Time-Motion Characteristics and Heart Rate Profiles Displayed by Female University Ice Hockey Players

by

Joel Kent Jackson

A thesis submitted in partial fulfillment of the requirements for the degree of:

Master of Science

Faculty of Physical Education and Recreation

University of Alberta

Abstract

The purpose of this study was to estimate the demands of female Canadian Interuniversity Sport (CIS) ice hockey though the use of time-motion analysis (TMA) and heart rate (HR) measurement during league games. A convenient sample of 22 female ice hockey players (14 forwards and 8 defense) underwent fitness testing and were filmed during 3 CIS league games during which 13 players wore HR monitors. Time-motion analysis of the 3 games indicated that all players spent the majority of game time gliding forward (36.3 ± 6.2 %) and skating forward with moderate intensity (31.2 ± 6.2%). There were significant differences in the frequency and duration of movement patterns between the 3 different games, periods, and 2 positions during even strength play ($p<0.05$). There were also significant differences in the frequency and duration of movement patterns between the 3 different games and 2 positions during even strength play, penalty kills, and power plays (game-play situations) ($p<0.05$). All players displayed peak and mean HRs during shifts of 182 ± 10 and 174 ± 9 beats per minute (bpm), respectively, but there were no significant differences in any HR measures between positions. The shift and game work to rest ratios for all players during even strength play were 1 to 1.6 ± 0.5 and 1 to 3.7 ± 1.0, respectively, but there were no significant differences in either work to rest ratio between the 3 games or the 2 positions. The findings indicate that female CIS ice hockey was characterized by bouts of repeated high intensity effort interspersed with periods of low intensity activity during shifts followed by extended periods of passive recovery between shifts and periods. Forwards and defense displayed significantly different movement patterns during games regardless of the game-play situation. It was also apparent that female players display markedly high HR responses during game-play which was an indication of a substantial cardiovascular demand in the sport.

Acknowledgements

This document is the result of three and half years of work and there are numerous people I would like to thank for their contribution to the completion of my degree. Although it did take me slightly longer than originally anticipated I wouldn't change a thing as I am truly blessed to have been given such an incredible opportunity to study at the University of Alberta.

I would like to start by thanking my advisor Dr. Gordon Bell. I honestly do not know where to start because you have done so much for me. Whether it was a question about my thesis work, or to lend a helping hand with the hockey teams' fitness testing results; your door was always open. During the final stages of finishing this thesis and leading into my defense is when I was able to fully appreciate your attention to detail and the standard that you set with my writing. Not to mention your patience with my ongoing struggle to write scientifically! I am so proud to be able to say that you were my advisor and it is an honour to be your last graduate student. Thank you Gordon.

To the rest of my committee, Vicki Harber and Dan Syrotuik, thank you for your roles in this process. Vicki you are an amazing woman and such an outstanding role model to me. I truly enjoyed having you as a professor and working with you in PEDS 101 and 103. Dan; in the words of a hockey player, you're a beauty. Thank you for your help with everything and for your regular words of encouragement. Also thank you to Pierre Gervais, for taking the time to chair my defense and rounding out the fully retired committee.

Thank you to the Golden Bears and Pandas varsity hockey programs, for giving me the opportunity to work with you as the strength and conditioning coach. Taking on this role, while trying to complete my thesis was a challenge, but it has been so rewarding. Coaches Ian Herbers and Howie Draper, I truly appreciate the support and respect you have shown me and continue to show me with my ongoing role with the teams. Being able to identify with the success that is instilled in both teams culture is something I do with great pride.

To Jessie Gill; thank you for taking time from your studies and helping to establish inter-rater reliability for this study. Also thank you to Alex Game for allowing me to work out of his lab space, as well as providing me with the use of training equipment for my work with the hockey teams.

To my beautiful wife Alysha; thank you for sticking by my side throughout my academic career and loving me unconditionally. During my undergraduate degree in Augustana, I was fortunate enough to meet you and downright lucky to find a girl who would put up with me as a student athlete. You do so much for me and ask for so little in return. I love you more than words could ever say and cannot wait to see what the future brings us.

Finally I want to thank my family and friends. Mom and Dad it goes without saying that you are the reason I am here. Your financial and moral support has been there in every journey I have taken so far in life and one thing I will never get tired of hearing is that you are proud of me. Always know that I am equally as proud to have you as my parents. To Jessica thank you for being everything I could ask for in a little sister and supporting me in my journey as a student. Ian and Nicole I want to thank you for supporting me throughout my whole life and I hope that we end up living closer to each other in the future, I love you both dearly. To my many friends that I have met along the way, no matter how big or small of a role you have played in my life; know that you mean the world to me and I wouldn't have made it this far without your support.

Table of Contents

Chapter 1: Introduction

1.1 Introduction 1

1.2 Purpose and Hypothesis 4

1.3 Significance 6

1.4 Delimitations 6

1.5 Limitations 7

Chapter 2: Review of Literature

2.1 A Brief History of Ice Hockey 9

2.2 Methods in Time-Motion Analysis 11

Available Methods 11

Camera Placement 13

Video Analysis Software 14

Automated Time-Motion Analysis Systems 15

2.3 Validity in Time-Motion Analysis 19

Determination of Movement Categories 19

Work to Rest Ratios 21

Issues in Representativeness 22

2.4 Reliability in Time-Motion Analysis 24

2.5 Time-Motion Analysis in Ice Hockey 26

2.6 Heart Rate Analysis in Ice Hockey 31

Chapter 3: Time-Motion Characteristics and Heart Rate Profiles Displayed by Female University Ice Hockey Players

3.1 General Introduction 33

3.2 Methods 35

Participants and Experimental Design 35

Aerobic Fitness Testing 36

Game Selection and Heart Rate Measurement 37

Camera Setup and Locations 38

Time-Motion Analysis 38

Definition of Movement Categories 39

Definition of Work to Rest Ratios 41
Reliability of Video Analysis 42
Statistical Analysis 42
3.3 Results 43
Participant Characteristics 43
General Game Characteristics 44
Time-Motion Analysis 44
Percentage of game time spent in different movement categories. 44
Comparison of the frequency of movement categories between games, periods and positions during even strength play. 45
Comparison of the duration of movement categories between games, periods and positions during even strength play. 49
Comparison of the frequency of movement categories between games, game-play situations and positions. 52
Comparison of the duration of movement categories between games, game-play situations and positions. 56
Heart Rate Analysis 59
Comparison of the heart rate response to even strength play between games, periods and positions. 59
Comparison of heart rate responses between games, gameplay situations and positions. 60
Work to Rest Ratios 61
3.4 Discussion 62
Time-Motion Analysis 63
Percentage of game time 63
Frequency and duration of movement categories during even strength play 64
Frequency and duration of movement categories during game-play situations 65
Heart Rate Responses 66
Heart rate response to even strength play 66
Heart rate response to game-play situations 68
Work to Rest Ratios 69

Limitations 72
Summary and Conclusions 73
Practical Applications 74
Future Directions 77
References 79-93
Appendix A 94
Appendix B 95
Appendix C 96
Appendix D 97
Appendix E 98
Appendix F 99

List of Tables

Table 1. 44

Table 2. 45

Table 3. 48

Table 4. 51

Table 5. 55

Table 6. 58

Table 7. 60

Table 8. 60

Table 9. 61

Table 10. 62

Table 1A. 94

Table 1B. 95

Table 1C. 96

Table 1D. 97

Table 1E. 98

Table 1F. 99

Chapter 1

Introduction

1.1 Introduction

Intermittent team sports involve a unique set of physiological demands which are determined by a number of factors including: duration of the match, the variable level of exertion required during play, the amount of rest between those exertions, the amount of rest between divisions of the game (periods, quarters, sets, etc.), and the position of the player (Bracko, Fellingham, Hall, Fisher, & Cryer, 1998; D'Auria & Gabbett, 2008; Duthie, Pyne, & Hooper, 2005; Lythe & Kilding, 2011). In order to objectively measure and assess the physical demands of a team sport, researchers often use time-motion analysis (TMA). Early studies used the subjective method of notational analysis and rarely reported any type of observer reliability (Green, Bishop, Houston, McKillop, Norman, & Stothart, 1976; Sanderson & Way, 1977; Seliger, 1972). However, TMA has evolved over the years and has become technically advanced and more accurate. Two of the more sophisticated and reliable TMA measures commonly used now are video-based analysis and global positioning system (GPS) analysis, (Dobson & Keogh, 2007; Roberts, Trewartha, & Stokes, 2006) but GPS has been difficult to apply to sports played indoors such as ice hockey.

The literature using TMA in the sport of ice hockey has been limited (Green et al., 1976; Leger, 1980; Romet, Goode, Watt, Allen, Schonberg, & Duffin, 1978; Thoden & Jette, 1975). Green et al. (1976) can be considered the most thorough assessment of ice hockey in regards to time-motion characteristics and physiological demands. In male, varsity hockey players they found that time on ice for forwards and defense was 20.7 and 28 minutes and number of shifts per game was 14 and 21, respectively. The average shift time for all players was 85.4 seconds and significantly elevated heart rates were observed (Green et al., 1976). A concern with this latter study and other previous research (Seliger et al., 1972; Thoden & Jette, 1975) is that it was conducted more than 30 years ago. Since that time various rules and physical attributes of players have dramatically changed (Montgomery, 2006; Quinney et al., 2008). There has also been many technological advancements in time-motion and heart rate (HR) assessment during this time (Barris & Button, 2008; Strath et al., 2000). Most importantly it appears there has been no published TMA research done on female ice hockey. Therefore, the time-motion characteristics of female hockey have not been examined.

In conjunction with TMA, often various physiological measurements are made during competition in an attempt to quantify the demands of a sport. This can be done using a number of different measures, some of which may include HR, expired metabolic gas analysis, sweat rate and composition, rating of perceived exertion (RPE), blood pressure, and a number of blood analyses such as lactate concentration (Matthew & Delextrat, 2009; Palmer, Logan & Spriet, 2010; Seliger et al., 1972; Virr, Game, Bell, & Syrotuik; 2013). These may reflect the intensity of the effort, but also the psychological responses such as the stress associated with competition. The classification and number of these types of measurements vary and can be associated with the different activities performed by players during ice hockey games. This provides valuable information about a variety of factors associated with the individual athlete and the various challenges of the game. The application of this type of information also has the potential to influence coaching methods during practises and games and the nature of supplementary conditioning programs implemented off and on the ice (Dobson & Keogh, 2007; Duthie, Pyne, & Hooper, 2005).

There have been a number of studies that have combined TMA with physiological responses using HR measurements of players during a variety of intermittent sports including ice hockey, soccer, field hockey, rugby, basketball, and numerous racquet sports. Lythe and Kilding (2011) found that field hockey players' mean HR during match-play was ~85% of maximum heart rate (HR max), with 90% of the game being played above 75% of HR max and 60% of the game played above 85% of HR max. In a similar study with female basketball players, Matthew and Delextrat (2009) found that mean HR recorded during game play corresponded to ~89% of HR max. Green et al. (1976) found that HR ranged from 87-92% of HR max in men and Spiering et al. (2003) reported working HRs equivalent to 90% of HR max in females during ice hockey games. Thus, the elevated mean HR responses found in various intermittent sports, including ice hockey indicates a substantial involvement of the cardiovascular system in these types of sports that are often considered to be predominantly anaerobic in nature (Baechle & Earle, 2008; Lythe & Kilding, 2011; Matthew & Delextrat, 2009). However, as previously mentioned, it is difficult to determine the contribution of competition stress to these elevated HR's. Regardless of the exact cause of the elevated HR, the application of these findings would suggest that there is also a need for a well-developed cardiovascular fitness component in intermittent team sports.

Research that combines TMA and physiological measurements allows the different dynamic movements involved in hockey to be categorized and matched to the physiological demand (Green et al., 1976; Matthew & Delextrat, 2009). Another important aspect of this has been the ability to elucidate the work to rest ratios during actual game play (Dobson & Keogh, 2007). These types of ratios would have direct application to the conditioning of players and there has been little research on this in the sport of ice hockey. Furthermore, several unique aspects about the way in which ice hockey games are played can also be examined using TMA.

For example, an important part of ice hockey games is how players perform during power plays (5 on 4) and penalty killing (4 on 5). Time-motion analysis and even HR data collected during these aspects of the game would be novel and have not been reported.

Finally, the popularity of female hockey has steadily increased over the last 20 years and this trend is expected to continue. In the 2009-10 hockey season there were 85,624 registered female hockey players in Canada compared to 8,146 during the 1990-91 season (*Statistics & History*, n.d., ¶ 4). These statistics support the need for research involving female players and a report of the frequency and time spent performing game activities as well as the physiological demand of the game would make an important contribution to the literature.

1.2 Purpose and Hypothesis

The purpose of this study was to investigate the frequency and time spent performing the types of movement patterns in female Canadian Interuniversity Sport (CIS) ice hockey during league games. Part of the physiological demand of competition was assessed by measuring HR responses during actual games. The research questions were focussed on whether there were any differences in the TMA categories and HR responses between:

- Defense and forward positions for each period and each game;
- Even strength, power play, and penalty kill;
- Shift work to rest ratio and game work to rest ratio.

It was hypothesized that:

1. There will be a significant difference between defense and forwards in the frequency and duration of movement patterns during even strength play.

- The frequency and duration of movement patterns will not be significantly different between the three games examined.
- The defense will display a significantly higher frequency and duration of all backwards skating movement categories compared to the forwards.
- The forwards will display a significantly higher frequency and duration of high intensity forward skating compared to the defense.
- The frequency and duration of movement patterns will be significantly different between the three periods of the game.
- The forwards will display a significantly higher HR response than the defense, but there will be no significant difference between periods or games.

2. Defense and forwards will display significantly different frequency of movement patterns, duration of movement patterns, and mean HR responses during game-play situations (even strength, power play, and penalty kill).
   - There will be significantly more stationary/low intensity activity during power play and penalty kill compared to even strength in both forwards and defense.
   - There will not be a significant difference in any of these variables between games.
   - All players will display significantly higher mean HR responses during even strength compared to power play and penalty kill and forwards will display higher HR responses than defense in all conditions.
3. Defense and forwards will display significantly different work to rest ratios during a shift and during a game.
   - There will not be a significant difference in either shift or game work to rest ratios between the 3 different games.

- There will be a significantly lower shift work to rest ratio during power play and penalty kill compared to even strength, but the game work to rest ratio will be significantly higher during power play and penalty kill compared to even strength.

1.3 Significance

It has been suggested that TMA can provide empirical evidence of the physical demand of team sports through the quantification of movement patterns in terms of their type, direction, duration, speed, and distance covered (Dobson & Keogh, 2007). This type of information should allow for more effective strength and conditioning programs to better prepare athletes for the specific requirements of their particular sport (Dobson & Keogh, 2007). Applying this research method to the sport of ice hockey will provide strength and conditioning personnel with valuable information to consider when planning a players training year. It may also help to establish more consistency in the literature regarding hockey, especially with average shift times which have been reported to be anywhere from 30 seconds to >60 seconds (Thoden & Jette, 1975; Twist & Rhodes, 1993) as well as assess any changes in how the game is currently played.

Spiering et al. (2003) conducted a study on female hockey players and showed that mean working HR was ~90% HR max during games and ~76% HR max during practices. Green et al. (1976) also found that the mean HR response in male hockey players during a shift was approximately 89% of HR max. It was expected that similar game HR's would be recorded in this study which will further help to establish the importance that the aerobic energy system has in hockey.

1.4 Delimitations

For this study TMA and HR data were only analysed for defense and forwards; goaltenders were excluded from the analysis. The demands of the game for a goaltender have been shown to differ from a skater (Richard, Gionet, & Nowlan, 1995) and the frequency and type of movement activities of goaltenders have been recently reported (Bell, Snydmiller, & Game, 2008) although any differences between how men and women goaltend in ice hockey has not been established.

The participants in this study were female hockey players on the University teams' 2011-2012 active roster and may not be representative of all female University players. The games chosen for this study were three regular season matches against teams in which the head coach identified as strong opponents. This decision was based on the desire to capture the most competitive games for analysis. Time-motion analysis was performed on all forwards and defense that played in the video recorded games; however, HR data was only analysed from the players that agreed to wear HR monitors. All games were video recorded with a digital camera (GoPro® Hero) and complete analysis of the video files was done using Dartfish computer software. Video-based TMA was chosen because it is the most practical choice for indoor sports such as ice hockey and the expense associated with an indoor GPS system was beyond the scope and budget for this study. It has also been reported that GPS-based TMA has reliability and sample rate limitations, as well as inability to track high-speed sports involving body contact and rapid changes of direction (Dobson & Keogh, 2007).

1.5 Limitations

Participants were a convenient sample of volunteers from the female University hockey team and no random selection was used. Therefore, the results from this study may not be completely generalized to other CIS hockey teams or other levels and age groups of female hockey. This also limits the sample size for this study.

All participants were experienced hockey players; however this cannot eliminate the effect of anxiety prior to and during competition. The psychological factors that are part of competitive sports can influence HR responses therefore; elevated HR's during a game may not always be solely representative of the player's physical activity. It also has to be assumed that the highest HR retrieved from each player's maximal oxygen uptake (VO_2max) test represents their true HR max.

Chapter 2

Review of Literature

2.1 A Brief History of Ice Hockey

The game of ice hockey is believed to have originated from a variety of European stick and ball games including shinty, bandy, and hurley. Although it is generally agreed upon that bandy is the game that is most like ice hockey, it is relatively unclear how the game evolved since the 13th century. However, G. Creighton is generally credited with organizing the first hockey game at McGill University on March 3rd, 1875 (Marsh, n.d., ¶ 2-3). Following this game, the University formed the first organized team in 1879; the McGill University Hockey Club. Thereafter, the sport gained popularity across Canada (Marsh, n.d., ¶ 4). According to the International Ice Hockey Federation there were 1,602,876 registered hockey players in the world in 2012, a number that continues to increase every year (Merk, 2012, ¶ 1). As well, professional hockey has also gained in popularity with the average NHL franchise being worth $282 million dollars during the 2011-2012 season (Ozanian, 2012, ¶ 5).

Female hockey originated in Ottawa, Ontario where the first documented game was played between the Rideau Skating Club and the Government House in 1889 (Harrington, 2013, ¶ 6). Subsequently, female hockey started gaining popularity across Canada. The first female hockey club was established at Queen's University in 1895, who were also part of the first female university league in the 1920's along with teams from Alberta, Quebec, and other parts of Ontario (Harrington, 2013, ¶ 10,14). The popularity of female hockey declined in the early 1940's, likely due to the end of the Great Depression and the onset of World War 2. The 1960's brought a surge in the prominence of female hockey and a number of teams and leagues throughout the country began to re-emerge (Harrington, 2013, ¶ 18). Finally, in 1990 the sport became fully recognized worldwide with the first International Ice Hockey Federation Women's World Hockey Championships being held in Ottawa.

There has been much research done in the sport of ice hockey looking at different physical measures and how well they correlate with success in the sport including how anthropometrical measurements, birthdate, and a variety of off-ice fitness indicators predict skating performance, draft selection, and transition into the NHL (Burr, Jamnik, Dogra, & Gledhill, 2007; Green, Pivarnik, Carrier, & Womack, 2006; Potteiger, Smith, Maier, & Foster, 2010; Sherar, Baxter-Jones, Faulkner, & Russell, 2007; Tarter et al., 2009; Vescovi, Murray, Fiala, & VanHeest, 2006). From a biomechanical perspective, researchers have studied hip function during skating as well as optimal skating economy and how it differs between level of play and different skating surfaces (Chang, Turcotte, & Pearsall, 2009; Nobes et al., 2003; Stull, Philippon, & LaPrade, 2011; Upjohn, Turcotte, Pearsall, & Loh, 2008). There has also been research, on player assessment; injury occurrence and prevention; and a variety of physiological responses (e.g. heart rate) to the game (Game & Bell, 2006; Green et al., 2010; Nadeau, Richard, & Godbout, 2008; Noonan, 2010; Palmer, Logan, & Spriet, 2010; Stevens, Lassonde, de Beaumont, & Keenan, 2008). Despite the relatively large number of sport science studies done on individual ice hockey players, there remains a lack of research in the analysis of movement patterns such as that done with TMA. Also note that the majority of the existing work was published more than 30 years ago (Green et al., 1976; Leger, 1980; Seliger et al., 1972; Thoden & Jette, 1975). Along with the numerous rule changes and increased size and condition of players over the last three decades it is clear that the time-motion characteristics of the game need to be re-evaluated (Quinney et al., 2008). Furthermore, much less research has been done on female ice hockey in comparison to males.

