Knowledge creation and translation in sports biomechanics: applications in ice hockey

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April 2024

A thesis submitted to McGill University in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Kinesiology Sciences

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Abstract

The overarching goal of sports science research is to improve sports performance through the scientific process, though a gap exists between sport research and practice. Knowledge translation (KT)– the process by which research can be developed, implemented, and maintained over time to improve the applicability and effectiveness of research findings to end users– can help bridge this gap. The knowledge-to-action (KTA) process provides researchers with a framework for designing and implementing research projects that better meet the needs of stakeholders. This dissertation aimed to examine aspects of KT in sports science and employ the KTA process in creating and translating sports biomechanics knowledge, with an emphasis on ice hockey.

We began by creating knowledge to address gaps in skating coordination research. Specifically, our first two objectives were to compare lower extremity inter-segment coordination for high vs. low-calibre male hockey players during steady state forward skating strides (chapter 3) and male vs. female hockey players during forward accelerative skating (chapter 4). High-calibre males tended to use more out-of-phase modes of coordination for the shank-thigh segments than low-calibre males and high-calibre females. High-calibre females also demonstrated a greater change in mode of coordination between transitional ice contact events than high-calibre males. Findings suggest that utilising more out-of-phase modes of coordination may allow players to more easily adjust to optimal modes of coordination throughout skating strides, while more in-phase coordination may provide greater stability and act as a protective measure during skating.

The tailoring of knowledge and knowledge creation was examined next, as chapter 5 examined the relationship between sports science researchers and industry partners as well as the

process of identifying research endeavours that improve sport knowledge and guide product implementation. Interviews and focus groups were conducted with students, academic staff, and industry researchers who had at least one year of experience in their partnership and was analysed using thematic analysis. It was found that academic and industry research partners in sports science contend with competing institutional logics, namely differences in time cycles, goals, and learning needs that can hinder feelings of satisfaction in the partnership. However, despite these conflicting institutional logics, cultural differences could be reconciled through dialogue, leadership, and structuring, ultimately creating a mutually beneficial institutional logic.

Lastly, we examined the use of the KTA process to apply sports biomechanics knowledge with a First Nation hockey team. Biomechanical analyses were conducted with youth hockey players for skating and shooting tasks, and training on the use of remote presence sporting technology was provided to the coaching staff to facilitate project sustainability and allow for more community autonomy and governance. In this setting, the flexibility of the KTA process was an asset, but the lack of support for certain populations creates a need for using additional appropriate frameworks to address the context-specific gaps of the KTA process.

These findings had direct implications for their specific domains, but also shed light on the greater process of knowledge translation in sports biomechanics such as the inadequacy of the knowledge creation funnel in representing the realities of sport science research in which findings may not be synthesized prior to application. Ultimately, the KTA process can be an effective tool for translating sports biomechanics knowledge, though some adjustments to the process could be beneficial to KT outcomes in sports science. All aspects of research, from formulating research questions to applying research findings, should bear the process of taking knowledge to action in mind to maximize research relevance and applicability.

Abrégé

L'objectif principal de la recherche en sciences du sport est d'améliorer les performances sportives par le biais du processus scientifique, bien qu'il existe un fossé entre la recherche sportive et la pratique. L'application des connaissances (knowledge translation, KT) - le processus par lequel la recherche peut être développée, mise en œuvre et maintenue dans le temps afin d'améliorer l'applicabilité et l'efficacité des résultats de la recherche pour les utilisateurs finaux - peut contribuer à combler ce fossé. Le processus de mise en pratique des connaissances (Knowledge-to-action, KTA) fournit aux chercheurs un cadre pour la conception et la mise en œuvre de projets de recherche qui répondent mieux aux besoins des parties prenantes. Cette thèse visait à examiner les aspects de la mise en pratique de KT dans les sciences du sport et à utiliser le processus KTA dans la création et l'application des connaissances en biomécanique sportive, en mettant l'accent sur le hockey sur glace.

Nous avons commencé par créer des connaissances pour combler les lacunes de la recherche sur la coordination du patinage. Plus précisément, nos deux premiers objectifs étaient de comparer la coordination entre les segments des membres inférieurs chez les joueurs de hockey masculins de haut calibre par rapport à ceux de bas calibre pendant les foulées de patinage avant à l'état stable (chapitre 3) et chez les joueurs de hockey masculins par rapport aux joueurs de hockey féminins pendant le patinage accéléré vers l'avant (chapitre 4). Les hommes de haut calibre ont eu tendance à utiliser des modes de coordination plus déphasés pour les segments tibia-cuisse que les hommes de bas calibre et les femmes de haut calibre. Les femmes de haut calibre ont également démontré un plus grand changement de mode de coordination entre les événements de contact de transition sur la glace que les hommes de haut calibre. Les résultats suggèrent que l'utilisation de modes de coordination plus déphasés peut permettre aux joueurs de

s'adapter plus facilement à des modes de coordination optimaux tout au long des foulées de patinage, tandis qu'une coordination plus en phase peut fournir une plus grande stabilité et agir comme une mesure de protection pendant le patinage.

