for accurate quantification of running demands specific to the individual and prescription of effective training and recovery practices. Furthermore, while these individualised velocity bands thresholds are beneficial for the monitoring of individual players, using a mean speed threshold for high-intensity running may provide coaches and sport scientists with a gross understanding of the overall game intensity, as well as differentiate the aerobic fitness of players within a team (Clarke et al., 2015). However, the use of speed zones, whether absolute, relative, or in combination, may mask the intermittent nature of many sports, and underestimate metabolically taxing activities such as abrupt changes in speed (di Prampero et al., 2005), direction (Stevens et al., 2015) or the mode of locomotion (Williford et al., 1998). Furthermore, athletes who performs predominantly in confined spaces, rarely have the opportunity to reach the criterion speeds for high-speed running or sprint zones, yet the energy cost of their maximal accelerations may be 3-fold that of an athlete running at constant speeds (Malone, 2017).

Having a greater data collection within each team over an Olympic cycle, would also allow year to year comparisons to be made, and would also provide a greater sample size to not only compare match to match, but also across tournaments, which may lead to further discoveries about the variances that may exist from tournament to tournament that may influence the physical outputs and used to inform training practices.

In analysing the GPS data, future research should examine the effect of removing the additional time from corners and goals on action profiles, as this will affect players work rate statistics and physical profiling of the various positions within hockey and effective how teams prepare for competition (Abbott, 2016). Furthermore, the sampling rate of GPS units need to be considered as this will provide more accurate data and represent the actual actions produced in a game which provides coaches sport scientist and strength and conditioners more confidence in using the data to inform periodization strategies. Previous research using 1 and 5 Hz GPS units may have underestimated the actions performed by athletes, therefore for future research athlete profiling in hockey need to use up to date technology and be examined with GPS units sampling at 10 or 15 Hz.

5.5 Conclusion

In summary, the aims of this thesis were to 1) quantify the effect of changing the match format in international hockey from 2 x 35 min halves to 4 x 15min quarters, as implemented by the FIH in 2015, on player physical outputs, and 2) determine the effects of two different SSG periodization strategies on aerobic fitness in elite female hockey players. The main findings of this thesis were that difference in physical outputs between game formats occurred mostly at the low to moderate velocity ranges, with an increase in distance spent in these ranges, and the average player work rate decreasing, after the rule change. This practically indicates that athletes were spending more time running at easy or moderate jogging speeds and covering less metres per minute on average, translating to a decrease in work rate after the rule change. Secondly, it was revealed that of the two different periodized SSG training interventions, that the long to short periodization in Block 2, had a positive effect on aerobic system and speed development, suggesting that this strategy can be applied during the competitive season. Collectively, the studies presented in this thesis add to the very limited literature of the effect of rule changes on physical outputs at the elite level, and the effects of SSG periodization in the real-world setting of elite women's hockey and may be used to inform optimal training and programming strategies for highly training hockey players.

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Appendices

Appendix 1: Participant information sheet

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

14 July 2015

Physical outputs of training and match play in elite hockey.

Hi, my name is Brad Conza 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 female hockey, with respect to understanding how the game has changed under the new rules and how effective 2 different Small side games periodization models influence physical outputs in preparing athletes for pinnacle tournament hockey.
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.

What will happen in this research?

You will be required to partake in all Black Sticks Hockey commitments including tournaments and match play (selection dependant), hockey training sessions and strength and conditioning sessions as per the Black Sticks calendar.
As a part of the strength and conditioning sessions, there will be physical monitoring including Maximal aerobic speed testing over a 1600 metre time trial (MAS), maximum sprinting speed testing over 40 metres (MSS), Maximal isometric force testing (Mid thigh pull) & Power Profiling consisting of Pogo's Counter Movement Jump and Static Jump. You will be familiar with all tests as they are a regular part of the Black Sticks sport science program.
At hockey trainings and games (selection dependant) you will be required to wear a GPS unit and a heart rate monitor. You will be familiar with both of these devices as they have in the Black Sticks sport science program since 2012. Training sessions will be run by the coaches and myself and include skills, small sided games, drills, and team conditioning exercises. Training sessions will last between 90-120minutes.
The GPS units we will use are the Catapult Minimax V4 units (Catapult Innovations, Melbourne, Australia) (http://www.catapultsports.com) which is now used by many of the professional sports

teams in the world. The GPS unit is extremely lightweight and fits snugly between your shoulder blades when wearing the Catapult neoprene vest (see Fig 1 below). Your Black Sticks game uniform has a built in pocket for the Catapult GPS unit to fit in and will rest between the shoulder blades. The Heart Rate monitors will be the Polar Heart Rate system and consist of a heart rate strap and a clip on monitor that attaches to the strap. The heart rate straps will be worn around the upper body in line with the bottom of the sternum.

Figure 1. Images of GPS units worn by players during team sports.

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. We will minimise the chance of injury by providing sufficient warm ups prior to all training sessions. There may be slight discomfort with wearing the heart rate monitors and GPS for the first time but you will quickly get used to them and forget you are wearing them. Most top professionals clubs around the world wear similar equipment during their daily training sessions. They don't restrict your movement or hinder the way you play during the training sessions and matches.

What are the benefits from this project?

1. Enhanced knowledge of the demands of hockey, making training more specific to each of positional requirements.

2. Constant GPS monitoring during training will help us tailor and adjust training sessions so that we are not over training and injury risk is lessened.

3. There will be no extra conditioning sessions as part of your hockey program, all conditioning will be done on the hockey turf during normal training times or in the gym for your strength and muscle balance work.

4. Regular testing sessions will monitor your progress as you build up to key competitions.

What compensation is available for injury or negligence?

As per the normal support from High Performance Sport New Zealand, you will have access to accredited physios in a timely manner of any injury, or injury concern. Booking for these appointments will go through the normal channels that are well known and established.

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 (Brad Conza) and the thesis supervisor (Andrew Kilding & Stephen Hill-Haas

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.

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:

Brad Conza, High Performance Sport New Zealand, SPRINZ School of Sport and Recreation, AUT University, brad.conza@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 *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix 2: Consent form

Consent to Participation in Research

Project Title: *Effects of rule changes and training periodization strategies on game physical outputs and fitness in elite female field hockey players*

Project Supervisors: *Assoc Prof Andy Kilding*

Researcher: *Brad Conza*

- I have read and understood the information provided about this research project (Information Sheet dated 14 July, 2015).

  Yes/No

- I have had an opportunity to ask questions and to have them answered.

  Yes/No

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

  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, including journal publications and post-graduate thesis

  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
High Performance Sport New Zealand
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 Date XXXX

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

Auckland University of Technology Ethics Committee
WA505F Level 5 WA Building City Campus
Private Bag 92006 Auckland 1142 Ph: +64-9-921-9999 ext 8316 email ethics@aut.ac.nz