2.2 Methods in Time-Motion Analysis

Available Methods

Time-motion analysis is a tool that allows researchers to determine the frequency, time and sometimes the distance covered during various activities performed in a sport (Rudkin & O'Donoghue, 2008). Through the use of TMA an athlete's movements can be counted and timed. Typically there will be a number of movement categories that are specific to the sport being studied and these can be assessed from videotape of games or through the use of global positioning systems (GPS) that allow for the measurement of speed, distances, frequencies, and/or durations of each predetermined category. Time-motion analysis has a number of advantages and disadvantages in terms of sophistication, accuracy, and reliability as well as practicality (Dobson & Keogh, 2007). However, TMA has benefited from the many technological advancements in various software packages used for analysis.

Dobson and Keogh (2007) identified the two primary methods of TMA in sport as video based analysis and GPS analysis. These two methods are arguably the most commonly used, but Barris and Button (2008) further divide the TMA methods into manual vision-based tracking systems, automated vision-based tracking systems, and commercially available vision-based tracking systems. Most TMA systems for research and coaching use either a manual or automated operating system. For the purposes of this literature review, TMA methods will be categorized into manual systems and automated systems. Manual systems will include anything that requires subjective monitoring and automated systems will include anything that does not require the researcher to continually track and subjectively record the athletes' movement (Barris & Button, 2008). It should also be mentioned that automated tracking systems require different degrees of operator intervention and it does not appear that there is a fully automated system available at this time (Barris & Button, 2008).

Manual TMA systems depend upon some sort of notational method which requires the researcher to monitor athlete activity to acquire information regarding type, frequency, and duration of different movements specific to the sport (Barris & Button, 2008; Roberts, Trewartha, & Stokes, 2006). Early notational methods involved the researcher simply viewing the athlete(s) competing while taking written notes and many of these methods originated in racket sports and soccer (Barris & Button, 2008; Hughes, Hughes, & Behan, 2007). For example, Sanderson and Way (1977) developed a notational system for squash that recorded 17 different strokes as well as winning shots, forced errors and unforced errors. The unique aspect of this system at the time was that shorthand symbols were used instead of word-initials and they recorded each movement category on separate court plans. Although simple, it was an improvement from the accuracy and time efficiency of previous systems (Sanderson & Way, 1977).

Two of the earliest studies to apply TMA methods to the sport of ice hockey were by Seliger et al. (1972) and Green et al. (1976). This early study by Seliger and colleagues (1972) was conducted in the Czech Republic and the language used by the authors makes it difficult to decipher the method they used for TMA. It appears that a graphical method was used to measure the distances covered by players and the intensity of their movements was estimated by the training staff (Seliger et al., 1972). The full detail of how this was conducted was not explained making it a shortfall of the study. Green and colleagues (1976) used a combination of videotape and direct observation to conduct TMA on university hockey players. This latter analysis reported basic durations of playing time, shift time, active time on-ice, inactive time on-ice, and recovery time between shifts. They also reported number of shifts, play stoppages per shift and average velocity per shift. The time-motion measures in this study were basic, but it was one of the first to utilize video recording for TMA purposes. At this time it allowed the researchers to carry out some of the analysis post competition instead of only taking direct observations during live play.

Camera Placement

Modern video analysis systems used for TMA of sport have used anywhere from 1 to ~7 cameras to track player movements (Dobson & Keogh, 2007). The number of cameras used has been suggested to be dependent on the sport, the number of players involved, the size of the playing surface, and the desired detail sought by the observer (Dobson & Keogh, 2007). D'Auria and Gabbett (2008) investigated women's water polo match play using two cameras and randomly chose seventeen matches from an international tournament and two players from each match to be analyzed. The individual players selected were the primary focus for filming and were followed for the entire match, including bench time and timeouts (D'Auria & Gabbett, 2008). Dobson and Keogh (2007) labelled this method of video analysis as one of the more popular approaches as it provides observers with a close-up view of the player; therefore increasing the accuracy when coding their movement.

A different video analyzing method was used by Matthew and Delextrat (2009) in which only one, immobile camera which was placed to the side of the court, at the middle line, and elevated to a height that would allow for recording of the full playing surface during a basketball game. This method allows for all players to be viewed and analyzed from the same video recording. Dobson and Keogh (2007) found that another advantage to this method over following individual players was that it was much less time consuming to film and analyze. In a stationary view the researcher can also use reference points (boundary and dividing lines of the playing surface), which enhance the ability to judge athletes' speed, something that is a disadvantage of a close-up view.

Video Analysis Software

Currently there are a number of software programs available that allow for a time efficient means to analyze players' movement from video recordings. Some of these video analysis systems include Dartfish (Fribourg, Switzerland), Game Breaker (Sportstec, Australia), and Digital Soccer (Italy) (Barris & Button, 2008). The Dartfish software requires the operator to code predetermined movement patterns into the program by representing them with different key strokes. The observer can then watch the video recording while coding players' movements which are automatically stored in a spreadsheet format for further analysis. For example, Forbes, Kennedy and Bell (2013) used Dartfish to analyze the movement patterns of canoe polo athletes. The Dartfish software allowed the observer to code individual movements of all eight canoe polo team members during each game and the software determines the time spent in each movement category. As a part of a follow-up analysis, other measurements including time spent engaging in offensive and defensive play among other variables can be derived (Forbes, Kennedy, & Bell, 2013). The aforementioned other software programs such as Game Breaker (Sportstec, Australia) allow for similar analyses.

Automated Time-Motion Analysis Systems

Automated TMA has been applied to a number of other domains besides sport performance such as police/military surveillance, medical diagnostics, and video conferencing (Aggarwal & Cai, 1999; Barris & Button, 2008). However, Barris and Button (2008) point out that automated motion tracking systems have been more successful outside of sport because in many situations precise spatio-temporal tracking and identification of the tracked objects is unnecessary. Regardless, there are a number of advantages and limitations associated with automated TMA systems and the effectiveness of these systems has been highly dependent on the sport being analyzed (Barris & Button, 2008; Dobson & Keogh, 2007). Automated TMA systems rely on different methods of computer vision technology for examining both indoor and outdoor sports (Barris & Button, 2008). Typically these systems will use a series of fixed cameras which are expertly calibrated using the relations between pixel coordinates (within each recorded image) and coordinates of the playing area (Perš & Kovačič, 2000). The actual tracking of the players and other objects (ball, puck, etc.) involved in the sport has been done through the use of a tracking algorithm or a combination of tracking algorithms (Perš & Kovačič, 2000).

The use of GPS allows for the tracking of athletes in a number of outdoor sports, but Australian rules football, soccer, rugby union, and rugby league make up the majority of the literature (Dobson & Keogh, 2007; Edgecomb & Norton, 2006; Vescovi, 2012). The use of GPS in sport first started as a training tool for some endurance athletes such as long distance cyclists and runners (Dobson & Keogh, 2007). Sports such as these are ideal for the use of GPS technology because it is most accurate when measuring movement that is linear, composed of few directional changes, and involves minimal interruption of the athlete's motion (contact with other athlete's or objects) (Dobson & Keogh, 2007). However, there are numerous issues that arise when using GPS technology.

Prior to some recent technological advancements, sampling rate was a limiting factor in GPS tracking in team sports. A GPS's sampling rate is the speed at which it collects data and is measured in hertz (Hz). The GPS units on today's market are available with 1-, 5-, and 10-Hz sampling rates with the higher number providing more accurate measurements (Cummins et al., 2013). At the time of the Dobson and Keogh (2007) review regarding methodological concerns in the TMA research, the highest available sample rate for GPS was 1-Hz, reducing the accuracy of any research using this rate. Cummins and colleagues (2013) reported that 1-Hz GPS units are incapable of measuring any movements that take less than one second to perform, which is very concerning for movements in many sports. A sampling rate of 10-Hz is now available and offers the greatest accuracy as established by Cummins et al. (2013).

It should also be mentioned that GPS tracking does not work well in large stadiums that enclose the playing surface with high stands or partially enclosed bowl seating. Other problems include stadiums in heavily developed areas, indoor facilities or any other places that would restrict satellite access (Cummins et al., 2013; Dobson & Keogh, 2007). Indoor GPS tracking has been attempted and there have been some recent advances in its usability, however it is expensive and not widely reported as yet (Cummins et al., 2013). Another disadvantage to using GPS to monitor athletes is that they have to wear a tracking device on their person while competing. The device is roughly the size of a cellular phone and is usually placed between the athlete's shoulder blades. Even though the investigators do their best to keep the athlete(s) comfortable while still protecting the device, there remains the possibility that it will distract them and/or get damaged during play (Cummins et al., 2013; Dobson & Keogh, 2007).

Even with the consistent developments in automated TMA systems there are still a number of limitations (Barris & Button, 2008; Perš & Kovačič, 2000; Perš, Bon, & Kovačič, 2001). A primary issue stems from the complicated movement patterns displayed in team sports which surpass the limits of many automated tracking systems. Sports such as ice hockey, field hockey, and basketball require a significant amount of speed and agility and involve unpredictable changes in direction and player collisions. This poses a problem because tracking algorithms along with other aspects of computer vision technology have been based on smooth, uninterrupted movements (Barris & Button, 2008; Perš & Kovačič, 2000). For this reason there are few tracking systems that are completely automated and none that are without limitations in tracking players involved in certain sports; therefore, all TMA analysis systems involve some degree of observer intervention (Barris & Button, 2008).

Perš, Bon, and Kovačič (2001) summarized the main sources of error in automated tracking systems as movement of player extremities, VCR tape noise and compression artifacts, quantization error, imperfect camera calibration, and operator error. The problem of VCR tape noise and compression artifacts has been eliminated with the use of high definition digital video cameras. However, the remaining sources of error are still potential problems for automated TMA systems in current research (Barris & Button, 2008). An advantage of automated TMA systems is their accuracy for measuring distance covered and velocity of athlete's (Dobson & Keogh, 2007; Roberts, Trewartha, & Stokes, 2006). The reason for this is that automated TMA systems eliminate the subjective aspect of analysis unlike notational systems.

Roberts, Trewartha, and Stokes (2006) directly compared a digitized system to a manual notational system. The researchers analyzed 2 English premiership rugby matches using the two different TMA methods (Roberts, Trewartha, & Stokes, 2006). The players' movements were divided into seven different categories which were the same for both the digitizing and notational methods. The digitized method defined each of the six gait patterns as a specific speed range (ie. Jogging = 1.7 to 3.6 m/s). The notational method involved an experienced observer coding player movements using a software program similar to Dartfish (Roberts, Trewartha, & Stokes, 2006). The digitized method used an image based tracking system that required sophisticated camera calibration and a global 2-dimensional Cartesian coordinate system. This allowed for player speed to be averaged over one second increments throughout the entire match providing an accurate assessment of players' velocities and distance covered. The notational method simply used the time spent in each movement category and multiplied it by the pre-determined average speed for each respective movement in order to calculate distance. Although this gives a rough indication of distance covered during the match, it was much less accurate than the digitized method (Roberts, Trewartha, & Stokes, 2006). It should also be mentioned that the digitized method was not automated and was more time consuming than the notational method, improving accuracy but was less practical.

Despite its inaccuracy Roberts, Trewartha, and Stokes (2006) still found value in the notational method. They pointed out that the digitized method strictly used the players' velocity to categorize them into the appropriate movement category. Therefore, acceleration and deceleration were not taken into account during the digitized method which underestimates the time spent in maximal effort. This offers value to notational methods because their subjective aspect becomes important when judging a players effort level (Roberts, Trewartha, & Stokes, 2006). Accurate measurement of time spent in high intensity movement categories is very important because it will have the greatest impact on strength and conditioning methods (Roberts, Trewartha, & Stokes, 2006; Taylor, 2003).

2.3 Validity in Time-Motion Analysis

Determination of Movement Categories

Dobson and Keogh (2007) identified several areas of concern for validity in TMA studies such as the determination of movement categories, method of distance measurement, representativeness issues, and work to rest ratios. Method of distance measurement, although a legitimate concern, does not apply to the current proposed thesis study as it will not be measured. Determination of movement categories becomes an issue when researchers identify movements and gait patterns typical of a given sport and assign them with appropriate terms. This is evident when you see researchers analyzing the same sport, but defining their dominant movements somewhat differently (D'Auria & Gabbett, 2008; Lupo, et al., 2013). However, there has been some agreement for the selection of 3 to 5 gait patterns involved in team sports that involve running and include standing (stationary), walking, jogging, running, and sprinting (Dobson & Keogh, 2007). Some researchers will argue that standing and walking can be one category as well as jogging and running, because the activities have similar metabolic costs (Dobson & Keogh, 2007; McInnes, Carlson, Jones, & McKenna, 1995) but these could be at quite different intensities. The agreement of these movement categories is important for TMA research, but they do not apply to sports that require other means of locomotion such as water polo, wheelchair basketball, and ice hockey.

There are also numerous movements that are unique to their respective sports such as rugby where players utilize a number of specific movement patterns during competition (Cummins et al., 2013; Docherty, Wenger, & Neary, 1988). Duthie, Pyne, and Hooper (2005) analyzed the frequency, total time, and mean duration of nine different movement categories in rugby in addition to the five universal categories mentioned previously. These were static exertion (scrums, rucks, and mauls), jumps, lifts, and tackles and were specific to the sport of rugby (Duthie, Pyne, & Hooper, 2005). Other sports that involve a considerable amount of "struggling" including body contact need to acknowledge these when analyzing the demands of competition. Canoe polo and water polo are two team sports that have identified struggling including body contact as a high intensity activity in TMA research (D'Auria & Gabbett 2008; Forbes, Kennedy, & Bell, 2013). Ice hockey also involves a significant amount of struggling activities between players whether it be body checking; 1 vs. 1 battling for position or puck possession; or in some leagues, fighting. Bracko and colleagues (1998) reported time spent in body contact situations during a hockey game and found that players spent 10.4% of the total time struggling for the puck or position. The proper identification and recording of these movements in team sport is important because they are considered high intensity and therefore, have implications for strength and conditioning programs (Duthie, Pyne, & Hooper, 2005).

To determine the relevant movement categories in a particular sport, it is important to involve experienced researchers and coaches who would be considered experts on that particular sport or activity in question (Bloxham, Bell, Bhambhani, & Steadward, 2001; Dobson & Keogh, 2007). There should also be a strong correlation between the intensity that each movement category is labelled with and their respective physiological responses (Taylor, 2003). For this reason, studies that combine TMA and physiological measurements such as HR response and/or blood lactate analysis provide a more complete understanding of the demands of the activity (Hill-Haas, Dawson, Coutts, & Rowsell, 2009; Taylor, 2003). Bracko and colleagues (1998) conducted a pilot study where they attempted to observe 54 different movement categories that included many individual skating skills in professional hockey players which were then reduced to 27 for the full study. These skills and movements were determined after a review of literature and then refined based on their occurrence in the pilot study of the latter researchers. Thus, it is important to validate the various movement patterns within a particular sport which forms the foundation for TMA.

Work to Rest Ratios

The intensity of each movement characteristic also becomes important when determining the work to rest ratios for a particular sport. This refers to the ratio of time spent in activity to the time spent in inactivity, recovery or even stoppages in play. In most cases it is clear which activities can be classified high intensity (work) and low intensity (rest), but the process of measuring these ratios is still considered subjective (Dobson & Keogh, 2007). Rhea, Hunter and Hunter (2006) analyzed high school, collegiate, and professional American football games and defined the work periods as the time from when ball was snapped to when the whistle sounded to end the play. The rest periods were defined as the time from when the whistle sounded ending a play until the ball was snapped for the next play (Rhea, Hunter, & Hunter, 2006). In this case, segments within the game were used for the ratio, where other studies have specifically observed players movements during active playing time in order to assess work to rest intervals (Bloomfield, Polman, & O'Donoghue, 2007). Determining a work to rest ratio from the active and inactive periods during playing time is specific to the games demands and is arguably more applicable to a sport's conditioning than the type of work to rest ratio in the Rhea, Hunter, and Hunter (2006) study.

Rudkin and O'Donoghue (2008) separated the high intensity and low intensity movements of first-class cricket fielders to determine a work to rest ratio. Their work periods consisted of shuffling, running, and high intensity fielding and rest periods were standing, walking, jogging, and low intensity fielding (Rudkin & O'Donoghue, 2008). The researcher's involved decide how sophisticated the work to rest measurements will be, but it is important that the physiological demand of the activities labelled as work, and rest are appropriate in order for the data to be applicable to conditioning programs (Dobson & Keogh, 2007).

There has been minimal investigation of competition work to rest ratios in the sport of ice hockey. Green and colleagues (1976) measured actual playing time, stop time during shifts, and the recovery/bench time between shifts during a men's university hockey game. However, there was no attempt to establish an actual work to rest ratio from the data presented. Seliger and colleagues (1972) reported time-motion characteristics from what they referred to as a model training match. The details of this training match are vague, but they reported a working time of 1.17 minutes and a recovery period of 21.00 minutes. These times cannot be compared to an actual game and are limited in application to hockey. A more current and accurate assessment of work to rest ratios for hockey players needs to be established.

Issues in Representativeness

Issues in TMA research such as number of participants, number of games, positional differences, environment and level of play being analyzed can influence how representative the analysis is of the actual activities performed in a particular sport (Dobson & Keogh, 2007). The main concern when investigating the time-motion characteristics of team sport is that no one game is exactly the same and as a result small sample sizes or a lack of competitiveness (pre-season or exhibition games) can misrepresent performance in actual competitive (e.g. league) games (Dobson & Keogh, 2007). Other factors that determine how a team approaches a game include lineup changes due to injuries; strengths and weaknesses of the opposing team; whether the game is home or away; timing of the game within a season; coaching strategy and the significance of the game. All of these factors can alter the way in which a game is played and how the coaching staff and players prepare for each game. Therefore, a large sample size and several observations should limit the influence of these factors and increase the representativeness of the data collected. However, the process involved in extracting time-motion data from games is often very time consuming making it difficult to observe a large number of games with an adequate sample size of players (including within various positions; Dobson & Keogh, 2007). The variation in physical demand required by different positions are important considerations for TMA research (Dobson & Keogh, 2007). For example, TMA of the sports of rugby and soccer have established that the demands of different positions can be quite dissimilar (Bloomfield, Polman, O'Donoghue, 2007; Duthie, Pyne, Hooper, 2003). Although the TMA research in ice hockey has been limited, differences between forwards, defensemen, and goaltenders have been examined (Bell, Snydmiller, & Game, 2008; Green, et al., 1976; Lafontaine, Lamontagne, & Lockwood, 1998).

Lafontaine, Lamontagne, and Lockwood (1998) analyzed the time-motion characteristics of all six ice hockey positions which include: left wing (LW), center (C), right wing (RW), left defense (LD), right defense (RD), and goaltenders (G). They used movement categories similar to those presented by Bracko and colleagues (1998) and looked at male hockey players at the major junior level and university level. Although they only reported frequencies of movements, there was a significant difference between the three forward and two defensive positions, in backwards skating (Lafontaine, Lamontagne, & Lockwood, 1998). Although Lafontaine and colleagues (1998) claimed that they analyzed the frequency of goaltender movements, it was not reported. Regardless, there have been other investigations of the time-motion and movement characteristics of goaltenders at various levels of hockey (Bell, Snydmiller, & Game, 2008; Richard, Gionet, & Nowlan, 1995).

Finally, Dobson and Keogh (2007) suggest that the level of competition from which the data was analyzed can influence the validity of the TMA of a particular sport. In many sports there are often a number of different standards of play that will range from recreational to professional. Similarly, different age categories as well as different genders should be considered. The concern with the level of competition, age, or gender of TMA data has been the potential of differences between the various standards of play. However, Lafontaine, Lamontagne, and Lockwood (1998) found no significant differences between the junior and university players for the frequency of 13 different skating/movement characteristics during an ice hockey game. Hughes, Wells, and Matthews (2000) compared the movement activities of elite, county, and recreational female squash players and found that elite and county squash players reproduced similar playing patterns in comparison to the recreational players. Despite these studies, there has been limited research comparing level of play in various sports (Dobson & Keogh, 2007).