L'adaptation des connaissances et la création de connaissances ont ensuite été examinées, le chapitre 5 portant sur la relation entre les chercheurs en sciences du sport et les partenaires industriels ainsi que sur le processus d'identification des travaux de recherche qui améliorent les connaissances sur le sport et guident la mise en œuvre des produits. Des entretiens et des groupes de discussion ont été menés avec des étudiants, du personnel universitaire et des chercheurs industriels ayant au moins un an d'expérience dans leur partenariat et ont été analysés à l'aide d'une analyse thématique. Il a été constaté que les partenaires de recherche universitaires et industriels en sciences du sport sont confrontés à des logiques institutionnelles concurrentes, à savoir des différences dans les cycles temporels, les objectifs et les besoins d'apprentissage qui peuvent entraver les sentiments de satisfaction dans le partenariat. Toutefois, malgré ces logiques institutionnelles conflictuelles, les différences culturelles peuvent être conciliées par le dialogue, le leadership et la structuration, pour finalement créer une logique institutionnelle mutuellement bénéfique.

Enfin, nous avons examiné l'utilisation du processus KTA pour appliquer les connaissances en biomécanique sportive à une équipe de hockey des Premières Nations. Des analyses biomécaniques ont été effectuées sur de jeunes joueurs de hockey pour des tâches de patinage et de tir, et une formation à l'utilisation de la technologie sportive de présence à distance a été dispensée à l'équipe d'entraîneurs pour faciliter la viabilité du projet et permettre une plus grande autonomie et une meilleure gouvernance de la communauté. Dans ce contexte, la flexibilité du processus KTA a été un atout, mais le manque de soutien pour certaines populations crée le besoin d'utiliser d'autres cadres appropriés pour combler les lacunes du processus KTA spécifiques au contexte.

Ces résultats ont eu des implications directes pour leurs domaines spécifiques, mais ont également mis en lumière le processus plus large d'application des connaissances en biomécanique du sport, comme l'inadéquation de l'entonnoir de création de connaissances pour représenter les réalités de la recherche en sciences du sport, où les résultats peuvent ne pas être synthétisés avant d'être appliqués. En fin de compte, le processus KTA peut être un outil efficace pour l'application des connaissances en biomécanique du sport, même si certains ajustements au processus pourraient être bénéfiques pour les résultats de KT en sciences du sport. Tous les aspects de la recherche, de la formulation des questions de recherche à l'application des résultats de la recherche, devraient garder à l'esprit le processus de mise en pratique des connaissances afin de maximiser la pertinence et l'applicabilité de la recherche.

Acknowledgements

The completion of this dissertation would not have been possible without the seemingly endless support of many wonderful people to whom I will forever be thankful.

To my primary supervisor, Dr. Shawn Robbins, thank you for your guidance, mentorship, and patience. I cannot overstate how much I appreciated your consistency and knowing I always had your support. You've shown me what good leadership looks like and your faith in me to make it all work has allowed me more growth than I could have imagined at the start of this journey. Thank you for taking a chance on me, even if I *am* a Red Wings fan. To the other half of my wonderful supervisory duo, Dr. David Pearsall, thank you for your everlasting optimism. You provided me with more opportunities than I can list, and which moulded me into the biomechanist and human I am today. I will always be grateful that you gave me your card at ASB all those years ago – I am forever changed because of it.

Thank you to Bauer Hockey Ltd., NSERC, the McGill Department of Kinesiology & Physical Education (DKPE) and School of Physical & Occupational Therapy (SPOT), and the SSHRC of Canada for providing funding to support my work.

Thank you to my committee members, Dr. Peter Nugus and Dr. Lee Shaeffer. Your guidance and expertise have been integral to my success. To Dr. Jordan Koch, thanks for making school fun and for letting me play a major role in the Bodies of Power group. That research and the friendships I've gained from it will always hold a special place in my heart. To Dr. Jessica Kolopenuk, I have loved learning from you and I hope we will continue to find ways to work together. To Bobby Angelini, thanks for navigating the world of qualitative research with me.

To my Ice Hockey Research Group(+) family – Aimée, Aaron, Lily, Dan, Sean, Neil, Mikey, Matt, Harry, Taylor, Gab, Sam, Aïda, Laura, Kristin, Andrew, Nat, and Tayfun – you've made Currie home over these many years. Thanks for always allowing me to bounce a million and one thoughts off you and for keeping me sane (or close to it). Extra special shout out to Aimée, Aaron, and Lily for continuing to always make time for this friendship, and to my "Icy Hot Radical Glenns:" our nacho nights, mimosa brunches, and countless other shenanigans sustained me during my final semesters in Montreal; thanks for making me feel young and old at the same time. Finally, to the one who keeps us all in line, Phil Renaud, thank you infinitely for always making time to help (and have fun), especially when *our pets' heads are falling off*.

To the students and staff of the DKPE, thank you for giving me such an incredible community to be a part of and making my time in Montreal so special. Matt Slopecki, thanks for being my life raft, I am forever grateful for your friendship. To my "ride or die," Tayah Liska, thank you for always being there for me, even in subzero temperatures. To Derek Wasyliw & Mike Auksi, thanks for being the best traveling research buddies a girl could ask for. And to the rest of my KPE fam, you know who you are, and you will always have a friend in me.

To Dr. Arnel Aguinaldo, I owe my initial love of biomechanics to you and am ever thankful for your mentorship. Special thanks as well to my Meat Birds/Rowdy Crew and the Boat Squad for never letting me lose myself in the chaos.

To Mom, Dad, Mike, and Derek, thank you for never leaving my corner, even if you're not always entirely certain what it is that I'm doing. I could not be where or who I am today without your unwavering love and support. Thanks for always letting me follow my dreams, wherever they may take me, and for keeping things interesting along the way. I love you guys.

Finally, to *mon poisson*, Robert, thank you for being my rock. I've always been able to count on you to lift me up or bring me back to Earth when I need it, and knowing you were there for me (despite the distance) helped more than you know. Now, on to the next adventure.