2.4 Reliability in Time-Motion Analysis

In order for the movement characteristics and demands of a certain sport to be accurately quantified by TMA, there must be an acceptable level of reliability in the observations (Dobson & Keogh, 2007). Intra-observer or rater reliability indicates how accurately one observer will code the same sequence of movements on two separate occasions. Measuring intra-observer reliability usually involves an observer coding one segment of a game on two different occasions separated by an acceptable time period before repeating the analysis. Inter-observer or rater reliability is when there is more than one coder involved in the data collection and it indicates how accurately the two or more different observers will code the same sequence of game play. In a review, Hughes, Cooper and Nevill (2002) found that 70% of the notational TMA studies examined did not report any sort of reliability and the remaining 30% of the studies used questionable statistical methods (Hughes, Cooper, & Nevill, 2002). With respect to ice hockey, five of eight studies did not report any type of reliability (Dillman, Stockholm, & Greer, 1984; Green, et al., 1976; Lafontaine, Lamontagne, & Lockwood, 1998; Montgomery, 1979; Seliger, et al., 1972). Thus, reliability is imperative to establish in TMA research.

There are several examples of reliability analysis for TMA research. Duthie and colleagues (2003) establish the intra-observer reliability of a TMA method used to quantify the demands of Super 12 rugby union. The researchers used typical error of measurement (TEM) as the statistical method to represent the reliability coefficient. The standards for TEM were: good (<5 %); moderate (5-10 %); and poor (>10 %) (McInnes et al., 1995). Duthie, Pyne, and Hopper (2003) found that total time spent in individual movement categories had moderate to poor reliability (5.8 – 11.1 % TEM); frequency of individual movement categories had good to poor reliability (4.3 – 13.6 % TEM); and mean duration of individual movement categories had moderate reliability (7.1 – 9.3 % TEM) (Duthie, Pyne, & Hooper, 2003). Roberts, Trewartha, and Stokes (2006) reported intra-observer reliability ranging from 0.1% - 1.8% TEM which was much better than that reported by Duthie et al., (2003). Finally, Hulka, Cuberek, and Svoboda (2013) assessed the reliability of the Video Manual Motion Tracker software program by using male basketball players. Intra-observer reliability was quantified using intraclass coefficients (ICC) and was quite high (ICC = 0.999) as was the inter-observer reliability (r = 0.994). These are examples of the use of various statistics to establish reliability of different types of variables commonly used in TMA research.

2.5 Time-Motion Analysis in Ice Hockey

Based on a literature search, there are sixteen different studies that have reported either time-motion, skating, or movement characteristics of ice hockey players (Bell, Snydmiller, & Game, 2008; Bracko, et al., 1998; Dillman, Stockholm, & Greer, 1984; Green, et al., 1976; Green, Daub, Painter, & Thompson, 1978; Lafontaine, Lamontagne, & Lockwood, 1998; Leger, 1980; Linseman, Palmer, Sprenger, & Spriet, 2014; Montgomery, 1979; Montpetit, Binette, & Taylor, 1979; Paterson, 1979; Richard, Gionet, Nowlan, 1995; Romet, et al., 1978; Seliger, et al., 1972; Thoden & Jette, 1975; Wilson & Hedberg, 1975). The studies by Bell et al., (2008) and Richard et al., (1995) both examined the time-motion characteristics and movement patterns of goaltenders. As mentioned previously goaltenders will not be analyzed in this research therefore, these two studies will not be discussed. Additionally, the studies by Romet et al., (1978) and Seliger et al., (1972) reported TMA data from training matches/practices which are not indicative of the demands of competitive games and will not be discussed.

The movement categories selected for ice hockey TMA studies have been either simplistic or quite extensive. Many of the early studies simply reported various measures for ice time and rest time with no distinction of the actual movement patterns observed during competition. Green and colleagues (1976) reported actual playing time, number of shifts, playing time per shift, number of stoppages per shift, playing time between stoppages, stoppage time, recovery time between shifts, and velocity per shift. Green pursued another study where they also examined player shift patterns and measured the same variables as the previous study

(Green et al., 1978). Leger (1980) examined midget and junior players and reported mean values for ice time per game, number of shifts per game, shift length, active time per shift, inactive time per shift, and bench time between shifts. Montgomery (1979) reported time spent on the bench between shifts, inactive playing time, and active playing time. Montpetit and colleagues (1979) reported number of shifts, total time on ice per shift, active time per shift, inactive time per shift, number of plays, active time per play, and inactive time per play. Paterson (1979) reported total ice time, number of shifts, mean shift time, mean time between stoppages, and number of stoppages per shift. Finally, Wilson and Hedberg (1975) reported mean shift times and mean total ice time over three games. These studies all used basic time-motion measurements and lack detailed distinction between high intensity and low intensity movements.

However, there have been numerous studies that have identified player movement patterns based on their physical demand. Bracko and colleagues (1998) reported 15 timed skating characteristics and the frequency of 12 skating characteristics in NHL players. The timed skating characteristics were two foot glide, two foot glide with puck, cruise, cruise with puck, low intensity skating, low intensity skating with puck, medium intensity skating, medium intensity skating with puck, high intensity skating, high intensity skating with puck, two foot stationary, two foot stationary with puck, struggle for puck or position, struggle with puck, and backward skating. The frequency based skating characteristics were gliding right turn, gliding right turn with puck, gliding left turn, gliding left turn with puck, right cross-over turn, right cross-over turn with puck, left cross over turn, left cross over turn with puck, forward to backward pivot, backward to forward pivot, stop/start, and stop/start with puck. Dillman, Stockholm, and Greer (1984) examined national level male hockey players and quantified time spent accelerating, time spent decelerating, time spent coasting, distance covered, mean shift velocity, mean peak velocity, and mean low velocity. Lafontaine, Lamontagne, and Lockwood (1998) observed both major junior and university level male players and reported frequencies in the following categories: skate forward, skate backward, glide forward, glide backward, pivoting, standing, stopping, body-check give, body-check receive, left lateral cross-over, right lateral cross-over, left turn, and right turn. Linseman and colleagues (2014) observed skilled male hockey players during five on five scrimmaging and recorded the following physical and skill based measures: time on ice, on-ice breaks, time at high effort, distance covered, turnovers, takeaways, pass completion percentage, time spent with the puck, and shots attempted. Thoden and Jette (1975) analyzed elite junior and NHL players and reported percentage of time spent in anaerobically demanding movements (sprinting or bursting), coasting/gliding, and bench time. The data from these studies offer a better understanding of the sports demands compared to players' shift times alone.

The ice hockey TMA research that has reported basic ice times and rest times has shown some similarities, but appears to depend on a number of factors including age of players and level of play. Green and colleagues (1976, 1978) found that male university players displayed the following mean values: actual playing time (24.5 and 24 min), number of shifts (17.4 and 22.3), playing time per shift (85.4 and 66 s), playing time between stoppages (39.7 and 29 s), stoppage time (27.1 and 30 s), recovery time between shifts (3.75 and 4 min). Both Leger (1980) and Montpetit et al., (1979) analyzed midget age players and reported ice time per game (mean = 17.2 and 15.9 min), number of shifts per game (11.3 and 10.4), and shift time (91 and 201 s), respectively. The observed differences between these research studies may be also partly attributed to a small sample used in the Montpetit et al., (1979) study. Paterson (1979) analyzed three different competitive boys' league teams (U11, U13, and U15) and reported the following values for the U11's and U13's combined: total ice time (12.6 min), number of shifts (8.3), mean shift time (95.6 s), mean time between stoppages (42.1 s), number of stoppages per shift (2.3), and length of periods (30 min). The mean values for the same measures amongst the U15 group were 16.2 min, 10.5, 93.7 sec, 41.4 sec, 2.3, and 40 min, respectively. Finally, Wilson and Hedberg (1979) examined one player on the Swedish national team and reported mean shift times of 59, 62, and 58 seconds across three games which translated to an average ice time of 5.9 minutes per period and 17.7 minutes per game (Wilson & Hedberg, 1975). These results indicate some consistency in the various measurements of ice time within similar age groups and levels of play. However there is much variation in which measures are reported making comparisons between studies difficult.

Dividing a players' shift into movement patterns that are based on their respective intensities provides more relevant information for coaching strategies and conditioning plans. Bracko and colleagues (1998) revealed that professional hockey players spent 39% of their total ice time in a two foot glide; 16.2% in a cruise stride; 10% in a medium intensity stride; 9.8% struggling for puck or position; 7.8% in a low intensity stride; and 5% in a high intensity stride. They also found that players frequently used left and right gliding or crossover turns and that they turned left (38% of total occurrences) slightly more than they turned right (34.1% of total occurrences). Dillman and colleagues (1984) analyzed one 13.5 second video clip for each of the 22 players in their sample and found that they spent an average of 6.64 seconds accelerating, 5.47 seconds decelerating, and 1.39 seconds coasting. The average distance covered by all players was 56.79 meters and the average skating velocity of all players was 5.01 meters/second. Lafontaine and colleagues (1998) reported that the skating skills with the highest frequency amongst all players were forward skating and forward gliding, whereas the skills with the lowest frequency were left and right lateral crossovers. Thoden and Jette (1975) found that the junior and professional players had shift times ranging from 68-74 seconds, where the junior players spent an average of 14 seconds per shift engaged in anaerobically demanding movements and the professionals spent an average of 10 seconds per shift. This research provides evidence that players spend the majority of their ice time in a low intensity forward skating movement and a small amount of time sprinting or engaged in other high intensity movements.

Several of the aforementioned studies have also reported differences between forwards and defense and some have distinguished between the three forward and two defense positions (Green et al., 1976; Paterson, 1979; Thoden & Jette, 1975). Of those researchers that have examined various ice time measures the majority have reported that defensive players spend more time on the ice than forwards. Green and colleagues (1976) reported that defense played an average of 28 minutes per game and forwards played an average of 22 minutes. Paterson (1979) showed this trend also exists in younger players when he reported that U11-U15 defense played approximately 50% of the game and the forwards played 35%. Green et al., (1976) also found that the average velocity for forwards was 259.5 $m \cdot min^{-1}$ where it was only 160 $m \cdot min^{-1}$ for the defense, indicating a lower intensity. Similarly Dillman et al., (1984) found that forwards had a mean velocity of 4.31 $m \cdot s^{-1}$ and a mean peak velocity of 5.04 $m \cdot s^{-1}$ where the defense had a mean velocity of 3.76 $m \cdot s^{-1}$ and a mean peak velocity of 4.86 $m \cdot s^{-1}$. Lafontaine and colleagues (1998) found that defense skated backwards and pivoted more frequently than all forwards. They also reported that forwards delivered significantly more body checks than the defense, but all players received approximately the same number of body checks. Based on this research it appears that defensive players spend more time on the ice than forwards, but the forwards engage in higher intensity movement patterns.

Research comparing the TMA of game situations (penalty kill, power play, and even strength) has been lacking. In only one study, Lafontaine and colleagues (1998) found that the frequencies of all skills differed between the even strength, penalty kill, and power play conditions and that the frequency of forward skating was significantly different between the power play and penalty kill conditions. There also appears to be little to no TMA research investigating female hockey players. In a published abstract, Jackson, Game, Snydmiller, Draper, and Bell (2012) reported that forwards played an average of 46.8 seconds per shift and 11.18 minutes per game, and defense played an average of 54.5 seconds per shift and 15.68 minutes per game. Based on this limited amount of research, a more thorough examination of the time-motion characteristics across game conditions and in female hockey is warranted.

2.6 Heart Rate Analysis in Ice Hockey

There have been several studies that have reported HR responses of male and female ice hockey players during both practices and games indicating that HR is elevated during competition (Green et al., 1976; Seliger et al., 1972; Spiering, Wilson, Judelson, & Rundell, 2003; Bell et al., 2011; Game et al., 2011; Montgomery, 1979; Romet et al., 1978; Spiering et al., 2003). Bell and colleagues (2011) found that male defense displayed a mean and peak HR response of 92 and 96% of HR max, respectively, and recovered to 71% of their HR max between shifts. The forwards displayed a mean and peak HR response of 96 and 100% of HR max, respectively, and recovered to 75% of their HR max between shifts (Bell et al., 2011). Cox and colleagues (1995) found that male players spent anywhere from 8.5 to 19.1% of the game at or above their threshold HR. Mean HR during the game ranged from 126-132 bpm and players ice time ranged from 14.1-31.2 minutes. Davis (1991) found that mean HR for male players during a shift was 168 bpm and the mean HR between shifts was 120 bpm. Green et al. (1976)

reported that the on-ice HR of male players averaged between 87-92% of HR max and the average for the entire game was 89% of HR max. This latter research also reported that the defense displayed on ice HR's that were an average of 10-15 beats lower than the forwards. Linseman and colleagues (2014) observed a mean on-ice HR of 176 bpm amongst their participants; however they did not report HR max. Paterson and colleagues (1977) found that the mean on-ice HR in both groups of adolescent males was 93.5% of HR max and their average HR during recovery was 69.8% of HR max. The mean peak intensity for the competitive group was 190 bpm and 198 bpm. Spiering et al. (2003) observed a mean on-ice HR of 90% of HR max and an average HR during recovery periods of 59% of HR max in female players. It was also noted that the players spent 10.5% of the game above 90% of their HR max and 23.3% of the game above 80% of their HR max. Finally, Wilson and Hedberg (1979) reported that the average on-ice HR across three games was 180 bpm. This data provides evidence that the movement patterns displayed during ice hockey produce relatively high HR's.

The importance of measuring HR during ice hockey is that an elevated HR response indicates that there is a significant cardiovascular demand and potentially a need for cardiovascular conditioning in a game that is generally considered anaerobic in nature. There are several underlying reasons for the elevated HR response. Physiological factors such as an increase in sympathetic neural activity, circulating catecholamines (maximum effort bouts and competition induced stress), stimulation of chemoreceptors (elevated H+ and K+ ions), afferent neural activity (stimulation of mechano-receptors from high frequency limb movement), aerobic demand (resynthesis of ATP/PC during recovery), aerobic energy requirement (gliding and moderate skating), and thermoregulatory demands are all known to elevate HR and may be factors in ice hockey players (Bell et al., 2011; Game et al., 2010). These underlying physiological mechanisms require much further research. Regardless, a thorough understanding of HR activity throughout a competitive game may represent the cardio-respiratory demands of ice hockey and any differences that occur between player positions or different aspects of the game (e.g. penalty kill or power play).

Chapter 3

Time-Motion Characteristics and Heart Rate Profiles Displayed by Female University Ice Hockey Players

3.1 General Introduction

Ice hockey is a unique sport that it is dynamic and intermittent in nature and requires the players to compete on a frozen surface and apply a series of skillful movements in a random fashion (Bloomfield, Polman, O'Donoghue, McNaughton, 2007; Bracko et al., 1998; Cox et al., 1995). The complexity of the sport also requires players to possess a combination of fitness parameters to be successful. Ice hockey and other team sports that share similar characteristics have used TMA and HR response in order to assess the physical and physiological demand placed on the athletes competing (DiMascio & Bradley, 2013; Duthie, Pyne, & Hooper, 2003; Green et al., 1976; Hulka, Cuberek, & Svoboda, 2013). However, TMA research in the sport of ice hockey has been limited and the majority of studies that have reported time-motion characteristics of the game are more than 30 years old (Green et al., 1976; Seliger et al., 1972; Thoden & Jette, 1975). It also appears that time-motion data on penalty kills and power plays or any differences there may be with even strength play have not been reported. Furthermore, all of the hockey TMA research done to this point has included only male players therefore; the time-motion characteristics of female ice hockey has not been investigated.

Heart rate recording during gameplay has been applied to many team sports in order to assess one type of physiological demand of the activity (Bloxham et al., 2001; Deutsch et al., 1998; Hill-Haas et al., 2009; Spiering et al., 2003). Heart rate response to ice hockey has been reported in both females and males and both have displayed near maximal HRs during shifts. Green and colleagues (1976) reported that HR ranged from 87-92% of HR max in male players and Spiering et al. (2003) reported working HRs equivalent to 90% of HR max in females. These mean HR responses found in ice hockey games indicate a substantial involvement of the cardiovascular system in a sport that is often considered to be anaerobic in nature (Baechle & Earle, 2008). It also appears that there has been limited HR data reported in female university ice hockey (Spiering et al., 2003).

Another common application of measuring the time spent during and between activities in TMA research are work to rest ratios that separate the activities of the game in different categories based on their intensity (Dobson & Keogh, 2007). Work to rest ratios are measurements that give an indication of the nature of the activity being performed. A higher ratio (1:1) indicates repeated high intensity efforts were separated by shorter rest periods whereas a lower ratio (1:5) indicates high intensity efforts separated by longer periods of rest. Some researchers have reported work to rest ratios by segmenting periods of the game as work and rest intervals (Rhea, Hunter, & Hunter, 2006) whereas others have established movement patterns as high and low intensity in order to determine a work to rest ratio during actual game-play (Bloomfield, Polman, & O'Donoghue, 2007; Rudkin & O'Donoghue, 2008). A number of studies have identified different movements and skating patterns in hockey games based on their intensity, but work to rest ratios have not been reported (Bracko & colleagues, 1998; Dillman, Stockholm, & Greer, 1984; Linseman et al., 2014). Work to rest ratios combined with TMA and

HR response to hockey games can provide an additional physical and physiological component to the evaluation of game-play and may offer insight into coaching methodologies and conditioning strategies applied to the sport.

The purpose of this study was to investigate the frequency and time spent performing the types of movement patterns in female Canadian Interuniversity Sport (CIS) ice hockey during league games and between periods. Part of the physiological demand of competition was assessed by measuring HR responses during actual games. It was hypothesized that there would be no differences between three different CIS hockey games but there would be differences between periods of each game. It was also hypothesized that there would be a significant difference between defense and forwards in the frequency and duration of movement patterns during CIS ice hockey games throughout even strength play; that defense and forwards would display significantly different frequency of movement patterns, duration of movement patterns, and HR responses during game-play situations; and that defense and forwards would display significantly different work to rest ratios during a shift and during a game.

3.2 Methods

Participants and Experimental Design

A convenient sample of 22 female hockey players (14 forwards and 8 defense) volunteered to be in this research study. All participants were active members of the University of Alberta female varsity hockey team, who competed in the CIS Canada West Division. The participants were considered healthy and highly active based on their practice, training, and competition schedule during the season. Prior to all fitness testing and data collection participants were required to complete a Physical Activity Readiness Questionnaire (PAR-Q), as well as read and sign an informed consent document which was approved by the University of Alberta Research Ethics Board.

The fitness assessments of the players were completed prior to the start of the CIS season. Three regular season home games that were played against different CIS Canada West division rivals were chosen to conduct videotaping and HR measurements. The games chosen for analysis were played in the months of October, November and December and prior to the first recorded game the team had already played six exhibition games and three regular season games. Home games were chosen so that the camera setup and ice arena environment would be identical for all games. Player demographic information such as years' experience, position, etc. was recorded prior to testing (Appendix A).

Aerobic Fitness Testing

Each participant completed graded exercise test to volitional exhaustion on a Monark cycle ergometer (Sweden) while connected to a metabolic measurement system. The initial power output for the graded exercise test was set at 70 watts (W) which was increased by 34 W every two minutes. Once the software's graphical display of ventilation to carbon dioxide production (V_E/VCO_2) reached a minimum and began to systematically increase, the power output was then increased by 34 W every minute until volitional exhaustion. Expired air was collected from the participant during the test using a low resistance, two-way valve (Hans Rudolph 2700) and this air was analyzed using a calibrated metabolic cart (ParvoMedics TrueOne 2400, Utah). Volume calibration was performed using a 3 liter calibration syringe prior to testing and O_2 and CO_2 gases of a known concentration were used to calibrate and verify the gas analysers before and after each test. Ventilatory threshold was visually determined from the graph of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) as the departure from linearity (V-slope, Wasserman et al., 1972). The criteria for peak oxygen consumption was a peak and/or plateau in oxygen consumption in combination with a respiratory exchange ratio of > 1.15, achievement of age predicted or a known maximum HR (with 5 b×min^{-1}) and volitional exhaustion. Heart rate was measured continuously during the aerobic fitness tests using Polar HR monitors (Polar Canada, Quebec) and HR at ventilatory threshold and at VO_2peak was determined. The participants' age was recorded; height was measured in cm using a wall mounted stadiometer (Tanita, Arlington, IL) and weight was measured in kg using a balance beam scale (HealthoMeter, Bridgeview, IL) prior to the aerobic fitness test.