Contributions to Original Knowledge

This dissertation is comprised of four original manuscripts. Chapter 3 has been published, chapter 4 is currently under review by a peer-reviewed journal, and chapters 5 and 6 are in preparation for submission.

Chapter 3, titled *"Differences in inter-segment coordination of high- and low-calibre ice hockey players during forward skating"* is the first study to evaluate lower limb coordination during ice hockey skating, particularly steady-state forward skating. This study is also the first study to compare skating coordination patterns in high- and low-calibre ice hockey players.

Chapter 4, titled *"Differences in inter-segment coordination of high-calibre male and female ice hockey players during forward skating starts"* is the first study to evaluate lower limb coordination during accelerative ice hockey skating. It is also the first study to compare skating coordination patterns of high-calibre male and female ice hockey players.

Chapter 5, titled *"Knowledge translation with an industry partner: a deeper look at academic-industry research collaboration in sports science"* is the first qualitative study of our knowledge to investigate academic-industry research partnerships specifically within sports science. The inclusion of participants on multiple levels of the partnership (i.e., academic staff, students, and industry staff) is uncommon, and this is the first study to investigate these perspectives in a sport science context.

Chapter 6, titled *"Using Knowledge-to-Action to guide the implementation of a remote biomechanical analysis program in a rural First Nation community"* is the first study to consider the use of the KTA process for implementing remote biomechanical analyses. This study is also the first to evaluate the use of the KTA action cycle in a sport context within a First Nation community.

Contributions of Authors

This dissertation consists of four original research projects that are primarily the work of Miss Caitlin M. Mazurek, completed under the joint supervision of Dr. Shawn Robbins and Dr. David Pearsall. Miss Mazurek has first authorship on all manuscripts as she was responsible for developing all research questions and research design; participant recruitment (chapter 5) and data collection (chapters 5 and 6); data processing, analyses, and interpretation; and manuscript preparation. Miss Mazurek was not involved in data collection for chapters 3 and 4 as they used existing datasets from Mr. Philippe Renaud and Miss Jaymee Shell, respectively.

For chapters 3 and 4, Mr. Philippe Renaud is listed as third author as he was involved in data collection, data processing, as well as reviewing the prepared manuscripts. Dr. Shawn Robbins contributed to the development of the research questions and study design, data analyses and interpretation of the results, and editing and refining the manuscripts up to publication. Dr. David Pearsall contributed to the research designs and provided insight for final version of the manuscripts.

For chapter 5, Mr. Bobby Angelini is listed as second author in recognition of his contributions to data collection, data analysis and interpretation, and reviewing the prepared manuscript. Dr. Peter Nugus provided methodological expertise and contributed to the study design, interpretation of results, and editing and refining of the manuscript. Dr. Shawn Robbins played a role in the conceptualization of the study and editing and refining of the manuscript throughout the writing process.

For chapter 6, Mr. Philippe Renaud is listed as second author in recognition of his contributions to study conceptualization, participant recruitment, data collection, and preparation of the manuscript. Dr. Jordan Koch and Dr. Jessica Kolopenuk played critical roles in the development of the project and obtaining funding. Dr. Jordan Koch also assisted with participant recruitment, data collection, and was involved in editing and refining the manuscript. Dr. Jessica Kolopenuk played a key role in the writing process and preparation of the manuscript.

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List of Abbreviations

-2LL	–2 log-likelihood
2D	two-dimensional
3D	three-dimensional
CIHR	Canadian Institutes of Health Research
COM	centre of mass
CRP	continuous relative phase
GRF	ground reaction force
HLM	hierarchical linear models
IIHF	International Ice Hockey Federation
iKT	integrated knowledge translation
KT	knowledge translation
KTA	knowledge-to-action
NSO	national sport organization
PC	principal components
PCA	principal component analysis
PYD	positive youth development
REB	research ethics board
ROM	range of motion
WHO	World Health Organization

Chapter 1: Introduction

1.1 Introduction to Knowledge Translation

1.1.1 Defining Knowledge Translation

Knowledge translation (KT) refers to the process by which research can be developed, implemented, and maintained over time to improve the applicability and effectiveness of research findings to end users, though there is no single agreed upon definition for KT. The World Health Organization (WHO) officially defines KT as "the synthesis, exchange, and application of knowledge by relevant stakeholders to accelerate the benefits of global and local innovation in strengthening health systems and advancing people's health," (WHO, 2016). The Canadian Institutes of Health Research (CIHR) definition of KT is "a dynamic and iterative process that includes synthesis, dissemination, exchange, and ethically-sound application of knowledge to improve [health], provide more effective health services and products, and strengthen the healthcare system" (CIHR, 2015). While these definitions appear to be very similar, the CIHR definition highlights the fluidity of the KT process, whereas the WHO definition draws attention to the importance of involving stakeholders at all levels of the research process. Both concepts are integral to KT, which places an emphasis on mixing scientific knowledge with local contextualized knowledge practices through a complex system of interactions between researchers and knowledge users to foster sustainable and contextually appropriate change (Graham & Tetroe, 2010; Kitto et al., 2012).

Approaches to KT can be broadly divided into two categories: end-of-grant KT and integrated KT. End-of-grant KT tends to view KT as a knowledge transfer problem, whereas integrated KT tends to see it as a knowledge production problem. End-of-grant KT refers to activities intended to diffuse, disseminate, or apply the results of a research project and is the most used approach to KT, particularly in sports science (CIHR, 2015). The appropriateness of KT activities to each research project is important to consider and there is a need to disseminate what is already known but, in designing impactful sports science research, it is also important to consider the needs of knowledge users (Gould, 2016). The intention of integrated KT is to improve the relevance of research findings and increase the likelihood of their adoption into practice by involving knowledge users from the development of the research question to dissemination of results (CIHR, 2015).

1.1.2 Knowledge-to-Action

KT conceptual frameworks can provide a frame of reference for organizing thinking, guide action and interpretation, and potentially increase the likelihood of changed practice (Field et al., 2014; Holt, Pankow, Camiré, et al., 2018). Because there are so many components housed within the KT process, several conceptual frameworks, models, and theories have been established to assist researchers in taking a more systematic approach to the whole or portions of the KT process. As described by Nilsen (2015) the overarching aims of theories, models, and frameworks within KT are: 1) describing and/or guiding the process of translating research into practice (including the discovery/production of research-based knowledge), 2) understanding and/or explaining influences on implementation outcomes, and 3) evaluating implementation.

The knowledge-to-action (KTA) process is one of the more popular knowledge translation models and has been adopted by the CIHR as the accepted model for promoting the application of research as well as a framework for the process of KT (Straus et al., 2013). In this model (Figure 1.1), the knowledge-to-action process concerns both knowledge creation and knowledge application (referred to as the action cycle) as part of an iterative, complex and dynamic process, with fluid and permeable boundaries between the two main components (Graham et al., 2006). The knowledge creation component is divided into primary studies (first-generation knowledge), the synthesis of existing knowledge (second-generation knowledge), and knowledge tools/products (third-generation knowledge). Additionally, each phase of knowledge creation can be tailored to the needs of potential knowledge users (Holt, Pankow, Camiré, et al., 2018). The knowledge funnel feeds directly into the action cycle through the initial step of identifying, reviewing, and selecting knowledge for application. This action step should also guide the knowledge creation funnel in determining a problem that may need to be investigated or knowledge that needs to be tailored for a particular application.

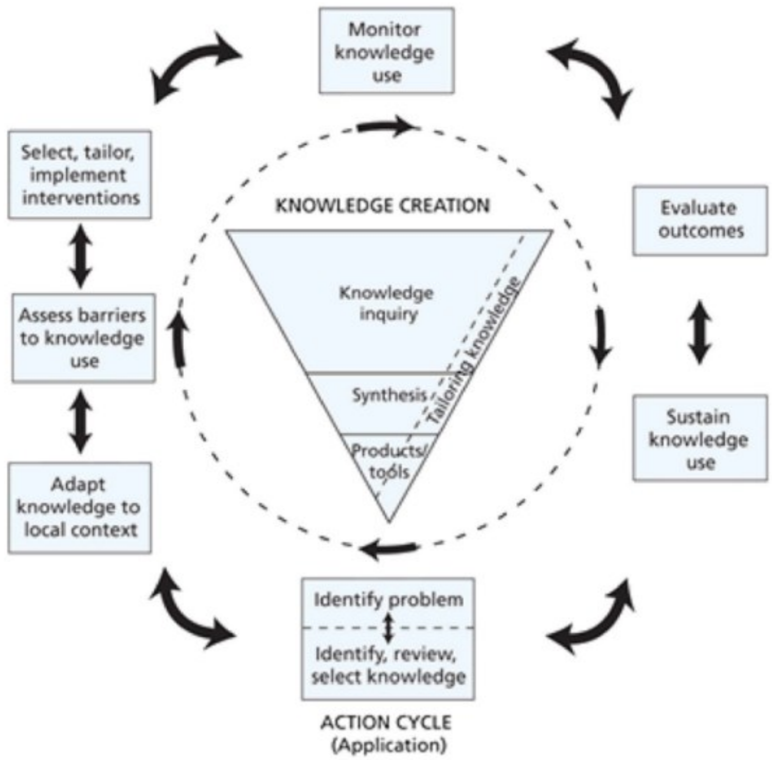

Figure 1.1 The Knowledge to Action Framework (Graham et al., 2006)

The action cycle focuses on the implementation or application of knowledge via dynamic phases. Each phase of the action cycle may be influenced by the other phases and as such, phases may occur sequentially or simultaneously (Graham et al., 2006). Phases of the action cycle are as follows: 1) identify the knowledge-to-action gaps; 2) adapt the identified knowledge or research to the local context; 3) assess barriers/facilitators to knowledge use; 4) select, tailor, and implement interventions to promote the use of knowledge; 5) monitor knowledge use; 6) evaluate the outcomes of using the knowledge; 7) sustain ongoing knowledge use. This framework has been widely used in the literature to guide knowledge translation within a variety of settings and topics, highlighting its adaptability (Field et al., 2014).

1.2 Thesis Rationale

Biomechanics is defined as the use of mechanical principles in the study of living organisms (Hall, 2012). One common application for biomechanics is in sport, with improving performance and preventing injury serving as the two primary goals (Zheng & Barrentine, 2000). Sports biomechanics knowledge has often been primarily disseminated via academic journals rather than translated directly to and with specific knowledge users, resulting in suboptimal knowledge relevance and application. The idea that research knowledge must be made more accessible and understandable for end-users is often depicted as the sole solution to bridging the gap between research and practice in sports science (Bekker et al., 2018). However, the need for research teams to conduct relevant research by incorporating knowledge users and other stakeholders in the research development process has been established. Without further examination of other aspects of the complex process of knowledge translation within sports science, there is an increased risk of research not being effectively transferred and applied to the knowledge users, thus limiting the benefits of sports science research.