Game Selection and Heart Rate Measurement

Three CIS league games were chosen for analysis. The decision on which games were recorded was partly based on the coaching staff's identification of the most competitive opponents in their division during the first half of the season and at a point in their schedule when they had already played several games. There were 13 players who agreed to wear Polar® Team Sport HR monitors during the games and these were pre-set to record and store five second HR averages to memory and were downloaded to a computer after each game. Approximately two hours before the start of the game, a female research assistant distributed the HR monitors to the appropriate players and showed them the proper way to fit the chest strap. Each participant wore the HR monitor directly on the chest underneath their protective equipment. The monitors were pre-programmed to begin recording HR 15 minutes before the scheduled start of the game and continued recording for the duration of the game. The participants wore the HR monitors during several practices prior to the data collection during games to become accustomed to them. The timing of the HR monitors was synchronized with the time displayed on the video cameras.

Camera Setup and Locations

Two cameras were mounted on opposite sides of the arena, in-line with center ice at an identical height of 20 meters. The wide angle lens on the digital cameras (GoPro® Hero; 720p, 60fps) as well as the height they were mounted allowed for the entire ice surface to be captured with minor exception. This allowed for the movement analysis of all players from the same recording vantage point. There were small blind spots in both ice surface corners closest to the cameras' location therefore; in the event that the play took place in a blind spot the opposite camera was used to analyse the players' movement in these locations. The video files were stored to SD cards that were later downloaded to a computer.

Time-Motion Analysis

In order to refine the categories of movement for university hockey players, a panel of five individuals with combined expertise in skill analysis, coaching hockey and sport science research from the University of Alberta and Augustana Faculty discussed which movement patterns were most descriptive of a typical competitive game (Bloxham et al., 2001). To begin this process an investigator reviewed the available literature and created a series of movement categories with descriptions for each and distributed this for review by the panel. A subsequent meeting was held during which video clips of CIS games were viewed and a round table discussion occurred to provide feedback and refine the movement categories and their descriptions. This process was conducted with male CIS players and the same categories were later established as applicable to female CIS players by the same group. As a result of the panel discussion and after preliminary analysis, it was further decided that moving with and without the puck would not be labelled as separate categories. Therefore, the proposed on-ice movement pattern categories were: standing or very low intensity movements, forward start, gliding or cruising forward, moderate intensity forward skating, high or maximal intensity forward skating, backward start, gliding or cruising backward, moderate intensity backward skating, high or maximal intensity backward skating, and struggling for position or battling for the puck.

Dartfish TeamPro 5.0 software version 5.0.10529.0 (Fribourg, Switzerland) was used to code all ten movement categories within the three CIS games. The positional groupings used for coding were: left wing (LW), center (C), right wing (RW), left defense (LD), and right defense (RD). Each established movement category was coded to a specific keystroke. The observer watched the game while recording each player's movement through selection of the appropriate key assigned to the movement category. The software automatically recorded the number of events and the duration of each event which was then exported for further analysis. The total and mean duration as well as frequency of each activity was measured. Each player's shift and game work to rest totals, intervals and ratios were also determined.

Definition of Movement Categories

1) <u>Standing or very low intensity movements:</u> Stationary or displaying very little motion that would be considered energy demanding. Most often taking place away from the puck/play. Examples include; a defensive player standing on the offensive blue line, a player standing in front of the net without being engaged with an opposing player, and/or a forward anticipating a play to develop (breakout or regroup) with little movement.
2) <u>Forward start:</u> Two to three forward strides that are used to accelerate the player from a stationary or near stationary position. The movement is characterized by a strong arm swing and knee drive as well as a pronounced forward lean as the player works to

overcome inertia. As the player builds speed (accelerates) the intensity increases exponentially.

3) Gliding or cruising forward: No or very little skating movement. The exception being easy/low intensity strides that would be used to maintain speed.

4) Moderate intensity forward skating: Stride frequency is at a moderate rate and speed is above slow, but would not be considered maximal. The player displays purposeful movements to contribute to the offensive rush or to gain defensive positioning. The players arm movements are contributing to their stride, but there is less upper body lean than seen with a maximal effort.

5) High or maximal intensity forward skating: The fastest rate of stride frequency which corresponds with; forceful knee drive of the recovery leg; pronounced upper body lean; and deliberate arm movements which add to the strength of the stride. The forward start may also be included in this category if the player continued maximal intensity skating beyond the 2-3 strides associated with the forward start.

6) Backward start: Two to three fast backward strides that are used to accelerate the player from a stationary or near stationary position. The movements can be characterized as an effort to overcome inertia. As the player builds speed (accelerates) the intensity increases exponentially.

7) Gliding or cruising backward: No or very little skating movement. The exception being easy/low intensity strides that would be used to maintain speed.

8) Moderate intensity backward skating: Stride frequency is at a moderate rate and speed is above slow, but would not be considered maximal. The player displays purposeful movements to maintain position on an opposing player through the neutral zone.

9) High or maximal intensity backward skating: The player is using fast, powerful pushes or fast, accelerating backwards crossovers in order to match the speed of an attacking opposing player. The backward start may also be included in this category if the player continued maximal intensity skating beyond the 2-3 strides associated with the backward start.

10) Struggling for position or battling for the puck: The player is using any number of utility movements (lateral crossovers, stops, starts) along with upper body activity to gain/maintain position on an opponent, to protect the puck, or gain possession of the puck. These activities are considered high intensity since there is forceful lower and upper body work. Examples include: corner battles, pins, battles for puck possession, and battles in front of the net.

Definition of Work to Rest Ratios

Two separate work to rest ratios were created for the ice hockey players (Leger, 1980; Montgomery, 1979; Montpetit, Binette, & Taylor, 1979; Paterson, 1979; Thoden & Jette, 1975). The first took into account the time spent engaged in demanding and undemanding movements during a shift and the other simply used time spent on the ice and on the bench during the periods.

1) Shift work to rest ratio: Ratio of the time spent engaged in high intensity activity to the time spent engaged in low intensity activity. High intensity activities include: forward start, moderate intensity forward skating, high or maximal intensity forward skating, backward start, moderate intensity backward skating, high or maximal intensity backward skating, and struggling for position or battling for the puck. Low intensity activities

include: standing or very low intensity activity, gliding or cruising forward, gliding or cruising backward, and stoppages in play where the player remains on the ice.

2) Game work to rest ratio: Ratio of the time spent on the ice during active play to the time spent between stoppages of play on the ice and time on the bench.

Reliability of Video Analysis

Intra-observer, test-retest reliability was established utilizing the same trained observer that coded all movement patterns during one period from a selected game for ten different players on two different occasions separated by one week. The mean intra-observer intra-class coefficient (ICC) for the frequency and duration of all movement categories was 0.75 and 0.76, respectively (range = 0.5 – 0.99 for frequency and 0.36 – 0.98 for duration; Appendix A). In order to determine inter-observer, test-retest reliability, a different trained observer coded the same players during the same period and game. The mean inter-observer ICC for frequency and duration of all movement categories was 0.85 and 0.84, respectively (range = 0.68 – 0.97 for frequency and 0.39 – 0.94 for duration; Appendix A). Appendix A also includes the typical error of measurement (TE) for frequency and duration of all movements as described by Hopkins (2000), as well as the Pearson correlation coefficient for measurements between trials.

Statistical Analysis

Mean and standard deviations of time and frequency of each movement category were calculated for all players during the three games. The percentage of the game time spent in each movement category was also reported. Both shift and game work and rest intervals were calculated. Mean HR during shifts, between shifts and between periods were determined. Peak and low HR during and between shifts as well as between periods was also determined. All descriptive statistics were analysed using Microsoft Excel 2010.

Inter and intra rater, test retest reliability was assessed using an intra-class coefficient (ICC) according to Hopkins (2000) and was calculated using an Excel spreadsheet created for public use by Hopkins (Hopkins, 2014, para. 9).

Separate three-way analysis of variance (ANOVA) procedures were used to compare the frequency of movement patterns, duration of movement patterns and HR responses between position (2), periods (3) and games (3), with repeated measures on periods and games. Separate three-way ANOVA procedures were used to compare the frequency of movement patterns, duration of movement patterns and HR responses between position (2), games (3), and game-play situations (3). Separate three-way ANOVA procedures were used to compare the work to rest ratios between position (2), games (3), and game-play situations (3). Any significant main effects or interactions were further evaluated using a Tukey's HSD multiple comparison test. All statistics were analysed using Statistica and significance was set at $P < 0.05$ a priori.

3.3 Results

Participant Characteristics

The sample used in this study had a mean (±SD) age of 20 ± 1 years and 2 ± 1 years playing experience at the varsity level. The average height and weight of the team was 169.4 ± 5.7 cm and 69.3 ± 6.2 kg. The participant's full fitness testing results can be found in Appendix B.

General Game Characteristics

The game statistics and outcomes are reported in Table 1.

Table 1. General features and results of three different regular season, CIS female ice hockey games.

Game	Result	Goals For (#)	Goals Against (#)	Shots For (#)	Shots Against (#)	Power Plays (#)	Penalty Kills (#)	Penalties (#)
1	Loss	0	1	18	22	5	7	12
2	Win	3	1	26	25	4	5	9
3	Win	2	0	22	21	4	3	7
	Mean ± SD	2 ± 2	1 ± 1	22 ± 4	23 ± 2	4 ± 1	5 ± 2	9 ± 3

Time Motion Analysis

i) – Percentage of game time spent in different movement categories

Table 2 contains the mean percentage of time spent in the various movement categories observed during all three ice hockey games and indicates that the greatest proportion of game time was spent in the gliding or cruising forward and moderate intensity forward skating movement categories ($P<0.05$).

Table 2. Percentage (%) of time spent in movement categories during different regular season, CIS female ice hockey games.

Movement Category	All Players (n=22)	Defense (n=8)	Forwards (n=14)
STND	7.1 ± 5.9	13.5 ± 4.5**	3.9 ± 3.5
FSTA	0.9 ± 0.6	0.5 ± 0.2	1.1 ± 0.7
FGLD	36.3 ± 6.2*	31.3 ± 3.4**	38.9 ± 5.8
FMOD	31.2 ± 6.2*	25.1 ± 2.4**	34.2 ± 5.2
FMAX	5.3 ± 3.3	1.9 ± 1.0**	7.0 ± 2.7
BSTA	0.1 ± 0.3	0.3 ± 0.4	0.0 ± 0.0
BGLD	9.5 ± 4.1	13.9 ± 2.7**	7.3 ± 2.7
BMOD	3.1 ± 3.3	7.3 ± 1.8**	1.0 ± 1.0
BMAX	0.0 ± 0.1	0.1 ± 0.2	0.0 ± 0.0
STRG	6.3 ± 2.6	5.6 ± 1.8	6.7 ± 2.8

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. Values are the mean ± SD across all three games.

* = significantly different from all other movement categories (P<0.05).
** = significantly different from the forward position (P<0.05).

ii) – Comparison of the frequency of movement categories between games, periods and positions during even strength play

There were no significant differences in frequency of movements between games, periods, or player position for the forward start, moderate intensity forward skating or struggling categories (Table 3). It should also be noted that a statistical comparison of the backward start and high intensity backwards skating movement categories could not be performed due to a low number of observations. Table 3 contains the mean (±SD) frequency of both of these movement categories in individual games and periods among defense and forwards.

Standing or very low intensity movements (Standing)

There was a significant interaction effect for the standing category between games, periods and positions. Multiple comparisons revealed that all players, regardless of position stood more often in game three compared to games one and two (main effect, $P<0.05$). It was also found that the defense stood more frequently in game one compared to the forwards in all three games ($P<0.05$) (Table 3).

There was a main effect for periods that showed all players stood significantly more often in the first period compared to the third period, but not the second period. The defense also displayed a significantly higher frequency of standing in the first periods compared to the forwards in all three periods. Furthermore, a main effect for position was found that showed a significantly higher frequency of the standing movement category in the defense compared to the forwards (Table 3).

Gliding or cruising forward

There was a significant interaction effect for forward gliding between games, periods, and positions. All players, regardless of position displayed a higher frequency of forward gliding during game one compared to game two (main effect, $P<0.05$). The defense displayed a significantly higher frequency of forward gliding during the first period compared to the second period, but not the third period in all games (Table 3).

High or maximal intensity forward skating

There was a main effect for position that showed the frequency of high intensity forward skating was significantly higher in the forwards compared to the defense (Table 5). There were no significant differences found between games or periods.

Gliding or cruising backward

There was an interaction between periods and positions that indicates the first and third period frequencies for backward gliding in the defense were higher than the frequencies displayed by the forwards in all three periods, in all games ($P<0.05$). Furthermore, it was found that all players displayed a significantly higher frequency of backward gliding in the first and third games compared to the second game (main effect; Table 3).

Moderate intensity backward skating

There was a significant interaction effect for moderate intensity backward skating between games, periods and positions. All players displayed a significantly higher frequency of moderate intensity backward skating in game one compared to games two and three. The frequency of moderate intensity backward skating was also significantly higher in the defense during all three games compared to the forwards (Table 3).

Table 3. Mean (±SD) for frequency of movement categories in individual regular season, CIS female ice hockey games.

		Game 1				Game 2				Games 3			
MC	**Pos.**	**P1**	**P2**	**P3**	***Total***	**P1**	**P2**	**P3**	***Total***	**P1**	**P2**	**P3**	***Total***
	D[a]	16 ± 6[efj]	12 ± 3	13 ± 6[k]	14 ± 5[ch]	12 ± 2[efj]	7 ± 7	8 ± 7[k]	9 ± 6	19 ± 4[efj]	9 ± 5	11 ± 6[k]	13 ± 6[i]
STND	F	3 ± 3	3 ± 2	2 ± 1	3 ± 2	3 ± 3	3 ± 3	2 ± 2	3 ± 2	6 ± 4	9 ± 6	6 ± 5	7 ± 5[bc]
	AP	6 ± 7[g]	5 ± 5	5 ± 5	5 ± 5	5 ± 5[g]	4 ± 4	4 ± 4	4 ± 4	9 ± 7[g]	9 ± 5	7 ± 5	8 ± 6[bc]
	D	0 ± 1	0 ± 1	1 ± 1	0 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	0 ± 1	1 ± 1	1 ± 1
FSTA	F	2 ± 1	1 ± 1	1 ± 2	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	2 ± 1	2 ± 1	2 ± 1	1 ± 1
	AP	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	2 ± 1	2 ± 1
	D	42 ± 13[l]	30 ± 8	37 ± 12	36 ± 11	33 ± 1[l]	28 ± 5	28 ± 2	30 ± 4	37 ± 2[l]	24 ± 5	31 ± 7	31 ± 7
FGLD	F	32 ± 7	33 ± 3	28 ± 5	31 ± 6	26 ± 7	24 ± 8	30 ± 9	27 ± 8	25 ± 8	32 ± 11	29 ± 11	29 ± 10
	AP	34 ± 9	32 ± 4	30 ± 8	32 ± 7[c]	28 ± 6	25 ± 7	30 ± 8	28 ± 7	28 ± 8	30 ± 10	30 ± 10	29 ± 9
	D	42 ± 8	39 ± 9	36 ± 11	39 ± 8	33 ± 5	24 ± 6	28 ± 2	28 ± 6	38 ± 3	25 ± 6	31 ± 6	31 ± 7
FMOD	F	30 ± 8	35 ± 6	29 ± 6	31 ± 7	28 ± 7	25 ± 10	29 ± 8	27 ± 8	26 ± 7	32 ± 9	30 ± 11	29 ± 9
	AP	33 ± 9	36 ± 6	30 ± 8	33 ± 8	29 ± 7	24 ± 9	28 ± 7	27 ± 8	28 ± 8	30 ± 9	30 ± 10	30 ± 9
	D[a]	4 ± 3	3 ± 1	2 ± 1	3 ± 2	5 ± 2	2 ± 2	3 ± 2	3 ± 2	2 ± 2	3 ± 2	2 ± 2	2 ± 2
FMAX	F	8 ± 3	9 ± 5	7 ± 4	8 ± 4	8 ± 3	6 ± 2	6 ± 2	7 ± 2	4 ± 2	5 ± 3	6 ± 3	5 ± 3
	AP	7 ± 3	8 ± 5	6 ± 5	7 ± 4	7 ± 3	5 ± 3	5 ± 2	6 ± 3	3 ± 2	5 ± 3	5 ± 3	4 ± 3
	D	1 ± 1	1 ± 1	0 ± 0	0 ± 1	0 ± 1	0 ± 1	1 ± 1	1 ± 1	0 ± 1	0 ± 1	1 ± 1	0 ± 1
BSTA	F	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	AP	0 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 1	0 ± 0
	D[a]	18 ± 3[j]	17 ± 2[m]	23 ± 3[j]	19 ± 3	12 ± 2[j]	14 ± 1[m]	19± 2[j]	15 ± 4	19 ± 5[j]	15 ± 4[m]	20 ± 10[j]	18 ± 6
BGLD	F	11 ± 3	10 ± 4	9 ± 4	10 ± 4	8 ± 4	7 ± 3	7 ± 4	7 ± 3	11 ± 6	9 ± 4	10 ± 4	10 ± 5
	AP	13 ± 4	11 ± 5	12 ± 7	12 ± 5[c]	9 ± 4	8 ± 4	10 ± 6	9 ± 5	13 ± 7	10 ± 5	12 ± 7	12 ± 6[c]
	D[a]	10 ± 3	10 ± 2	13 ± 6	11 ± 3[ch]	8 ± 1	5 ± 2	7 ± 2	7 ± 2[h]	12 ± 3	7 ± 3	9 ± 5	9 ± 4[h]
BMOD	F	2 ± 2	3 ± 3	2 ± 2	2 ± 2	2 ± 2	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	2 ± 2	1 ± 1
	AP	4 ± 4	4 ± 4[n]	5 ± 6[n]	4 ± 5[cd]	3 ± 3	2 ± 2	2 ± 3	2 ± 3	3 ± 5	2 ± 3	3 ± 4	3 ± 4
	D	0 ± 1	0 ± 1	0 ± 0	0 ± 0	0 ± 0	1 ± 1	1 ± 1	0 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0
BMAX	F	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	AP	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 1	0 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	D	8 ± 1	9 ± 2	9 ± 3	6 ± 3	9 ± 2	5 ± 2	7 ± 3	7 ± 3	8 ± 2	6 ± 2	5 ± 2	6 ± 2
STRG	F	6 ± 3	8 ± 2	4 ± 3	9 ± 2	5 ± 3	7 ± 4	6 ± 3	6 ± 3	6 ± 3	7 ± 4	7 ± 4	7 ± 3
	AP	6 ± 3	8 ± 2	5 ± 3	6 ± 3	6 ± 3	6 ± 4	6 ± 3	6 ± 3	7 ± 3	7 ± 3	6 ± 3	7 ± 3

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. MC=Movement category; PO=Position; P1-P3=Period1-Period 3; Total=Game average; D=Defense; F=Forwards; AP=All players. Values given are the Mean ± SD for the frequency of each movement.

a = significantly different from forwards; b = significantly different from game 1; c = significantly different from game 2; d = significantly different from game 3; e = defense in the first period of all games were different from all other positions and periods of all games; f = the defense in the third period of all games were different from forwards in periods 1 and 3 of all games g = all players in the first period were different from all players in the third period for all games; h = the defense were different from forwards in all three games; i = the defense in game 3 were different from forwards in game 1 and 2; j = significantly different from forwards in all periods for all games; k = significantly different than forwards in periods 1 and 2 for all games; l = defense in period 1 differed from defense in period 2 of all games; m = significantly different than forwards in periods 2 and 3 for all games; n = all players in game 1, periods 2 and 3 differed from all players in game 2, periods 2 and 3 and game 3, period 2.

iii) – Comparison of the duration of movement categories between games, periods and positions during even strength play

There were no significant differences between games, periods, or player position for time spent in the following movement categories: gliding or cruising forward; forward start; moderate intensity forward skating; and struggling (Table 4). It should also be noted that a statistical comparison of the backward start and high intensity backwards skating movement category could not be performed due to a low number of observations. Table 4 contains the mean (±SD) duration of both of these movement categories in individual games and periods among defense and forwards.

Standing

There was a significant interaction effect for standing between periods and positions (Table 4). The defense spent more time standing in the first and third period compared the forwards in all three periods, in all games ($P<0.05$) and the duration of standing was significantly higher in the defense compared to the forwards. There was also a main effect for games that showed all players stood for a significantly longer duration in game three compared to games one and two.

High or maximal intensity forward skating

The duration of high intensity forward skating was higher in the forwards compared to the defensive players (main effect; $P<0.05$;Table 4).

Gliding or cruising backward

The defense spent more time gliding backwards in all three periods across all games compared to the forwards (interaction effect; $P<0.05$; Table 4).

Moderate intensity backward skating

There was a significant interaction effect for moderate intensity backward skating between games, periods and positions. All players engaged in moderate intensity backward skating for a longer duration in game one compared to game two ($P<0.05$). Furthermore, the defense spent significantly more time skating backward with a moderate intensity in all three games compared to the forwards. The defense also spent more time skating backward with a moderate intensity in all three periods across all games compared to the forwards ($P<0.05$) (Table 4).

Table 4. Mean (±SD) for duration of movement categories in individual regular season, CIS female ice hockey games.

		Game 1				**Game 2**				**Game 3**			
MC	**PO**	**P1**	**P2**	**P3**	***Total***	**P1**	**P2**	**P3**	***Total***	**P1**	**P2**	**P3**	***Total***
STND	D[a]	29.3±11.6[ef]	23.7±11.7	34.6±12.0[e]	29.2±11.2	41.9±8.0[ef]	20.1±18.7	20.4±21.2[e]	27.5±18.2	58.1±14.3[ef]	34.9±21.2	40.4±39.8[e]	44.5±25.9
	F	7.6±7.5	5.6±4.7	3.1±2.8	5.5±5.5	6.5±6.0	6.1±5.3	4.7±6.7	5.8±5.9	17.7±15.9	19.3±15.6	16.7±17.1	17.9±15.7
	AP	12.6±12.4	9.8±10.1	10.4±14.8	10.9±12.3	14.6±16.7	9.3±10.8	8.3±12.5	10.8±13.5	27.0±23.2	22.9±17.5	22.1±24.3	24.0±21.4[bc]
FSTA	D	0.4±0.7	1.0±1.7	0.7±0.6	0.7±1.0	1.3±1.2	1.3±1.6	1.1±0.9	1.2±1.1	1.3±1.3	0.5±0.9	1.4±1.4	1.1±1.1
	F	3.0±1.7	1.7±1.6	1.7±2.3	2.1±1.9	1.8±1.2	1.7±1.1	1.9±1.5	1.8±1.2	3.2±2.3	2.6±2.5	3.9±2.3	3.2±2.4
	AP	2.4±1.9	1.5±1.6	1.4±2.1	1.8±1.8	1.7±1.2	1.6±1.2	1.7±1.4	1.7±1.2	2.8±2.2	2.1±2.4	3.3±2.3	2.7±2.3
FGLD	D	103.7±33.4	92.8±13.3	97.5±20.3	98.0±21.2	83.5±9.9	82.5±19.6	81.2±12.2	82.4±12.6	82.9±16.9	73.0±8.2	88.0±20.7	81.3±15.5
	F	87.8±31.0	86.1±12.3	69.3±17.3	81.0±22.6	73.2±23.3	64.3±24.1	80.9±24.7	72.8±24.2	73.4±29.1	92.1±37.1	80.2±35.2	81.9±33.7
	AP	91.4±30.9	87.6±12.3	75.8±21.1	85.0±23.2	75.6±21.1	68.5±23.8	80.9±22.0	75.0±22.3	75.6±26.5	87.7±33.3	82.0±31.8	81.8±30.3
FMOD	D	74.8±17.9	70.5±13.4	67.9±20.4	71.1±15.4	74.0±11.2	50.4±10.5	64.3±3.5	62.9±13.0	75.1±19.1	67.0±22.4	71.2±15.6	71.1±17.0
	F	69.4±20.1	85.3±15.2	71.7±20.5	75.5±19.4	63.8±20.2	54.5±20.7	65.4±17.1	61.2±19.3	62.8±17.9	77.7±19.4	70.9±25.6	70.5±21.4
	AP	70.6±19.0	81.9±15.7	70.8±19.7	74.5±18.5	66.1±18.7	53.6±18.5	65.2±14.9	61.6±17.9	65.7±18.2	75.2±19.7	70.9±23.0	70.6±20.3
FMAX	D[a]	5.8±5.4	4.7±2.7	3.7±2.7	4.7±3.4	10.4±2.3	3.9±5.1	6.8±4.1	7.0±4.5	3.0±3.0	6.7±3.3	4.0±2.2	4.5±3.0
	F	14.3±6.2	18.2±11.8	13.7±8.3	15.4±9.0	15.9±7.6	12.8±5.3	13.0±4.2	13.9±5.8	9.2±5.3	11.4±7.7	14.5±6.5	11.7±6.7
	AP	12.3±6.9	15.1±11.8	11.4±8.5	12.9±9.2	14.6±7.0	10.8±6.4	11.6±4.9	12.3±6.2	7.8±5.5	10.3±7.1	12.1±7.3	10.1±6.7
BSTA	D	1.3±2.3	1.4±1.2	0.0±0.0	0.9±1.5	0.5±0.8	0.5±0.9	2.6±2.3	1.2±1.6	0.5±0.9	0.7±1.3	2.1±3.7	1.1±2.1
	F	0.0±0.0	0.2±0.5	0.0±0.0	0.1±0.3	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	AP	0.3±1.1	0.5±0.9	0.0±0.0	0.3±0.8	0.1±0.4	0.1±0.4	0.6±1.5	0.3±0.9	0.1±0.4	0.2±0.6	0.5±1.8	0.3±1.1
BGLD	D[a]	32.6±14.0[e]	35.9±8.9[e]	42.1±7.9[e]	36.9±10.1	28.3±9.1[e]	29.8±8.7[e]	38.1±4.2[e]	32.0±8.1	34.5±12.1[e]	34.3±10.0[e]	42.3±14.9[e]	37.0±11.5
	F	17.9±6.4	17.8±6.5	14.6±6.1	16.8±6.3	14.3±7.8	12.5±6.9	12.6±8.7	13.1±7.6	19.9±13.6	17.4±8.7	20.4±10.4	19.2±10.8
	AP	21.3±10.3	22.0±10.4	21.0±13.6	21.4±11.2	17.5±9.9	16.5±10.3	18.5±13.6	17.5±11.1	23.3±14.3	21.3±11.3	25.4±14.5	23.3±13.2
BMOD	D[a]	19.2±2.9[e]	22.6±3.7[e]	28.4±13.9[e]	23.4±8.4[cd]	18.6±3.6[e]	11.9±2.6[e]	17.8±3.3[e]	16.1±4.2[d]	24.6±14.9[e]	13.9±5.3[e]	22.8±3.8[e]	20.4±9.6[d]
	F	2.4±2.3	4.5±5.1	3.0±2.8	3.3±3.6	2.9±3.2	1.1±1.7	1.0±1.7	1.7±2.4	1.1±1.8	1.2±1.4	2.8 ± 3.4	1.7±2.4
	AP	6.3±7.7	8.7±9.2	8.9±12.8	7.9±9.9[c]	6.5±7.6	3.6±5.1[g]	4.9±7.6	5.0±6.8	6.5±12.1	4.1±6.1	7.4±9.4	6.0±9.4
BMAX	D	0.2±0.4	0.3±0.6	0.0±0.0	0.2±0.4	0.0±0.0	1.3±2.3	1.4±2.4	0.9±1.8	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	F	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	AP	0.1±0.2	0.1±0.3	0.0±0.0	0.0±0.2	0.0±0.0	0.3±1.1	0.3±1.2	0.2±0.9	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
STRG	D	14.0±0.8	16.3±1.9	12.0±3.8	14.1±2.9	21.6±2.3	7.5±1.7	17.8±10.4	15.6±8.3	26.6±8.4	15.8±3.5	13.9±3.7	18.8±7.7
	F	11.4±5.5	14.2±4.5	7.6±5.4	11.1±5.7	11.2±6.6	12.7±11.3	13.8±8.4	12.6±8.7	15.7±9.4	15.5±9.2	18.0±15.7	16.4±11.4
	AP	12.0±4.9	14.7±4.1	8.6±5.3	11.8±5.3	13.6±7.3	11.5±10.0	14.8±8.6	13.3±8.6	18.2±10.0	15.6±8.1	17.1±13.8	16.9±10.7

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. MC=Movement category; PO=Position; P1-P3=Period1-Period 3; Total=Game average; D=Defense; F=Forwards; AP=All players. Values given are the Mean ± SD for the seconds spent engaging in each movement pattern.

a = significantly different from forwards; b = significantly different from game 1; c = significantly different from game 2; d = the defense were different from forwards in all three games; e = significantly different from forwards in all periods for all games; f = defense in period 1 differed from defense in period 2 of all games; g = all players in game 2 period 2 were significantly different from all players in game 1 periods 2 and 3.

iv) Comparison of the frequency of movement categories between games, game-play situations and positions.

There were no significant differences in frequency between games, game-play situations or player position for forward start or forward glide (Table 5). It should also be noted that a statistical comparison of the backward start and high intensity backwards skating movement category could not be performed due to a low number of observations. Table 5 contains the mean (±SD) frequency of both of these movement categories in individual games and game-play situations among defense and forwards.

Standing

There was a significant interaction effect for the standing movement category between game-play situations and positions. All players displayed a lower frequency of standing during power plays compared to even strength play and penalty kills ($P<0.05$). Furthermore, the defense stood significantly less often during even strength play and penalty kills compared to the forwards during power plays (Table 5).

Moderate intensity forward skating

There was a significant interaction effect for moderate intensity forward skating between games and game-play situations. All players, regardless of position displayed a higher frequency of moderate intensity forward skating during even strength play and power plays compared to penalty kills (main effect, $p<0.05$). The frequency of moderate intensity forward skating was higher during even strength play in the first game compared to the penalty kills in all three games ($P<0.05$, Table 5).

High or maximal intensity forward skating

There was a significant interaction for high intensity forward skating between game-play situations and positions. High intensity forward skating was more frequent among the forwards compared to the defensive players ($P<0.05$). The forwards displayed a significantly higher frequency of high intensity forward skating during even strength play and penalty kills compared to the defense during all three game-play situations. The forwards also displayed a significantly higher frequency of high intensity forward skating during power plays compared to the defense during even strength play and penalty kills, but not power plays (Table 5).

Gliding or cruising backward

There was a significant interaction for backward gliding between games, game-play situations and positions. Defensive players glided backwards significantly more often than the forwards and the frequency of backward gliding for defense during power plays was significantly higher compared to the forwards during power plays and even strength play. It was also found that the defense glided backwards more often during the power plays of the third game compared to the forwards during even strength and power plays in the first game; all three game play situations in the second game, and during even strength play and power plays of the third game ($P<0.05$, Table 5).

Moderate intensity backward skating

There was a significant interaction for moderate intensity backward skating between game-play situations and positions. Defensive players skated backwards with a moderate intensity more often than the forwards ($P<0.05$). The frequency of moderate intensity backward skating was significantly higher in the defense during even strength play and power plays compared to the forwards during all three game-play situations (Table 5).

Struggling

There was a significant interaction for struggling between game-play situations and positions. All players, regardless of position displayed a higher frequency of struggling during penalty kills compared to power plays, but not even strength play ($P<0.05$). Furthermore the frequency of struggling in the defense was higher during penalty kills compared to power plays, but not even strength ($P<0.05$, Table 5).

Table 5. Mean (±SD) for frequency of movement categories during different game-play situations in individual regular season, CIS female ice hockey games.

		Game 1			Game 2			Game 3			Averages		
MC	**PO**	**EVS**	**PK**	**PP**	**EVS**	**PK**	**PP**	**EVS**	**PK**	**PP**	**EVS**	**PK**	**PP**
STND	D	3 ± 0	2 ± 1	2 ± 1	3 ± 0	3 ± 1	1 ± 0	3 ± 0	3 ± 1	1 ± 1	3 ± 0[c]	3 ± 1[c]	1 ± 1
	F	1 ± 0	1 ± 1	1 ± 1	1 ± 1	2 ± 1	1 ± 1	2 ± 0	1 ± 1	2 ± 1	1 ± 1	2 ± 1	1 ± 1
	AP	2 ± 2	2 ± 1	1 ± 1	2 ± 1	2 ± 1	1 ± 1	2 ± 1	2 ± 1	1 ± 1	2 ± 1[c]	2 ± 1[c]	1 ± 1
FSTA	D	0 ± 0	0 ± 0	1 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	F	1 ± 0	1 ± 1	1 ± 0	1 ± 0	2 ± 3	1 ± 1	0 ± 0	3 ± 3	0 ± 0	1 ± 0	2 ± 2	1 ± 1
	AP	0 ± 0	0 ± 1	1 ± 0	0 ± 0	2 ± 2	1 ± 1	0 ± 0	2 ± 3	0 ± 0	0 ± 0	1 ± 2	1 ± 0
FGLD	D	8 ± 2	7 ± 0	7 ± 0	7 ± 0	9 ± 1	8 ± 0	6 ± 1	8 ± 1	9 ± 1	7 ± 1	8 ± 1	8 ± 1
	F	8 ± 1	9 ± 2	8 ± 2	9 ± 1	10 ± 1	9 ± 1	7 ± 1	10 ± 2	9 ± 0	8 ± 1	9 ± 2	8 ± 1
	AP	8 ± 1	8 ± 2	8 ± 2	8 ± 1	9 ± 1	8 ± 1	7 ± 1	9 ± 2	9 ± 1	8 ± 1	9 ± 2	8 ± 1
FMOD	D	9 ± 1	5 ± 1	7 ± 1	7 ± 0	6 ± 0	7 ± 0	6 ± 1	6 ± 0	6 ± 0	7 ± 1	6 ± 1	6 ± 1
	F	9 ± 1	7 ± 2	8 ± 2	9 ± 1	6 ± 1	8 ± 0	8 ± 1	7 ± 2	9 ± 1	9 ± 1	6 ± 1	8 ± 1
	AP	9 ± 1[d]	6 ± 1	8 ± 2[e]	9 ± 1[e]	6 ± 1	8 ± 1[e]	8 ± 1[e]	7 ± 2	8 ± 2[e]	8 ± 1[b]	6 ± 1	8 ± 1[b]
FMAX	D[a]	0 ± 0	2 ± 1	1 ± 0	1 ± 0	0± 0	1 ± 0	0 ± 0	0 ± 1	1 ± 1	1 ± 0[f]	1 ± 1[f]	1 ± 0[g]
	F	3 ± 1	3 ± 1	2 ± 1	2 ± 0	1 ± 1	2 ± 0	2 ± 1	2 ± 1	2 ± 2	2 ± 1	2 ± 1	2 ± 1
	AP	2 ± 1	2 ± 1	1 ± 0	2 ± 1	1 ± 1	1 ± 0	1 ± 1	2 ± 1	1 ± 1	2 ± 1	2 ± 1	1 ± 1
BSTA	D	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	F	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	AP	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
BGLD	D[a]	4 ± 1	3 ± 1	4 ± 0	3 ± 0	4 ± 0	4 ± 1	4 ± 0	2 ± 0	6 ± 0[i]	4 ± 0	3 ± 1	4 ± 1[h]
	F	2 ± 1	4 ± 0	2 ± 1	2 ± 0	2 ± 1	2 ± 2	2 ± 0	3 ± 0	2 ± 1	2 ± 0	3 ± 1	2 ± 1
	AP	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 2	3 ± 1	3 ± 1	4 ± 2	3 ± 1	3 ± 1	3 ± 2
BMOD	D[a]	2 ± 0	1 ± 1	2 ± 0	2 ± 0	1 ± 1	1 ± 0	2 ± 0	1 ± 1	1 ± 0	2 ± 0[bf]	1 ± 1[h]	1 ± 0[f]
	F	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	AP	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	0 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1
BMAX	D	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	F	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	AP	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
STRG	D	2 ± 0	3 ± 1	0 ± 0	2 ± 0	4 ± 1	1 ± 0	1 ± 0	2 ± 1	0 ± 0	2 ± 0	3 ± 1[c]	0 ± 0
	F	2 ± 0	2 ± 1	2 ± 1	2 ± 0	2 ± 1	3 ± 2	2 ± 0	2 ± 2	2 ± 1	2 ± 0	2 ± 1	2 ± 2
	AP	2 ± 0	3 ± 1	1 ± 1	2 ± 0	3 ± 1	2 ± 2	2 ± 1	2 ± 1	1 ± 1	2 ± 0	3 ± 1[c]	1 ± 1

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. MC=Movement category; PO=Position; EVS=Even strength play; PK=Penalty kill; PP=Power play; D=Defense; F=Forwards; AP=All players. Values given are the Mean ± SD frequency of each movement category per shift.

a = significantly different from forwards; b = significantly different from PK; c = significantly different from PP; d = significantly different from PK in all games; e = significantly different from PK in games 1 and 2; f = significantly different from the forwards during all 3 game-play situations; g = significantly different from the forwards during EVS and PK in all games; h = significantly different from the forwards during EVS and PP in all games; i = the defense differed from the forwards during EVS and PP of game 1; EVS, PK, and PP of game 2; EVS and PP of game 3; and significantly different than the defense during the PK of game 1 and 3.

v) Comparison of the duration of movement categories between games, game-play situations and positions.

There were no significant differences between games, periods, or player position for time spent in the following movement categories: forward start; gliding or cruising forward; high intensity forward skating; and gliding or cruising backward. Furthermore, there were no differences between games for the duration of any movement category which supports the hypothesis. It should also be noted that a statistical comparison of the backward start and high intensity backwards skating movement category could not be performed due to a low number of observations. Table 6 contains the mean (±SD) duration of both of these movement categories in individual games and game-play situations among defense and forwards.

Standing

All players spent more time standing during even strength play and penalty kills compared to power plays (main effect, $P<0.05$) (Table 6).

Moderate intensity forward skating

There was a main effect for game-play situations showing that the time spent skating forwards with a moderate intensity was significantly longer during even strength play and power plays compared to penalty kills in all players (Table 6).

Moderate intensity backward skating

The duration of moderate intensity backward skating was higher in the defense compared to the forwards (main effect, $P<0.05$) (Table 6).

Struggling

There was a significant interaction between game-play situations and position showing that the defense spent significantly more time struggling during penalty kills than they did during power plays, but not during even strength play (Table 6).

Table 6. Mean (±SD) for duration of movement categories during different game-play situations in individual regular season, CIS female ice hockey games.

Movement Category	Position	Even Strength	Penalty Kill	Power Play
STND	D	8.4 ± 2.2[c]	8.4 ± 2.9[c]	2.2 ± 0.9
	F	2.9 ± 2.0	4.1 ± 2.9	2.4 ± 2.4
	AP	5.1 ± 3.5[c]	5.8 ± 3.5[c]	2.3 ± 1.9
FSTA	D	0.2 ± 0.1	0.3 ± 0.4	0.5 ± 0.3
	F	0.8 ± 0.3	2.9 ± 3.2	0.9 ± 0.7
	AP	0.5 ± 0.4	1.8 ± 2.7	0.8 ± 0.6
FGLD	D	20.2 ± 2.5	23.2 ± 2.7	26.4 ± 2.6
	F	21.6 ± 4.4	22.7 ± 7.2	22.2 ± 6.6
	AP	21.1 ± 3.7	22.9 ± 5.7	23.8 ± 5.7
FMOD	D	14.6 ± 1.2	11.4 ± 2.0	15.5 ± 2.6
	F	20.4 ± 3.9	15.0 ± 4.9	21.3 ± 5.3
	AP	18.1 ± 4.2[b]	13.6 ± 4.3	19.0 ± 5.2[b]
FMAX	D	1.0 ± 0.5	1.7 ± 1.8	2.5 ± 0.8
	F	4.9 ± 1.5	4.5 ± 3.1	3.3 ± 3.7
	AP	3.3 ± 2.3	3.4 ± 2.9	3.0 ± 2.8
BSTA	D	0.3 ± 0.3	0.0 ± 0.0	0.1 ± 0.2
	F	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	AP	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.2
BGLD	D	7.2 ± 0.6	6.9 ± 3.2	9.8 ± 2.7
	F	3.9 ± 0.6	5.7 ± 2.3	4.1 ± 3.0
	AP	5.2 ± 1.8	6.2 ± 2.6	6.4 ± 4.0
BMOD	D[a]	4.0 ± 0.4	2.7 ± 2.3	2.1 ± 0.6
	F	0.5 ± 0.3	0.6 ± 0.6	0.3 ± 0.4
	AP	1.9 ± 1.8	1.4 ± 1.8	1.0 ± 1.0
BMAX	D	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
	F	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	AP	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
STRG	D	3.7 ± 0.7	5.4 ± 2.0[c]	0.9 ± 0.9
	F	5.0 ± 2.1	4.5 ± 3.1	5.4 ± 6.3
	AP	4.4 ± 1.8	4.9 ± 2.7	3.6 ± 5.3

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. Values given are the Mean ± SD for seconds spent engaging in each movement pattern per shift across all three games.

a = significantly different from the forwards; b = significantly different from PK; c = significantly different from PP.