Despite over 1.5 million registered ice hockey players in 70 countries worldwide, and an increase in the number of female registered players from 153,665 in 2007 to over 230,000 in 2020, ice hockey biomechanics have been studied less extensively than many other popular sports, especially for women (IIHF, 2020). Even less research has been conducted on actual ice, where gameplay takes place, though investigation of skating biomechanics may have implications for human locomotion overall. Given the popularity of ice hockey in Canada, paired with the dearth of hockey biomechanics knowledge and examination of application in local contexts, ice hockey provides a valuable setting for KT research.

It is the overall purpose of this dissertation to examine the process of creating and translating sport biomechanics knowledge within the knowledge-to-action (KTA) framework. More specifically, participation in knowledge creation (through knowledge inquiry) to address gaps in the literature for skating coordination, examination of academic and industry research partnerships that guide knowledge creation and involve the tailoring of knowledge, and in applying sports biomechanics knowledge within a specific community setting (action cycle). By engaging in different steps of the KTA framework, we hope to provide insight into current practices in the field that may help ultimately drive more effective knowledge translation practices in sports biomechanics, and specifically in ice hockey.

1.3 Thesis Objectives

The overall purpose of this work was to examine aspects of knowledge translation (KT) in sports science and employ the knowledge-to-action (KTA) process in creating and translating sports biomechanics knowledge. Specific objectives include:

1. To compare lower extremity inter-segment coordination between high- and low-calibre

male ice hockey players during forward full stride skating on a real ice surface. *(Chapter 3 – knowledge creation: knowledge inquiry)*

2. To compare lower extremity inter-segment coordination between high-calibre male and female ice hockey players during forward skating starts on a real ice surface. *(Chapter 4 – knowledge creation: knowledge inquiry)*

3. To examine the relationship between sports science researchers and industry partners and the process of identifying research endeavours that improve sport knowledge as well as guide product implementation. *(Chapter 5 – knowledge creation: tailoring knowledge inquiry)*

4. To investigate the use of KTA as a guiding process for implementation of a remote biomechanical analysis program with coaches in a rural Indigenous community and identify the strengths and limitations of this approach. *(Chapter 6 – action cycle)*

Chapter 2: Literature Review

The overarching goal of sports science research is improving sports performance through the use of scientific process (Bishop, 2008); however, it has been well-established that a gap exists between sport research and practice (Finch, 2006; Gould, 2016; Verhagen et al., 2014). Sports science research is often thought not to be relevant by potential knowledge users (e.g., coaches) or is not disseminated in a way that is easily accessed or applied (Martindale & Nash, 2013; Reade, Rodgers, & Hall, 2008). The knowledge-to-action cycle accounts for everything from initial knowledge inquiry to sustained use of tailored knowledge and can serve as a means for closing the research to practice divide.

2.1 Knowledge Creation in Ice Hockey

When considering the knowledge creation component of KT, especially in the knowledge inquiry (first-level knowledge) portion of the knowledge creation funnel, researchers must consider both what is missing in the existing literature as well as what information is relevant to knowledge users. Collaboration with stakeholders and knowledge users (e.g., industry research and development teams or coaches and athletes) can help identify a problem that needs addressing and examining the existing literature will inform whether the next step should be knowledge inquiry, synthesis, tailoring of knowledge, etc. In order to know what is missing from the literature, a comprehensive understanding of existing findings is necessary. This concept can be applied within sport and more specifically, the context of ice hockey skating biomechanics.

2.1.1 Introduction to Hockey Skating

Skating is the most fundamental and important skill in the game of ice hockey and while a fair amount of information has been established, there are still many knowledge gaps to be filled (Bracko, 2004). In this fast-paced sport, solid skating technique is crucial to be able to out-pace your opponent, create passing and scoring opportunities, and manoeuvre around opponents and obstacles. While skating bears similarities– such as a biphasic movement pattern– to other forms of human locomotion, it is also unique largely due to the properties of the surface on which it takes place. The low coefficient of friction between the ice surface and skate blade allows players to glide but also requires a different propulsion technique than those seen in walking or running, as sufficient force cannot be produced by simply pushing off parallel to the skate blade and opposite the desired direction of motion.

Ice hockey skating tasks can be divided into four main categories: linear skating, angular skating, starts, and stops. Different player positions require certain skating tasks to be used more frequently than others; for example, defensemen tend to utilize more backward skating than forwards (Bracko et al., 1998). Forward skating could be considered the most foundational skating task, as well as the most frequently used in gameplay.

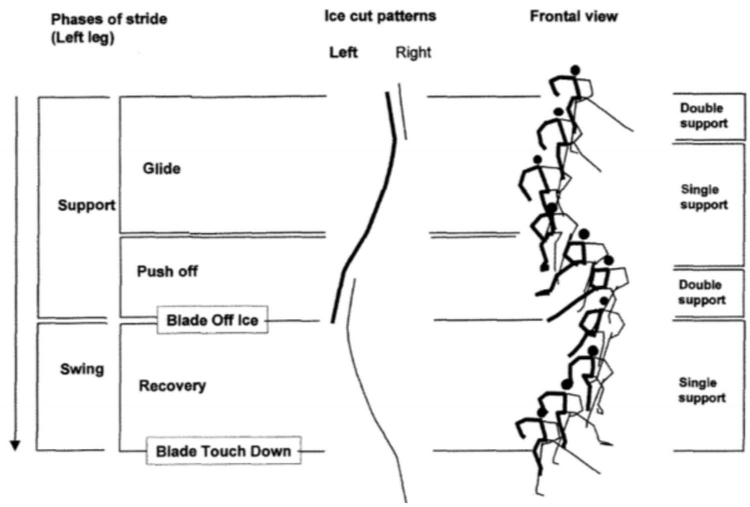

Figure 2.2.1 Lateral displacement of body during forward skating. Ice cuts depict sinusoidal skating pattern in the transverse plane (Pearsall et al., 2000).