Heart Rate Analysis

i) – Comparison of the heart rate response to even strength play between games, periods and positions.

Peak and mean heart rates during shifts

There were no significant differences in the peak or mean heart rate during player shifts between positions, periods, or games (Tables 7 and 8).

Recovery heart rates between shifts and periods

A main effect for periods was found showing that all players displayed significantly lower heart rates during the recovery time between shifts in the first periods compared to the second periods, but not the third periods. There were no significant differences in the mean shift recovery heart rates between positions, periods, or games (Tables 8).

The forwards displayed a significantly lower recovery heart rates in the first intermissions compared to the second intermissions (Table 7).

The forwards displayed significantly lower mean recovery heart rates during the first intermissions compared to the second intermissions (Table 7).

Table 7. Mean (±SD) for different heart rate measures during even strength play in individual regular season, CIS female ice hockey games.

HR Measurement	Defense (n=3)	Forwards (n=4)	All Players (n=7)
Peak Shift HR	184 ± 12	180 ± 7	182 ± 10
Mean Shift HR	176 ± 11	173 ± 7	174 ± 9
Recovery Low HR	129 ± 14	132 ± 10	131 ± 12
Recovery Mean HR	148 ± 14	148 ± 9	148 ± 11
INT 1 Recovery Low HR	103 ± 7	99 ± 8[a]	101 ± 8
INT 1 Recovery Mean HR	116 ± 9	112 ± 7[a]	114 ± 8
INT 2 Recovery Low HR	101 ± 9	108 ± 10	105 ± 10
INT 2 Recovery Mean HR	117 ± 10	123 ± 8	121 ± 9

INT=Intermission. Values given are the Mean ± SD of each heart rate measure across all three games.

a = significantly different from the second intermission value

Table 8. Mean (±SD) heart rate measures during even strength play in individual periods of regular season, CIS female ice hockey games.

HR Measure	Position	1st Periods	2nd Periods	3rd Periods
	D	183 ± 12	184 ± 13	184 ± 12
PSHR	F	180 ± 8	181 ± 7	179 ± 6
	AP	181 ± 10	182 ± 10	181 ± 9
	D	174 ± 11	176 ± 12	176 ± 11
MSHR	F	172 ± 9	174 ± 6	173 ± 7
	AP	173 ± 10	175 ± 9	175 ± 9
	D	125 ± 11	132 ± 15	129 ± 16
RLHR	F	128 ± 12	136 ± 8	133 ± 8
	AP	127 ± 11[a]	134 ± 11	132 ± 12
	D	147 ± 13	150 ± 14	148 ± 15
RMHR	F	145 ± 11	151 ± 7	148 ± 8
	AP	146 ± 12	151 ± 11	148 ± 11

PSHR=Peak Shift Heart Rate; MSHR=Mean Shift Heart Rate; RLHR=Recovery Low Heart Rate; RMHR=Recovery Mean Heart Rate. Values given are the Mean ± SD per period of each heart rate measure across all three games. n=7

a = significantly different from the second period value

ii) – Comparison of the heart rate response between games, game-play situations and positions.

Peak and mean heart rates during shifts

There were no significant differences in peak or mean heart rates during shifts between positions or game-play situations (Table 9).

Recovery heart rates between shifts

The lowest and mean heart rates in between shifts were lower during even strength play compared to power plays (P<0.05). This interaction was evident among all players regardless of position (Table 9).

Table 9. Mean (±SD) heart rate measures during different game-play situations in individual regular season, CIS female ice hockey games.

HR Measure	Position	Even Strength	Penalty Kill	Power Play
PSHR	D	182 ± 4	187 ± 6	183 ± 6
	F	183 ± 5	185 ± 9	179 ± 7
	AP	182 ± 5	186 ± 7	181 ± 6
MSHR	D	174 ± 3	177 ± 6	176 ± 5
	F	173 ± 5	177 ± 8	169 ± 5
	AP	174 ± 4	177 ± 7	172 ± 6
RLHR	D	129 ± 6	133 ± 11	136 ± 11
	F	125 ± 16	129 ± 8	134 ± 12
	AP	127 ± 12[a]	131 ± 9	135 ± 11
RMHR	D	148 ± 4	150 ± 12	156 ± 10
	F	143 ± 14	144 ± 5	150 ± 11
	AP	145 ± 11[a]	147 ± 9	153 ± 10

PSHR=Peak Shift Heart Rate; MSHR=Mean Shift Heart Rate; RLHR=Recovery Low Heart Rate; RMHR=Recovery Mean Heart Rate. Values given are the Mean ± SD across all three games. n=7

a = significantly different from power plays.

Work to Rest Ratios

Shift work to rest ratio

The shift work to rest ratios were greater during the penalty kills compared to the power plays but not even strength play among all players (main effect, P<0.05). There were no significant differences in the shift work to rest ratio between positions or games (Table 10).

Game work to rest ratio

There were no significant differences in the game work to rest ratio between positions, games, or game-play situations (Table 10).

Table 10. Mean (±SD) work to rest ratios during different game-play situation for all games.

HR Measure	Position	Even Strength	Penalty Kill	Power Play
	D	1 to 2.0 ± 0.2	1 to 2.2 ± 0.5	1 to 2.0 ± 0.4
Shift W:R	F	1 to 1.3 ± 0.5	1 to 1.5 ± 0.7	1 to 1.2 ± 0.5
	AP	1 to 1.6 ± 0.5	1 to 1.8 ± 0.7[a]	1 to 1.5 ± 0.6
	D	1 to 3.1 ± 0.5	1 to 3.7 ± 2.8	1 to 1.3 ± 0.7
Game W:R	F	1 to 4.1 ± 1.1	1 to 6.1 ± 6.5	1 to 2.2 ± 3.1
	AP	1 to 3.7 ± 1.0	1 to 5.1 ± 5.3	1 to 1.8 ± 2.4

W:R=Work to rest ratio. Values given are the Mean ± SD work to rest ratios for each game-play situation across all three games. n=5

a = significantly different from power plays

3.4 Discussion

Female ice hockey has increased in popularity over the past 20 years with a rise in participation of 59% from 2002 to 2013 reported by Hockey Canada (*Statistics & History*, n.d., ¶ 4); however, the sports science research quantifying the movement characteristics and physiological demands has been lacking, out of date and largely ignored in female hockey (Green et al., 1976; Leger, 1980; Romet et al., 1978; Spiering et al., 2003; Thoden & Jette, 1975). This type of information has much value in understanding the demands of the sport as well as providing a scientific basis to the design of more effective training programs and sport specific assessments (Dobson & Keogh, 2007; Taylor, 2003). Thus, the main purpose of this study was to investigate the movement patterns and physical demands typical of female Canadian Interuniversity Sport (CIS) ice hockey games using time motion analysis and heart rate measurements. There were significant differences in frequency and duration of several movement patterns observed during even strength play between defense and forwards lending support to the first hypothesis. There was also some support for the second hypothesis since defense and forwards displayed significantly different frequency and duration of certain movement patterns during different game-play situations. However, mean HR responses were not significantly different nor were there any significant differences in shift or game work to rest ratios between defense and forwards which did not support the proposed hypotheses, respectively.

Time Motion Analysis

Percentage of Game Time

The findings of this study revealed the various movement categories that were used throughout a typical CIS female ice hockey game as well as some significant differences in these categories between the forward and defense positions. All players, regardless of position spent the majority of the game time in the forward glide (36.3%) and moderate intensity forward skating (31.2%) movement categories (Table 2). This was similar to that reported by Bracko and colleagues (1998) where they revealed that professional male hockey players spend 39% of their total ice time in a two foot glide; 16.2% in a cruise stride; and 10% in a medium intensity stride. This indicates that players devote the majority of their on-ice time engaged in lower intensity movement categories. This was further supported by the fact that forward starting, maximum intensity forward skating, backward starting, maximum intensity backwards skating, and struggling totaled only 12.6 % of the game. There were also significant differences between defense and forwards in the movement categories indicating that defense stood and moved backwards more frequently but moved forward less frequently compared to the forward positions. This is supported by Lafontaine and colleagues (1998) who reported that defensemen skated backwards significantly more frequently than forwards. These differences between the defense and forwards can be explained by the contrast in positional obligations, where defense are required to skate forwards less, skate backwards more and remain stationary in front of the net more than the forwards.

Frequency and Duration of Movement Categories during Even Strength Play

This study revealed numerous significant differences in the frequency and duration of movement categories between the three different games, periods, and two positions. There were significant differences in frequency for standing, forward glide, moderate intensity forward skating, backward glide, and moderate intensity backward skating between games. For time spent in movement categories the only ones that displayed significant differences between games were standing and moderate intensity backward skating. This finding does not support one of the proposed hypotheses and there has been no previous research investigating differences between different games that can either refute or support this result. It is possible that there was some variation in the observer coding between games that caused the differences and it may also be because of actual differences between the way that the different games were played. Variations in game-plans, coaching strategies and how opponents respond during a game are all possibilities that may have contributed to these differences.

The defense displayed a significantly higher frequency and duration of backward gliding and moderate intensity backward skating compared to the forwards which supported the proposed hypothesis. As mentioned previously, this finding was supported by Lafontaine and colleagues (1998) and can be explained by the difference in positional requirements. The frequency and duration of maximal intensity forward skating as well as the duration of forward starting were significantly higher in the forwards compared to the defense which was also expected. Dillman et al., (1984) and Green et al., (1976) both found a higher average skating velocity in forwards compared to defense in male hockey, but differences in forward sprinting frequency and duration between positions has not been reported. Regardless, the aggressive fore-checking nature of the center and winger positions may explain this difference. Finally, there were significant differences between periods for the frequency of standing and forward gliding, but no differences in the duration of any of the movement categories which partially supports one of the proposed hypotheses. Both standing and forward gliding are considered to be low intensity and their frequencies were the highest in the first period which may indicate some hesitation and cautiousness at the onset of the games. Previous research comparing differences in frequency and duration of movement categories between games, periods and player positions has been limited; therefore, it is difficult to compare some of the current findings with similar studies.

Frequency and Duration of Movement Categories during Game-play Situations

The findings from this study showed a number of main and interaction effects for the frequency and duration of movement categories during different game-play situations between games and player positions. The frequency of standing was less and duration shorter during power plays compared to even strength play and penalty kills for all players and defense stood less often during even strength play and penalty kills compared to forwards during power plays. The frequency of backward gliding for the defense during power plays was significantly higher than the forwards during power plays and even strength play; however, there were no significant differences in forward glide frequency or duration between games, game-play situations, or player positions. These findings regarding the low intensity movement categories were somewhat unexpected. If a team can execute a power play efficiently they will gain control of the puck in the offensive zone which is characterized by a substantial amount of puck movement and smaller area adjustments in a player's position. In a penalty kill situation, a team is trying to keep their opposition in the outside perimeters of the zone and eliminate passing and shooting lanes that are in close proximity to their net, which similar to the power play, can be characterized by smaller area adjustments in player's position. Since there was significantly less standing and low intensity movement during the power plays it does not support this notion and may be explained by variation within the game. It remains a possibility that the majority of power plays were not well executed in the observed games. The defense also displayed a significantly higher frequency of backward gliding during the power plays of the third game compared to the forwards during even strength and power plays in the first and third game; and, all three game-play situations in the second game. This was somewhat unusual, but may be partially explained by the differences in positional requirements of the defense. Lafontaine and colleagues (1998) did report differences in skill frequencies between game-play situations, but did not include any information regarding the intensity of the movement patterns. Thus, the movement pattern profile during different game-play situations appears to vary significantly and further research will be needed for any true differences and patterns to emerge.

Heart Rate Reponses

Heart Rate Response to Even Strength Play

The time motion analyses of female CIS ice hockey revealed that the sport is characterized by brief periods of high intensity movement patterns interspersed by periods of low/moderate intensity movements and rest periods on the bench. A measure of the physiological demand of this intermittent sport was completed through the use of HR monitors worn by players during game-play (Davis, 1991; Forbes, Kennedy, & Bell, 2013; Spiering et al., 2003). The heart rate profile of female CIS ice hockey players during competitive games indicates that there was a high demand on the cardiovascular system. The average peak and mean shift heart rates represented 96% and 92% of HR max in all players, respectively; whereas the mean recovery HR between shifts and intermissions was 77% and 59% of HR max, respectively (Appendix C). Spiering and colleagues (2003) reported a mean on-ice HR of 90% of HR max in female hockey players which was similar to this study. Bell et al. (2011) reported average peak, mean, recovery between shifts, and recovery between periods HR's of 98%, 94%, 73%, and 62% of HR max, respectively in male hockey players. The results of this study are also similar to those reported by Bell and colleagues (2011) which may indicate that the level of cardiovascular stress involved during an ice hockey game is similar regardless of gender. Furthermore, a high game HR may also indicate the extent to which the aerobic energy system is involved and an associated elevated oxygen uptake.

There were no significant differences in peak and mean HR during shifts between forwards and defense which did not support the proposed hypothesis, since it was expected that forwards would have a greater cardiovascular response due to the anticipated higher intensity activities of playing this position. This finding was contrary to an observed difference in peak and mean shift HR values for male defense and forwards reported by Bell et al. (2011). Possible explanations for this may be that some of the defense were given more ice time and this may have elicited a higher peak and mean HR response than would have otherwise occurred. It may also be that the way in which the defense and forwards competed in the observed games stimulated HR to a similar extent.

The recovery HR's between shifts were significantly lower in the first period compared to the second period, but not the third. The forwards also displayed significantly lower recovery and mean recovery HR's in the first intermissions compared to the second intermissions. There has been no other research to this point that has analysed HR responses during the intermissions in ice hockey. Some things to consider when examining recovery heart rates during an intermittent game such as ice hockey is the effect of fatigue, dehydration, thermal stress (Linseman et al., 2014; Lythe & Kilding, 2011) and any psychological stress associated with the game. These stressors may explain the forwards higher recovery HR during the second period as the game progressed but does not explain the lower HR during the third period. Other factors that could contribute to recovery HR are the individual athletes' fitness levels as well as how competition stress may affect the player (Matthew & Delextrat, 2009; McInnes et al., 1995). Fernandez-Fernandez et al. (2014) reported that elite female tennis players displayed significantly higher mean HR during matches that they were losing compared to those that they were winning. In this study the team was never losing during the third period with the exception of game one where the opposition scored the winning goal with three minutes left in regulation time. This may partially explain why the recovery HR's were significantly lower during the third period compared to the second.

Heart Rate Response to Game-play Situations

The results from this study revealed that the HR response to penalty kill and power play situations was similar to even strength play even though a significantly higher mean HR response to even strength play was expected. The reason for this may be that there were less stationary and low intensity activities observed during power plays and penalty kills than expected. The results also revealed that recovery HR's between shifts were significantly higher during penalty kills compared to even strength play. This was also not expected, but may be explained by variation in how the players competed in the different games or any heightened stress associated with playing the penalty kill. One common penalty kill scenario is when players are unable to change for an extended period of time because the opposition has extended control of the puck. When players do get an opportunity to make a line change their bench time may be too short for their HR to recover before having to return to the ice for another shift. However, no previous research has analysed HR during different game-play situations so these explanations are only conjectures.

Work to Rest Ratios

Work to rest ratios (W:R) are found in numerous TMA studies on team sports and indicate the demands of a competition or certain parts of the competition by specifying how much time is spent performing activities of moderate-high intensity (work) compared to how much time is spent in lower intensity activities or recovery (rest). For a team sport such as hockey you can also categorize movement as purposeful or non-purposeful, where purposeful movement would include any attempt to contribute to the play (control of the puck) whether it be offensive or defensive in nature, whereas non-purposeful movements include those where the athlete is not engaging in the play (Bloomfield, Polman, & O'Donoghue, 2007). The W:R describes the repeated nature of intermittent sports such as ice hockey (Bloomfield, Polman, & O'Donoghue, 2007; Dobson & Keogh, 2007; O'Donoghue, 2008; Rudkin, & O'Donoghue, 2008) and depending on the ratio, it can somewhat indicate the energy demands of playing a sport. In this study the shift W:R was referring to time spent on the ice and a ratio that approached equal value (1:1) indicated that there were frequent bursts of high intensity activity separated by short rest periods, whereas a ratio that is much lower (1:5) would indicate less frequent bursts of high intensity movement separated by ample rest periods. The same concept applies to the game W:R but it is describing the time spent on the ice to the time spent on the bench. A ratio that is close to equal is often indication of a short amount of bench time between shifts, whereas a lower ratio indicated extended time on the bench between shifts.

The average shift W:R in all players during even strength play was 1:1.6 and the game W:R was 1:3.7. Bloomfield, Polman, and O'Donoghue (2007) established a W:R that distinguished purposeful movements from non-purposeful movements in elite male soccer players and reported a ratio 1:1.6. Although this ratio was the same as the shift W:R in the present study it is important to point out that the purposeful movements reported by Bloomfield, Polman, and O'Donoghue (2007) included various low intensity activities. In this thesis, the high intensity movements for the shift W:R also included moderate intensity backward and forward skating which were considered purposeful, however many instances of these movements throughout the games were somewhat low in intensity. In both the Bloomfield and colleagues (2007) study and the present study the division of purposeful and non-purposeful movements may have overestimated the demands of high intensity movements involved in the respective sports. This is indication of the difficulty in seamlessly separating the high and low intensity activities during game-play in order to establish W:R's in team sports, a problem that has been expressed by others (Bloomfield, Polman, & O'Donoghue, 2007; Rudkin & O'Donoghue, 2008) It is also difficult to compare W:R in sports such as soccer where players remain in play for the majority of the game versus a sport like ice hockey where players consistently substitute off and have time to recover. This also may provide evidence that segments of a soccer game that involve direct competition for ball possession have a similar repeated high intensity nature as a shift in ice hockey.

The results of this study revealed that the shift work to rest ratio was significantly lower during penalty kills (1:1.8) compared to power plays (1:1.5) indicating that penalty kills had an overall lower intensity than power plays, but not even strength play which did not support the hypothesis. It was expected that both penalty kills and power plays would have lower shift W:R's compared to even strength play (1:1.6) which would indicate a lower intensity during penalty kills and power plays compared to even strength play. This may be because a more passive style of penalty kill was adopted by the team in the current study which was characterized by an increase in stationary/low intensity activity and more focus on position in the defensive zone. It may also be because they struggled to gain possession of the offensive zone during power plays which resulted in continually trying to regroup and break the puck out of their own zone; a scenario that would be characterized by a significant amount of high intensity forward skating. There were also no significant differences in shift and game W:R's between games which was expected.

Based on the results from this study the average duration of a single high intensity movement pattern executed during a shift was 2.1 ± 2.3 seconds (Appendix E) and the average even strength shift time was 44.3 ± 17.9 seconds (Appendix D). When the shift W:R of 1:1.6 is considered along with these latter results and the repeated nature of the activities, it would indicate that there is a reliance on adenosine triphosphate phosphocreatine (ATP-PC) energy stores as well as energy produced by the anaerobic glycolytic pathway to support the on ice activities during a typical shift. Furthermore, the game of ice hockey is made up of three 20 minute, stop-time periods which are interspersed with 15-20 minute breaks between periods. When paired with the game W:R of 1:3.7 and the relatively high heart rate responses during the game, it is also apparent that hockey requires contribution from the aerobic energy system in order to compete during each shift and throughout a whole game. The aerobic energy system supports the demand of low and moderate intensity exercise, is important in recovering energy stores used during highly intense activities and involved in various physiological support mechanisms to exercise such as thermoregulation. Therefore, aerobic fitness is very important for repeated sprint ability which is supported by research in numerous other team sports that are characterized by repeated high intensity efforts (Jones et al., 2013; Meckel et al., 2013; Stanula, Roczniok, Maszczyk, Pietraszewski, & Zajac, 2014).

Limitations

The results of this study are specific to a single CIS female ice hockey team that competed during the 2011-2012 season. It should also be noted that these participants were a convenient sample of volunteers and no random selection was used. The use of a convenient sample of this size would have reduced statistical power in the present study. There were a number of players that did not compete in all three games which eliminated their data from any statistical comparison of movement patterns made between games, periods and players positions. A small sample size as a result of a low number of players agreeing to wear the HR monitors during game play was also a limitation for the HR analyses. Coaching strategies applied to differing opponents as well as in different game-play situations could not be controlled and can also be considered a limitation.

The time-motion analysis methods used in this study required an observer to subjectively categorize the movement patterns of female hockey players. The method is practical and inexpensive, but has validity and reliability issues and is also very time consuming (Barris & Button, 2008). Distinguishing between similar movement categories can be challenging and requires a decision from the observer coding the video which may result in poor intra or inter-rater reliability (Dobson & Keogh, 2007). An example of movement patterns that were difficult for the observers to distinguish were forward starting and standing or very low intensity movements which is shown by a lower reliability for these measures (Appendix A).

Lastly, the current analysis did not distinguish between movement times or frequency when the players were in control of the puck or were not. As well, no attempt in the current analysis was made to determine whether any differences in movement patterns were related to scoring chances, defensive success or game changing outcomes. Finally, differences in coaching strategy between games, periods or during game play situations was not investigated.

Summary and Conclusions

In summary, the forwards displayed a significantly higher frequency of moderate intensity forward skating and a higher frequency and duration of maximum intensity forward skating compared to the defense during even strength play. Furthermore the defense displayed a significantly higher frequency and duration of standing, backward gliding and moderate intensity backward skating compared to the forwards during even strength play. The forwards displayed a significantly higher frequency of maximum intensity forward skating during different game-play situations compared to defense, whereas the defense displayed a higher frequency of backward gliding and a significantly higher frequency and duration of moderate intensity backward skating compared to the forwards. There were no significant differences in mean or peak HR responses during even strength play between games, periods, or player position. There were also no differences in mean or peak HR responses during different game-play situations between games or player positions. Finally, there were no significant differences in shift or game work to rest ratios between player positions. As mentioned previously, there has been no previous research investigating the time-motion characteristics of female ice hockey for comparison. However, the high HR responses to actual game-play has been previously shown in both female and male hockey games (Bell et al., 2011; Green et al., 1976; Spiering et al., 2003).

This was a unique study that used TMA combined with HR monitoring to quantify the physical and physiological demands of female ice hockey. Time-motion analysis revealed that female ice hockey games involve repeated high intensity efforts interspersed with low intensity movement patterns while on the ice separated by extended periods of rest during bench-time and intermissions. The higher frequency and duration of maximal intensity forward skating in the forwards compared to the defense is an outcome of positional requirements which can also explain the higher frequency and duration and backward gliding and moderate intensity backward skating among the defense. There were no differences in movement frequencies or times during the different game-play situations. Furthermore, the absence of a difference in peak and mean HR response to game-play between forwards and defense was a novel finding. Finally, the lack of difference in shift work to rest ratios and game work to rest ratios between forwards and defense is in agreement with the HR response findings and supports the possibility that the two positions were played in a similar fashion during the games observed. This study is the first to report time-motion characteristics of female ice hockey players in combination with HR response and is also the first to report work to rest ratios. Therefore, this research adds new and more current data to the female and male ice hockey time-motion analysis literature.

Practical Applications

Similar to many other team sports, deliberate practice of the actual skills and game like scenarios required in ice hockey can be considered of utmost importance to success in the sport (Soberlack & Cote, 2003). However, it has been shown that practice time alone may not be a sufficient physiological stimulus to maintain all of the various fitness aspects required in ice hockey such as aerobic fitness, throughout a typical season (Spiering et al., 2003). The findings from this time motion and heart rate analysis study as well as others can contribute to the development of effective in-season and off-season conditioning programs (Gill, Bell, Draper, & Game, 2012; Spiering et al., 2003). Implementation of shift times, rest times and work to rest ratios into on and off ice conditioning can improve training effectiveness as well as aid in the selection of appropriate assessments to evaluate player fitness and monitor training; support in player selection; evaluate readiness to play after an injury or conditioning assignments; and design game simulation workouts for players that are a "healthy scratch" from league games so that they experience a game like exercise stimulus.

The division of phases in an annual training plan for a hockey player will be dependent upon several factors including the length of the competitive season. Regardless, most players training year will include off-season, pre-season, and in-season phases. In the off-season, the combination of the types of movements performed and the frequency and time spent in these movements along with the heart rate responses in a game would suggest that a player should include the development of the ATP-PC, anaerobic glycolytic and aerobic energy systems. As well, support training for these activities should include sprint training, plyometrics and traditional strength training exercises. Another possible training stimulus for developing the anaerobic glycolytic pathways is to utilize the game W:R (1:3.7) and average shift times (44.3 ± 17.9 s) for interval training (Table 9; Appendix D). It should also be mentioned that choice of exercise mode for off-season conditioning should stress the musculature used in skating and therefore adapt a more sport specific approach. The use of slide boards, inline skating, skating treadmills or on-ice skating would all be appropriate.

The transition from off-season to pre-season will usually be accentuated by an increase in time spent on-ice. Conditioning during this time will be dependent on the situation of the player and how frequent and intense their practices are in preparation for the season. Maintenance of several fitness parameters to support the on-ice demands would be recommended. Finally, as the competitive season begins and progresses (in-season), the conditioning program should supplement the physical conditioning aspects of the practises and may need to focus on maintaining or possibly improving the cardiovascular fitness of players while avoiding overuse of the skating specific muscle groups. The supplemental conditioning for this latter aspect could be in the form of interval training that elicits a heart rate response that is similar to that observed in the present study (working HR of >90% of HR max) and preferably utilizes an exercise mode that is of lower impact and distinct from actual skating. It should also be mentioned that muscular strength, power and endurance along with flexibility and body composition are all important to a hockey players' success. For this reason appropriately periodized resistance training that is tailored to the individual players needs should always be incorporated into the annual training plan regardless of the phase.

There has been much research that has investigated the use of off-ice fitness assessments and how the results differ between positions as well as how they correlate to on-ice capabilities in ice hockey (Burr et al., 2008; Farlinger, Kruisselbrink, Fowles, 2007; Green et al., 2006; Vescovi et al., 2006). A battery of tests implemented at appropriate times throughout the year has value as both an evaluative and developmental tool. The findings from this study established that ice hockey was characterized by the performance of a variety of movement activities that most often involve repeated high intensity efforts separated by extended periods of recovery. As a result, it is important to select appropriate fitness assessments that will provide valid and reliable evaluation of the primary fitness categories. The NHL combine testing (Burr et al., 2008) as well as research that has included fitness testing of professional ice hockey players (Montgomery, 2006; Quinney et al., 2008), female varsity ice hockey players (Geithner, Lee, & Bracko, 2006) and the current study are evidence that the fitness categories of body composition; muscular strength, power and endurance; anaerobic (e.g. repeated sprint testing); cardio-respiratory fitness are all important and should be included in a full fitness evaluation. Finally, sport specific testing can also provide effective supplementary fitness information.

Future Directions

Since this was the first study to investigate the time-motion characteristics of female ice hockey there is a need for future research that includes other teams, age groups and levels of play. A TMA study of females playing at the national level would also be warranted. This could establish a wider understanding of the activities and demands of the sport as well as provide valuable information in terms of on ice skill and energy system development to the athletes aspiring to play at all levels of women's ice hockey. A comparison between female and male hockey would also be an interesting study to determine any significant differences in the physical and physiological demands between the two sexes and whether differences in rules would influence these outcomes. It would also be valuable to include goaltenders in future studies because the latest research only analysed male NHL goaltenders and did not report any measures of physiological demand (Bell, Snydmiller, & Game, 2008). There are also continuous technological advancements in automated player monitoring that may benefit TMA studies in the sport of ice hockey (Cummins et al., 2013). If future automated TMA systems can overcome the issues associated with indoor arenas, consistent directional changes, and player to player collisions it may allow for much larger sample sizes to be investigated and significantly reduce the amount of time required to analyze games. Finally, a determination of whether any differences in TMA could lead to a variety of game changing performances such as scoring or preventing a goal that may change the outcome of a game would be highly warranted.

References

Aggarwal, J.K., & Cai, Q. (1999). Human motion analysis: A review. *Computer Vision and Image Understanding, 73*(3), 428-440. http://www.journals.elsevier.com/computer-vision-and-image-understanding/

Arts, F.J.P., & Kuipers, H. (1994). The relation between power output, oxygen uptake, and heart rate in male athletes. *International Journal of Sports Medicine, 15*(5), 228-231. doi: 10.1055/s-2007-1021051

Baechle, T.R., & Earle, R.W. (Eds.). (2008). *Essentials of strength training and conditioning* (3rd ed.). Windsor, ON: Human Kinetics.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine, 38*(12), 1025-1043. http://link.springer.com/journal/40279

Bell, G. J., Game, A., Bouchard, J., Reid, C., Gervais, P. & Snydmiller, G. (2011). Near maximal heart rate responses during a varsity ice hockey game. *Applied Physiology, Nutrition and Metabolism, 36* Supplement: S2. http://www.nrcresearchpress.com/journal/apnm

Bell, G.J., Snydmiller, G.D., & Game, A.B. (2008). An investigation of the type and frequency of movement patterns of National Hockey League goaltenders. *International Journal of Sports Physiology and Performance, 3*(1), 80-87. http://journals.humankinetics.com/ijspp

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA premier league soccer. *Journal of Sports Science and Medicine, 6*(1), 63-70. http://www.jssm.org/

Bloomfield, J., Polman, R., O'Donoghue, P., & McNaughton, L. (2007). Effective speed and agility conditioning methodology for random intermittent dynamic type sports. *Journal of Strength and Conditioning Research, 21*(4), 1093-1100. http://www.nsca.com/

Bloxham, L.A., Bell, G.J., Bhambhani, Y., & Steadward, R.D. (2001). Time motion analysis and physiological profile of Canadian World Cup wheelchair basketball players. *Research in Sports Medicine, 10*(3), 183-198. doi: 10.1080/10578310210398

Bracko, M.R., Fellingham, G.W., Hall, L.T., Fisher, A.G., & Cryer, W. (1998). Performance skating characteristics of professional ice hockey forwards. *Sports Medicine, Training and Rehabilitation, 8*(3), 251-263. http://www.tandfonline.com/loi/gspm19#.VINVUjHF8rU

Burr, J.F., Jamnik, R.K., Baker, J., MacPherson, A., Gledhill, N., & McGuire, E.J. (2008). Relationship of physical fitness test results and hockey playing potential in elite level ice hockey players. *Journal of Strength and Conditioning Research, 22*(5), 1535-1543. http://www.nsca.com/

Burr, J.F., Jamnik, V.K., Dogra, S., & Gledhill, N. (2007). Evaluation of jump protocols to assess leg power and predict hockey playing potential. *Journal of Stre*ngth *and Conditioning Research, 21*(4), 1139-1145. http://www.nsca.com/

Chang, R., Turcotte, R., & Pearsall, D. (2009). Hip adductor muscle function in forward skating. *Sports Biomechanics, 8*(3), 212-222. doi: 10.1080/14763140903229534

Cox, M.H., Miles, D.S., Verde, T.J., & Rhodes, E.C. (1995). Applied physiology of ice hockey. *Sports Medicine, 19*(3), 184-201. http://link.springer.com/journal/40279

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Medicine, 43*(10), 1025-1042. doi: 10.1007/s40279-013-0069-2

Davis, H. (1991). Passive recovery and optimal arousal in ice hockey. *Perceptual and Motor Skills, 72*(2), 513-514. http://www.amsciepub.com/loi/pms

D'Auria, S., & Gabbett, T. (2008). A time-motion analysis of international women's water polo match play. *International Journal of Sports Physiology and Performance, 3*(3), 305-319. http://journals.humankinetics.com/ijspp

Deutsch, M.U., Maw, G.J., Jenkins, D., & Reaburn, P. (1998). Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *Journal of Sports Sciences, 16*, 561-570. http://www.tandfonline.com/toc/rjsp20/current#.VINWszHF8rU

Dillman, C.J., Stockholm, A.J., & Greer, N. (1984). Movement of ice hockey players. *International Symposium on Biomechanics in Sports,* 189-194.

DiMascio, M., & Bradley, P.S. (2013). Evaluation of the most intense high-intensity running period in English FA premier league soccer matches. *Journal of Strength and Conditioning Research, 27*(4), 909-915. http://www.nsca.com/

Dobson, B.P., & Keogh, J.W.L. (2007). Methodological issues for the application of time-motion analysis research. *Strength and Conditioning Journal, 29*(2), 48-55. http://www.nsca.com/

Docherty, D., Wenger, H.A., & Neary, P. (1988). Time-motion analysis related to the physiological demands of rugby. *Journal of Human Movement Studies, 14*, 269-277.

Dogramaci, S.N., Watsford, M.L., & Murphy A.J. (2011). Time-motion analysis of international and national level futsal. *Journal of Strength and Conditioning Research, 25*(3), 646-651. http://www.nsca.com/

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine, 33*(13), 973-991. http://link.springer.com/journal/40279

Duthie, G., Pyne, D., & Hooper, S. (2003). The reliability of video based time motion analysis. *Journal of Human Movement Studies, 44*(3), 259-271.

Duthie, G., Pyne, D., & Hooper, S. (2005). Time motion analysis of 2001 and 2002 super 12 rugby. *Journal of Sports Sciences, 23*(5), 523-530. doi: 10.1080/02640410410001730188

Edgecomb, S.J., & Norton, K.I. (2006). Comparison of global positioning and computer based tracking systems for measuring player movement distance during Australian Football. *Journal of Science and Medicine in Sport, 9*, 25-32. http://www.jsams.org/

Farlinger, C.M., Kruisselbrink, L.D., & Fowles, J.R. (2007). Relationships to skating performance in competitive hockey players. *Journal of Strength and Conditioning Research, 21*(3), 915-922. http://www.nsca.com/

Fernandez-Fernandez, J., Boullosa, D.A, Sanz-Rivas, D., Abreu, L., Filaire, E., & Mendez-Villanueva, A. (2014). Psychophysiological stress response during training and competition young female competitive tennis players. *International Journal of Sports Medicine,* http://dx.doi.org/10.1055/s-0034-1384544

Forbes, S.C., Kennedy, M.D., & Bell, G.J. (2013). Time-motion analysis, heart rate, and physiological characteristics of international canoe polo athletes. *Journal of Strength and Conditioning Research, 27*(10), 2816-2822. doi: 10.1519/JSC.0b013e318280d2a2

Game, A.B., & Bell, G.J. (2006). The effect of a competitive season and environmental factors on pulmonary function and aerobic power in varsity hockey players. *Applied Physiology, Nutrition, and Metabolism, 31*, 95-100. doi: 10.1139/H05-005

Game, A., Snydmiller, G., Bouchard, J., Reid, C., Gervais, P. & Bell, G. J. (2011). Heart rate responses to an on-ice repeated sprint test in varsity ice hockey players. *Applied Physiology, Nutrition and Metabolism, 36* Supplement: S2. http://www.nrcresearchpress.com/journal/apnm

Geithner, C.A., Lee, A.M., & Bracko, M.R. (2006). Physical and performance differences among forwards, defensemen, and goalies in elite women's ice hockey. *Journal of Strength and Conditioning Research, 20*(3), 500-505. http://www.nsca.com/

Gill, J., Bell, G., Draper, H., & Game, A. (2012). Comparing heart rate responses during practices and games in female varsity ice hockey players. *Applied Physiology, Nutrition and Metabolism, 36* Supplement: S13. http://www.nrcresearchpress.com/journal/apnm

Gomez, M.A., Pollard, R., & Luis-Pascual, J.C. (2011). Comparison of the home advantage in nine different professional team sports in Spain. *Perceptual and Motor Skills, 113*(1), 150-156. http://www.amsciepub.com/loi/pms

Green, H.J., Batada, A., Cole, B., Burnett, M.E., Kollias, H., McKay, S.,…Tupling, S. (2010). Cellular responses in skeletal muscle to a season of ice hockey. *Applied Physiology, Nutrition and Metabolism, 35*, 657-670. doi: 10.1139/H10-060

Green, H., Bishop, P., Houston, M., McKillop, R., Norman, R., & Stothart, P. (1976). Time-motion and physiological assessments of ice hockey performance. *Journal of Applied Physiology, 40*(2), 159-163. http://jap.physiology.org/front

Green, H.J., Daub, B.D., Painter, D.C., & Thomson, J.A. (1978). Glycogen depletion patterns during ice hockey performance. *Medicine and Science in Sports, 10*(4), 289-293.

Green, M.R., Pivarnik, J.M., Carrier, D.P., & Womack, C.J. (2006). Relationship between physiological profiles and on-ice performance of National Collegiate Athletic Association Division I hockey team. *Journal of Strength and Conditioning Research, 20*(1), 43-46. http://www.nsca.com/

Harrington, P. (2013). "WWHC: A history of women's hockey in Canada." *TSN.* Retrieved from http://www.tsn.ca/canadian_hockey/story/?id=419704

Hill-Haas, S.V., Dawson, B.T., Coutts, A.J., & Rowsell (2009). Physiological responses and time-motion characteristics of various small-sided soccer games in youth players. *Journal of Sports Sciences, 27*(1), 1-8. doi: 10.1080/02640410802206857

Hoff, J., Kemi, O.J., & Helgerud, J. (2005). Strength and endurance differences between elite and junior elite ice hockey players. The importance of allometric scaling. *International Journal of Sports Medicine, 26*, 537-541. doi: 10.1055/s-2004-821328

Hopkins, W.G. (2014). Sports science. Retrieved from http://www.sportsci.org/

Hopkins, W.G. (2000). Measures of Reliability in Sports Medicine and Science. *Sports Medicine, 30*(1), 1-15. http://link.springer.com/journal/40279

Hughes, M., Cooper, S-M., & Nevill, A. (2002). Analysis procedures for non-parametric data from performance analysis. *International Journal of Performance Analysis in Sport, 2*(1), 6-20. http://www.ingentaconnect.com/content/uwic/ujpa

Hughes, M., Hughes, M.T., & Behan, H. (2007). The evolution of computerized notational analysis through example of racket sports. *International Journal of Sports Science and Engineering, 1*(1), 2-28. http://www.worldacademicunion.com/journal/SSCI/

Hulka, K., Cuberek, R., & Svoboda, Z. (2013). Time-motion analysis of basketball players: A reliability assessment of Video Manual Motion Tracker 1.0 software. *Journal of Sports Sciences.* doi: 10.1080/02640414.2013.805237

Jackson, J., Game, A., Snydmiller, G., Draper, H., & Bell, G. (2012). Game heart rate responses during women's ice hockey. *Applied Physiology, Nutrition and Metabolism, 37* Supplement: S16. http://www.nrcresearchpress.com/journal/apnm

Jones, R.M., Cook, C.C., Kilduff, L.P., Milanovi, Z., James, N., Sporis, G.,…Vukovi, G. (2013). Relationship between repeated sprint ability and aerobic capacity in professional soccer players. *The Scientific World Journal,* 1-5. http://dx.doi.org/10.1155/2013/952350

Lafontaine, D., Lamontagne, M., & Lockwood, K. (1998). Time-motion analysis of ice-hockey skills during games. *International Symposium on Biomechanics in Sport, 1*, 481-484.

Léger, L. (1980). Le hockey sur la glace. In M. Nadeau & F. Peronnet (Eds.), *Physiologie appliquée de l'activité physique* (pp. 115-129). St Hyacinthe, QC: Edisem.

Léger, L., Seliger, V., & Brassard, L. (1979). Comparison among VO2 max values for hockey players and runners. *Canadian Journal of Applied Sport Sciences, 4*(1), 18-21.