Forward skating strides consist of alternating periods of double and single support (Figure 2.1) and can be divided into a support phase and a swing phase (Marino, 1979; Pearsall et al., 2000). When focusing on one leg, the support phase refers to the period of time that the leg is in contact with the ice and can be further broken down into glide (~0-40% of total stride) and push-off (~40-60% stride) sub-phases. The swing (or recovery) phase (~60-100% stride) refers to the time following push-off when the skate is not in contact with the ice until the beginning of the subsequent stride upon initial contact (Figure 2.2). Although skating tasks from all four categories are crucial to gameplay, accelerative and steady-state forward skating are the most used, and therefore necessitate further investigation.

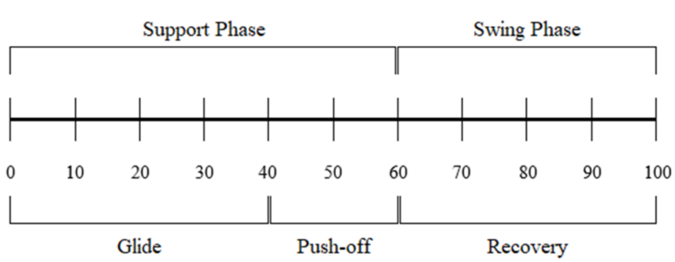

Figure 2.2 Phases of steady-state forward skating stride and % of stride cycle (Mazurek et al., 2023).

2.1.2 Established Skating Kinematics

Biomechanical analysis of ice hockey tasks, such as measures of player's body kinematic patterns, can highlight elements related to optimal technique and performance. For example, kinematic studies of forward skating starts and strides have found specific lower extremity angle differences between sex (Budarick et al., 2018; Shell et al., 2017) and skill level (Renaud et al., 2017; Robbins et al., 2018). Hence, kinematic analysis can yield relevant information to guide coaches and trainers in providing the most appropriate training techniques for their athletes. Additionally, identifying factors governing the locomotion of skating can reveal important information about coordination (Krasovsky & Levin, 2010). As skating is such an integral component of ice hockey, establishing an in-depth understanding of this task is warranted.

Forward Full Stride Skating

Kinematic differences between high- and low-calibre male hockey players have been compared using a range of equipment including 2-Dimensional video, electro-goniometry, accelerometers, and 3-Dimensional motion capture (Buckeridge et al., 2015; McCaw & Hoshizaki, 1987; Robbins et al., 2018). One study by McCaw and Hoshizaki (1987) filmed university students categorized as novice, intermediate, and elite skaters as they skated at maximal velocity. They found that step length did not significantly differ between skill levels but step rate, which was significantly correlated with skating velocity, was significantly higher in elite and intermediate skaters. Greater joint flexion prior to extension and greater joint displacement was also prevalent with increased skill level, though for the intermediate group, hip values were closer to the elite skaters, and knee values were closer to novice skaters. This study suggests that there may be a different rate of mature pattern development at the joints, necessitating further study of skill level differences in skating.

Robbins et al. (2018) compared hip, knee, and ankle joint angles during full stride skating in male hockey players who had played at (“high-calibre”) and below (“low-calibre”) the major junior level. The high-calibre group was found to have greater hip flexion throughout the stride and greater knee extension at push off than the low-calibre group for steady state skating. High-calibre skaters also demonstrated increased knee external rotation at push-off and increased ankle inversion at the end of push-off and recovery phases. These strategies may allow the skate edges to be utilized more effectively to increase horizontal ground reaction force (GRF) and transition quickly from the ice surface towards the midline for faster recovery, respectively (Robbins et al., 2018).

Another study comparing angular displacements of the knee (sagittal) and hip (sagittal and frontal) of high- and low-calibre male skaters during accelerative into steady state strides and had similar findings as the previously mentioned studies (Buckeridge et al., 2015). High-calibre skaters demonstrated greater hip extension at toe-off and greater hip range of motion (ROM) than low-calibre skaters. Alternatively, low-calibre skaters demonstrated greater hip abduction at initial contact, glide, and push-off phases, which suggests they are not making the most efficient use of frontal plane hip ROM and likely contributes to their slower velocity (Buckeridge et al., 2015). High-calibre male skaters have been consistently faster than low-calibre male skaters, supporting the idea that identifying biomechanical differences between these groups can highlight the variables relevant to high performance (Buckeridge et al., 2015). Findings suggest that different skill levels may use different strategies in an attempt to reach the same goal. Identifying biomechanical differences between skill levels can provide insight into the variables that contribute to high-level performance and allows for further inference into skill development.

Forward Skating Starts

Differences between skill levels for male as well as female ice hockey players have also been compared in skating starts. Although forward skating starts are an aspect of forward skating overall, significant differences exist between skating patterns of accelerative strides and steady state strides. Buckeridge et al. (2015) compared angular displacements of the knee and hip for high- and low-calibre males during maximal effort forward skating starts and speculated that significantly greater knee extension velocity during accelerative strides contributed to the increased speed of high-calibre skaters. Similar to steady-state forward skating, high-calibre skaters also demonstrated greater hip ROM than low-calibre skaters. For elite vs. non-elite female ice hockey players, elite players were faster overall and had better on-ice fitness than non-elite players, but kinematics were not assessed (Bracko, 2001).