Leone, M., Léger, L.A., Larivière, G., & Comtois, A.S. (2007). On-ice aerobic maximal multistage shuttle skate test for elite adolescent hockey players. *International Journal of Sports Medicine, 28*, 823-828. doi: 10.1055/s-2007-964986

Linseman, M.E., Palmer, M.S., Sprenger, H.M., & Spriet, L.L. (2014). Maintaining hydration with a carbohydrate-electrolyte solution improves performance, thermoregulation, and fatigue during an ice hockey scrimmage. *Applied Physiology, Nutrition and Metabolism, 39*, 1214-1221. doi: dx.doi.org/10.1139/apnm-2014-0091

Lupo, C., Tessitore, A., Cortis, C., Ammendolia, A., Figura, F., & Capranica, L. (2013). A physiological, time-motion, and technical comparison of youth water polo and Aquagoal. *Journal of Sports Sciences, 27*(8), 823-831. doi: 10.1080/02640410902946477

Lythe, J., & Kilding, A.E. (2011). Physical demands and physiological responses during elite field hockey. *International Journal of Sports Medicine, 32*, 523-528. doi: http://dx.doi.org/10.1055/s-0031-1273710

Nadeau, L., Richard, J-F., & Godbout, P. (2008). The validity and reliability of a performance assessment procedure in ice hockey. *Physical Education and Sport Pedagogy, 13*(1), 65-83. doi: 10.1080/17408980701444718

Nobes, K.J., Montgomery, D.L., Pearsall, D.J., Turcotte, R.A., Lefebvre, R., & Whittom, F. (2003). A comparison of skating economy on-ice and on the skating treadmill. *Canadian Journal of Applied Physiology, 28*(1), 1-11. http://www.nrcresearchpress.com/loi/cjap

Noonan, B.C. (2010). Intragame blood-lactate values during ice hockey and their relationships to commonly used hockey testing protocols. *Journal of Strength and Conditioning Research, 24*(9), 2290-2295. http://www.nsca.com/

Marsh, J. (n.d.). "Ice hockey." *The Canadian Encyclopedia.* Retrieved from http://www.thecanadianencyclopedia.com/articles/hockey-ice

Matthew, D., & Delextrat, A. (2009). Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *Journal of Sports Sciences, 27*(8), 813-821. doi: 10.1080/02640410902926420

Meckel, Y., Bishop, D., Rabinovich, M., Kaufman, L., Nemet, D., & Eliakim, A. (2013). Repeated sprint ability in elite water polo players and swimmers and its relationship to aerobic and anaerobic performance. *Journal of Sports Science and Medicine, 12*, 738-743. http://www.jssm.org

Merk, M. (2012). "52,892 new hockey players." *International Ice Hockey Federation.* Retrieved from http://www.iihf.com/home-of-hockey/news/news-singleview/browse/2/recap/7296.html?tx_ttnews%5BpS%5D=1351724400&tx_ttnews%5BpL%5D=2591999&tx_ttnews%5Barc%5D=1&tx_ttnews%5BbackPid%5D=187&cHash=e9809f1e09

McInnes, S.E., Carlson, J.S., Jones, C.J., & McKenna, M.J. (1995). The physiological load imposed on basketball players during competition. *Journal of Sports Sciences, 13*(5), 387-397. doi: 10.1080/02640419508732254

Montgomery, D.L. (1979). Characteristics of "old timer" hockey play. *Canadian Journal of Applied Sport Sciences, 4*(1), 39-42.

Montgomery, D.L. (2006). Physiological profile of professional hockey players – a longitudinal comparison. *Applied Physiology, Nutrition, and Metabolism, 31*, 181-185. doi: 10.1139/H06-012

Montpetit, R.R., Binette, P., & Taylor, A.W. (1979). Glycogen depletion in a game-simulated hockey task. *Canadian Journal of Applied Sport Sciences, 4*(1), 43-45.

O'Donoghue, P.G. (2008). Time-motion analysis. In Hughes, M., & Franks, I.M. (Eds.), *The Essentials of Performance Analysis: An Introduction* (pp. 180-205). New York: Routledge.

Ozanian, M. (2012). "NHL team values 2012: Toronto Maple Leafs are first hockey team worth $1 billion." *Forbes.* Retrieved from http://www.forbes.com/sites/mikeozanian/2012/11/28/nhl-team-values-2012-maple-leafs-first-hockey-team-worth-1-billion/

Palmer, M.S., Logan, H.M., & Spriet, L.L. (2010). On-ice sweat rate, voluntary fluid intake, and sodium balance during practice in male junior ice hockey players drinking water or a carbohydrate-electrolyte solution. *Applied Physiology Nutrition and Metabolism, 35*, 328-335. doi: 10.1139/H10-027

Paterson, D.H. (1979). Respiratory and cardiovascular aspects of intermittent exercise with regard to ice hockey. *Canadian Journal of Applied Sport Sciences, 4*(1), 22-28.

Paterson, D.H., Cunningham, D.A., Penny, D.S., Lefcoe, M., & Sangal, S. (1977). Heart rate telemetry and estimated energy metabolism in minor league ice hockey. *Canadian Journal of Applied Sports Science, 2*, 71-75.

Perš, J., Bon, M., & Kovačič, S. (2001). Errors and mistakes in automated player tracking. *In Proceedings of the Sixth Computer Vision Winter Workshop*, pages 25-36, Bled, Slovenia, February 7-9, 2001.

Perš, J., & Kovačič, S. (2000). A system for tracking players in sports games by computer vision. *Electrotechnical Review, 67*(5), 281-288. http://pe.org.pl/index.php?lang=1

Potteiger, J.A., Smith, D.L., Maier, M.L., & Foster, T.S. (2010). Relationship between body composition leg strength, anaerobic power, and on-ice skating performance in Division I men's hockey athletes. *Journal of Strength and Conditioning Research, 24*(7), 1755-1762. http://www.nsca.com/

Quinney, H.A., Dewart, R., Game, A., Snydmiller, G., Warburton, D., & Bell, G. (2008). A 26 year physiological description of a National Hockey League team. *Applied Physiology, Nutrition, & Metabolism, 33*, 753-760. doi: 10.1139/H08-051

Richard, J.F., Gionet, N., & Nowlan, J. (1995). Time-motion analysis of ice hockey goaltending. *Journal of Human Movement Studies, 29*(3), 115-131.

Roberts, S., Trewartha, G., & Stokes, K. (2006). A comparison of time-motion analysis methods for field-based sports. *International Journal of Sports Physiology and Performance, 1*, 388-399. http://journals.humankinetics.com/ijspp

Romet, T.T., Goode, R.C., Watt, T., Allen, C., Schonberg, T., & Duffin, J. (1978). Possible discriminating factors between amateur and professional hockey players in Canada. In F. Landry & W.A.R. Orban (Eds.), *Ice hockey: Research development and new concepts* (pp. 75-80). Miami, FL: Symposia Specialists.

Rudkin, S.T., & O'Donoghue, P.G. (2008). Time-motion analysis of first-class cricket fielding. *Journal of Science and Medicine in Sport, 11*, 604-607. doi:10.1016/j.jsams.2007.08.004

Sanderson, F.H., & Way, K.I.M. (1977). The development of objective methods of game analysis in squash rackets. *British Journal of Sports Medicine, 11*(4), 188. http://bjsm.bmj.com/

Seliger, V., Kostka, V., Grusova, D., Kovac, J., Machovcova, J., Pauer, M.,… Urbankova, R. (1972). Energy expenditure and physical fitness of ice-hockey players. *European Journal of Applied Physiology, 30*(4), 283-291. http://link.springer.com/journal/421

Sherar, L.B., Baxter-Jones, A.D.G., Faulkner, R.A., & Russell, K.W. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players? *Journal of Sports Sciences, 25*(8), 879-886. doi: 10.1080/02640410600908001

Spiering, B.A., Wilson, M.H., Judelson, D.A., & Rundell, K.W. (2003). Evaluation of cardiovascular demands of game play and practice in Women's Ice Hockey. *Journal of Strength and Conditioning Research, 17*(2), 329-333. http://www.nsca.com/

Stanula, A., Roczniok, R., Maszczyk, A., Pietraszewski, P., & Zajac, A. (2014). The role of aerobic capacity in high-intensity intermittent efforts in ice-hockey. *Biology of Sport, 31*(3), 193-199. doi: 10.5604/20831862.1111437

Statistics & History. (n.d.) Retrieved from http://www.hockeycanada.ca/en-ca/Hockey-Programs/Female/Statistics-History.aspx

Stevens, S.T., Lassonde, M., de Beaumont, L., & Keenan, P. (2008). In-game fatigue influences concussions in National Hockey League players. *Research in Sports Medicine, 16*, 68-74. doi: 10.1080/15438620701879020

Strath, S.J., Swartz, A.M., Bassett, D.R., O'Brien, W.L., King, G.A., & Ainsworth, B.E. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Medicine and Science in Sports and Exercise, 32*(9), 465-470. http://www.acsm.org/access-public-information/acsm-journals/medicine-science-in-sports-exercise

Stickland, M.K., Butcher, S.J., Marciniuk, D.D., & Bhutani, M. (2012). Assessing exercise limitation using cardiopulmonary exercise testing. *Pulmonary Medicine, 2012,* Article ID 824091, 13 pages. doi:10.1155/2012/824091

Stull, J.D., Philippon, M.J., & LaPrade, R.F. (2011). At-risk positioning and hip biomechanics of the Peewee ice hockey sprint start. *The American Journal of Sports Medicine, 39*(1), 29-35. doi: 10.1177/0363546511414012

Tarter, B.C., Kirisci, L., Tarter, R.E., Weatherbee, S., Jamnik, V., McGuire, E.J., & Gledhill, N. (2009). Use of aggregate fitness indicators to predict transition into the National Hockey League. *Journal of Strength and Conditioning Research, 23*(6), 1828-1832. http://www.nsca.com/

Taylor, J. (2003). Basketball: Applying time motion data to conditioning. *Strength and Conditioning Journal, 25*(2), 57-64. http://www.nsca.com/

Thomas, J.R., Nelson, J.K., & Silverman, S.J. (2011). *Research methods in physical activity* (6th ed.). Windsor, ON: Human Kinetics.

Thoden, J.S., & Jette, M. (1975). Aerobic and anaerobic activity patterns in junior and professional hockey. *Mouvement (Special Hockey), 2,* 145-153.

Upjohn, T., Turcotte, R., Pearsall, D.J., & Loh, J. (2008). Three-dimensional kinematics of the lower limbs during forward ice hockey skating. *Sports Biomechanics, 7*(2), 206-221. doi: 10.1080/14763140701841621

Vescovi, J.D. (2012). Sprint profile of professional female soccer players during competitive matches: Female athletes in motion (FAiM) study. *Journal of Sports Sciences, 30*(12), 1259-1265. doi: 10.1080/02640414.2012.701760

Vescovi, J.D., Murray, T.M., Fiala, K.A., & VanHeest, J.L. (2006). Off-ice performance and draft status of elite ice hockey players. *International Journal of Sports Physiology and Performance, 1*, 207-221. http://journals.humankinetics.com/ijspp

Virr, J.L., Game, A., Bell, G.J., & Syrotuik, D. (2013). Physiological demands of women's rugby union: Time-motion analysis and heart rate response. *Journal of Sports Sciences.* doi: 10.1080/02640414.2013.823220

White, D.J., & Olsen, P.D. (2010). A time motion analysis of bouldering style competitive rock climbing. *Journal of Strength and Conditioning Research, 24*(5), 1356-1360. doi: 10.1519/JSC.0b013e3181cf75bd

Wilson, G., & Hedberg, A. (1976). *Physiology of ice hockey: A report*. Ottawa, ON: Canadian Amateur Hockey Association.

Appendix A

Intra and Inter-Observer Reliability

Table 1A. Intra and inter-rater reliability analysis (n=10).

Movement Category	Intra (Freq)			Intra (Time)			Inter (Freq)			Inter (Time)		
	r	ICC	TE	r	ICC	TE	r	ICC	TE	r	ICC	TE
STND	0.81	0.50	4.10	0.58	0.36	8.73	0.90	0.68	2.54	0.58	0.39	7.85
FSTA	0.54	0.46	1.34	0.59	0.53	1.70	0.83	0.85	1.05	0.83	0.87	1.31
FGLD	0.95	0.96	1.94	0.87	0.90	9.21	0.92	0.94	2.41	0.93	0.94	6.96
FMOD	0.81	0.83	3.87	0.94	0.95	4.51	0.91	0.93	2.22	0.92	0.94	5.35
FMAX	0.84	0.88	1.71	0.97	0.98	1.48	0.88	0.78	1.82	0.92	0.91	2.50
BGLD	0.99	0.99	0.82	0.96	0.97	4.14	0.96	0.97	1.76	0.97	0.94	7.10
BMOD	0.84	0.87	2.14	0.94	0.96	2.81	0.89	0.92	1.57	0.85	0.86	4.44
STRG	0.48	0.54	2.03	0.40	0.45	3.45	0.74	0.72	1.34	0.81	0.85	1.97
MEAN	0.78	0.75	2.24	0.78	0.76	4.50	0.88	0.85	1.88	0.85	0.84	4.67

STND=Standing; FSTA=Forward start; FGLD=Gliding/cruising forward; FMOD=Moderate intensity forward skating; FMAX=High/maximal intensity forward skating; BGLD=Gliding/cruising backward; BMOD=Moderate intensity backward skating; STRG=Struggling. r=Pearson correlation, ICC=Intraclass correlation coefficient, TE=Typical error. Backward start and high/maximal intensity backward skating were not analyzed for reliability because of low number of observations.

Appendix B

Participant Characteristics

Table 1B. Participant fitness testing results.

Fitness Measure	Defense Average (n=8)	Forwards Average (n=14)
Body Composition		
Height (cm)	171.5 ± 6.6	168.7 ± 5.5
Weight (kg)	72.2 ± 5.6*	66.0 ± 4.7
Body Fat (%)	16.9 ± 2.7	17.3 ± 2.7
Anaerobic Fitness		
Peak Power (Watts)	869.9 ± 60.7	826.6 ± 78.0
Relative Peak Power (Watts/kg)	12.1 ± 1.3	12.4 ± 1.0
Mean Power (Watts)	765.7 ± 59.2	727.8 ± 58.4
Relative Mean Power (Watts/kg)	10.7 ± 1.2	11.0 ± 0.7
Fatigue Index (%)	21.0 ± 6.0	22.8 ± 6.5
Musculoskeletal Fitness		
Curl Ups (max reps)	95 ± 9	80 ± 28
Push Ups (max reps)	18 ± 8	18 ± 6
Combined Grip Strength (kg)	87.3± 11.4	87.2 ± 11.8
Sit & Reach (cm)	37.9 ± 4.3	36.5 ± 7.5
Speed & Agility		
40 metre Sprint (s)	6.4 ± 0.3	6.3 ± 0.3
Modified Illinois Agility (s)	11.6 ± 0.3	11.3 ± 0.3
Lower & Upper Body Power		
Vertical Jump Height (in)	16.5 ± 2.0	17.0 ± 1.7
Leg Power (Watts)	3753.1 ± 337.7	3522.0 ± 393.2
Medicine Ball Chest Pass (cm)	368.9 ± 16.6	356.5 ± 21.5
Aerobic Fitness		
Absolute VO_2 (L/min)	3.13 ± 0.21	2.92 ± 0.29
Relative VO_2 (ml/kg/min)	43.6 ± 4.3	44.6 ± 2.8
Max HR	186 ± 10.7	186 ± 6.7

Values are given in Mean ± SD.

* = Significantly different than the forward position ($p<0.005$).

Appendix C

Percentage of Heart Rate Maximum

Table 1C. Heart rate measures as a percentage of heart rate max.

HR Measurement	Position	Even Strength	Power Play	Penalty Kill
Peak Shift HR	D	97 ± 2	99 ± 3	97 ± 3
	F	96 ± 2	97 ± 4	95 ± 2
	AP	97 ± 2	98 ± 4	96 ± 3
Mean Shift HR	D	93 ± 2	93 ± 5	94 ± 3
	F	91 ± 3	93 ± 4	90 ± 2
	AP	92 ± 3	93 ± 5	92 ± 3
Recovery Low HR	D	69 ± 5	72 ± 7	71 ± 8
	F	66 ± 9	70 ± 7	73 ± 8
	AP	67 ± 7	71 ± 7	72 ± 8
Recovery Mean HR	D	79 ± 4	82 ± 6	79 ± 6
	F	76 ± 8	79 ± 6	77 ± 3
	AP	77 ± 6	80 ± 6	78 ± 5
INT 1 Recovery Low HR	D	51 ± 6		
	F	51 ± 6		
	AP	51 ± 6		
INT 1 Recovery Mean HR	D	59 ± 6		
	F	59 ± 4		
	AP	59 ± 5		
INT 2 Recovery Low HR	D	52 ± 6		
	F	53 ± 6		
	AP	53 ± 6		
INT 2 Recovery Mean HR	D	60 ± 6		
	F	58 ± 10		
	AP	59 ± 9		

PSHR=Peak Shift Heart Rate; MSHR=Mean Shift Heart Rate; RLHR=Recovery Low Heart Rate; RMHR=Recovery Mean Heart Rate; I1 RLHR=Intermission 1 Recovery Low Heart Rate; I1 RMHR=Intermission 1 Recovery Mean Heart Rate; I2 RLHR=Intermission 2 Recovery Low Heart Rate; I2 RMHR=Intermission 2 Recovery Mean Heart Rate. All values are given as mean ± SD and are based of the highest heart rate achieved during a VO_2 Max test. n=13

Appendix D

Shift Times

Table 1D. Shift times in different game-play situations.

Game-play Situation	Pos	Game 1	Game 2	Game 3	Average
Even Strength	D	45.5 ± 17.9	38.7 ± 13.1	54.0 ± 23.2	46.1 ± 18.1
	F	42.7 ± 19.1	39.7 ± 14.8	47.1 ± 19.0	43.2 ± 17.7
	AP	43.8 ± 18.7	39.3 ± 14.1	49.7 ± 20.9	44.3 ± 17.9
Penalty Kill	D	34.9 ± 16.0	32.3 ± 16.9	45.7 ± 27.1	37.6 ± 20.0
	F	32.6 ± 18.7	34.2 ± 17.7	45.3 ± 22.4	37.4 ± 19.6
	AP	33.7 ± 17.2	33.2 ± 17.2	45.5 ± 24.4	37.5 ± 19.6
Power Play	D	40.8 ± 23.6	37.8 ± 19.1	43.9 ± 18.7	40.8 ± 20.5
	F	44.1 ± 18.5	38.4 ± 15.8	41.1 ± 13.3	41.2 ± 15.9
	AP	44.6 ± 17.7	38.2 ± 17.1	42.2 ± 15.4	41.7 ± 16.7

Values are mean ± SD; n=18

Appendix E

Frequency and Duration of High Intensity Movements

Table 1E. Average high intensity movement measures.

Movement Category	Position	Duration (s)	Frequency	Duration per HI Movement (s)
High Intensity Movement Patterns	D	13.9 ± 18.6	7 ± 8	2.0 ± 2.2
	F	18.1 ± 22.8	9 ± 10	2.1 ± 2.2
	AP	16.7 ± 21.5	8 ± 10	2.1 ± 2.2

High intensity movement patterns include forward starting, maximum intensity forward skating, backward starting, maximum intensity backward skating, and struggling. D=Defense; F=Forwards; AP=All Players; HI=High Intensity. Duration and frequency values are given as an average per game. Values are mean ± SD; n=18

Appendix F

Number of Shifts

Table 1F. Number of shifts in different game-play situations**.**

Gameplay Situation	Pos	Game 1	Game 2	Game 3	Average
Even Strength	D	19 ± 1	18 ± 2	17 ± 1	18 ± 1
	F	15 ± 1	14 ± 2	14 ± 2	14 ± 2
	AP	16 ± 3	15 ± 3	15 ± 2	16 ± 3
Penalty Kill	D	4 ± 1	6 ± 2	3 ± 1	4 ± 1
	F	2 ± 1	4 ± 2	2 ± 1	3 ± 1
	AP	3 ± 1	5 ± 2	2 ± 1	3 ± 1
Power Play	D	3 ± 1	4 ± 2	3 ± 2	3 ± 2
	F	4 ± 1	3 ± 2	3 ± 2	3 ± 1
	AP	3 ± 1	3 ± 2	3 ± 2	3 ± 1

Values are mean ± SD; n=18