Another kinematic analysis of high- and low-calibre male hockey players during forward skating starts found that high-calibre skaters had shorter skate contact times (Renaud et al., 2017). They also demonstrated higher stride rates during accelerative strides and considerably higher centre of mass (COM) "bounce" than low-calibre skaters. High-calibre males had significantly higher velocity in the side-to-side direction and greater acceleration in both side-to-side and vertical directions in the first step, as well as greater hip external rotation over the first four steps.

Kinematic differences between male and female ice hockey skaters have been examined much less thoroughly than male high- and low-calibre skaters, though further investigation can help establish technical characteristics that may explain performance differences and guide training techniques. One study comparing the kinematics of high-calibre male and female hockey players found that females had ~10 degrees lower hip abduction throughout skating stance and ~10 degrees greater knee extension at initial ice contact than males (Shell et al., 2017). Males had greater maximum skating speeds, which was also found in a study conducted with the same cohort on forward skating run-to-glide mechanics (Budarick et al., 2018). Peak speed bears a strong correlation to peak leg strength, which was also found to be greater in males as determined by single leg jump distances (Budarick et al., 2018; Shell et al., 2017) Although males and females had similar stride-by-stride accelerations following the initial accelerative steps, males generated greater forward acceleration in their first four steps with accelerations particularly in the first two strides having the greatest effect on final speed (Budarick et al., 2018).

Despite many similarities between findings for accelerative and steady-state skating, the greatest differences between high- and low-calibre males exists during accelerative skating. During accelerative steps, stride rate was significantly higher in high-calibre males than low-calibre males whereas there was not a significant difference between high-calibre males and females. Between high-calibre males and females, significant differences particularly occurred during the first two strides. Significant distinctions between male and female strides suggest that skill development may differ for female hockey players, however, the limited number of studies including females or comparing sexes is a limitation. The noted variations in kinematics between skill level as well as sex offer insight into differences in skill development for skating, but do not provide a complete understanding of skating locomotion.

2.1.3 Identifying Knowledge Gaps: Skating Coordination

Skating locomotion, much like walking or running, is a complex, dynamic movement which requires considerable coordination (Longworth et al., 2018). In hockey biomechanics research to date, joints and segments have often been studied in isolation (Budarick et al., 2018; Mavor et al., 2018; Renaud et al., 2017; Robbins et al., 2018; Upjohn et al., 2008). While establishing individual joint kinematics is beneficial, understanding how the body coordinates segments and how these parts are integrated to achieve task specific goals can also provide valuable information about skating. Much like single joint or segment data, patterns of relative motion can be important indicators of performance. Inter-segment coordination can be defined as the relationship and relative timing between different body segments throughout a task (Krasovsky & Levin, 2010). Once phase angles have been calculated for segment pairs, continuous relative phase (CRP) can be used to quantify coordination. CRP is calculated by plotting the position of a segment relative to its velocity and comparing the plots – or phase planes – of two body segments to determine the absolute difference between the two (Eggleston et al., 2018; Robertson et al., 2013). Phase angle differences between segments can be expressed in degrees between 0 and 180 and a CRP value of 0 degrees indicates the segments are moving completely in-phase with one another (e.g., windshield wipers moving side to side together). As the value increases, segments are classified as more out-of-phase, and a value of 180 degrees indicates the segments are moving completely anti-phase (e.g., windshield wipers rotating to the centre at the same time) (Hamill et al., 1999).

Previous research has used CRP to evaluate coordination in a variety of sports providing a wide range of insight. In distance running, out-of-phase coordination has been associated with transitions throughout the gait cycle, and it has been suggested that this coupling pattern may allow for an easier and faster switch to a new coupling pattern in response to perturbations (Dierks & Davis, 2007). Additionally, shank-foot coordination during initial sprint accelerations had broadly similar coordination patterns for experienced male and female sprinters as a result of the specific requirements and limitations of the task (i.e., task constraints) (Donaldson et al., 2022). Seifert et al. (2010) compared inter-limb coordination of recreational swimmers to competitive swimmers during complete breaststroke cycles and found that recreational swimmers used largely in-phase elbow-knee coordination. Alternatively, a study on coordination and skill level in gymnastics long swing identified that elite gymnasts utilised more in-phase hip-shoulder coordination while successful novices tended to demonstrate more out-of-phase coordination (Williams et al., 2016). Such discrepancies in coordination suggest that the use of in-phase or out-of-phase coordination within a movement is highly task-specific.

In addition to discrepancies in coordination between tasks, coordination differences based on sex have also been highlighted. During walking, women demonstrated more in-phase coordination of the pelvis-thigh but more out-of-phase coordination of the shank-foot than men (Ghanavati et al., 2014). These findings suggest that men and women reduce their task control effort by altering the phase dynamics of different segment pairs. Given the similarities between walking/running and skating, it could be hypothesised that modes of coordination may be similar. Therefore, more out-of-phase coordination may be advantageous during skating to allow for adaptation to perturbations, though potential sex differences may be dependent on the segment pair.

The investigation of coordination during short-track speed skating has highlighted the use of more in-phase coordination during push-off strokes and cornering phases (Khuyagbaatar, 2017). While this does provide insight into skating coordination, significant differences in speed skating and ice hockey skating mechanics limit the applicability of these findings to hockey. The identification of gaps in knowledge such as those previously outlined allow us to tailor research projects appropriately and conduct relevant research. In this case, we can engage in the knowledge inquiry component of knowledge creation and create first-generation knowledge that provides insight into lower body segment coordination during forward skating starts and full stride forward skating and determine differences between sexes and skill levels.

2.1.4 Implications for Improving Performance

Overall performance in ice hockey is dependent upon a combination of factors including physical condition, individual skill, equipment, and environment (Federolf et al., 2008). The goal in comparing high- and low-calibre ice hockey players is to identify the extent to which these factors contribute to high level performance. The more that is known about differences in the mechanics of these populations, the more robust conclusions can be drawn regarding high level performance characteristics. Comparing male and female skater performance also allows for training and equipment to be better tailored to female skaters, which may improve their overall performance. To bring knowledge from the literature into coaching practices and industrial applications, the gap between sports scientists and coaches or other end-users must be more effectively bridged.

2.2 Applying KTA: Knowledge Translation in Sport

As evidenced by the various definitions of knowledge translation, the emphasis in KT has historically been focused on general health and healthcare systems. However, the KTA process has shown utility in the creation and translation of sport psychology and sports medicine research, and the flexibility of KTA can be useful in guiding other sports science research as well (Holt, Camiré, et al., 2018; Provvidenza et al., 2013). Within sports science research, there are a number of potential knowledge users and stakeholders who can be involved in the research process, depending on the scope of the project. Researchers may choose to engage coaches, sports organizations/governing bodies, industry partners, sports medicine practitioners, parents, athletes, or community members in various aspects of the KT process as deemed relevant and necessary per the focus of the research.

In an effort to gain insight into how knowledge implementation can be improved, some existing studies have evaluated the relationships between sports science researchers and stakeholders including coaches, Canadian national and provincial sport organizations, and community stakeholders. Although coaches generally believe that sports science makes a significant contribution to sports performance (Reade, Rodgers, & Spriggs, 2008), they also tend to feel that the research conducted lacks practical application and a direct relevance to their needs (Bishop, 2008; Martindale & Nash, 2013). Coaches have cited a lack of time to look for new ideas and a lack of interest in reading academic publications (Reade, Rodgers, & Spriggs, 2008) which highlights the need for sports scientists to become more active in disseminating research results through a range of modalities beyond academic avenues to enhance effectiveness (Martindale & Nash, 2013; Williams & Kendall, 2007). When it comes to the utilization of research evidence in sport organizations, research that addresses the priorities of stakeholders (Holt, Pankow, Tamminen, et al., 2018) as well as strong partnerships between sport scientists and the organization may facilitate the use of research findings (Kendellen et al., 2017). Sports science findings can also more effectively inform evidence-based policy change in sport through successful researcher and stakeholder partnerships. For example, McKay et al. (2014) engaged in knowledge exchange meetings with community stakeholders to inform body checking policy in youth ice hockey. These findings support the concept that the involvement of stakeholders in the research process and tailoring of knowledge to the needs of knowledge users is crucial to successful research implementation into practice outside of academic channels (Field et al., 2014).

2.3 Tailoring Knowledge Inquiry

Although the importance of knowledge translation in bridging the research to practice gap has been increasingly recognized over the last twenty or so years, sports science has been relatively slow to adopt and incorporate a KT perspective into research (Grimshaw et al., 2012; Richmond et al., 2014). Understanding the intricacies of relationships with different stakeholders is particularly important given that the same methods of knowledge dissemination will likely not work effectively with all potential end-users. For example, while the communication of research findings in peer-reviewed journal publications or conference presentations is an effective way to reach an audience within the research community, it is not very effective in getting information to other stakeholders. Coaches primarily learn from other coaches, citing a lack of time to look for new ideas and a lack of interest in academic publications as contributors to why they do not source information directly from sport scientists (Kubayi et al., 2019; Reade, Rodgers, & Spriggs, 2008). Sport organizations may experience difficulty interpreting and judging the credibility of research findings, thus limiting the usefulness of research disseminated via academic journals for this audience (Holt, Pankow, Camiré, et al., 2018). Despite these findings, implementation of research outside of traditional academic portals is often overlooked (Finch, 2011).

Successfully building relationships with stakeholders and knowledge users is continually at the foundation of successful research tailoring and implementation. Partnered academic and industry research teams hold a convenient position for implementing knowledge translation processes, with stakeholders (in this case, industry partners) involved in the development of research by/with the academic team and results disseminated directly to the industry team. The way academic and industry research partnerships function offers an excellent opportunity to employ the knowledge-to-action framework, as the basis of KT is to incorporate stakeholders into research development and implementation. However, due to the "black box" nature of collaborations with industry partners (i.e., delimited sharing of intellectual property), it is possible that there is much room for improvement in making the collaborative process between research teams more efficient and effective. To accomplish this, more information is needed about the processes that are currently in place.

Academic-industry partnerships have long been deemed important for driving innovation, enough so that whole organizations– such as Mitacs in Canada– are dedicated to facilitating and funding these partnerships. Billions of dollars of industry funding are invested in academic research annually and perhaps unsurprisingly, research investigating such partnerships has often been centred around output (Boccanfuso, 2010). Examples include whether industry funding impacts trial outcomes in research and publication volume or scholarly impact for academic researchers (Eloy et al., 2017; Ruan et al., 2018; Sismondo, 2008). Chandrasekaran et al. (2014) found that students and staff at an Australian university tended to view academic-industry partnerships positively, however, the inner workings of these partnerships have hardly been investigated at the inter-personal level. Furthermore, given that the biomechanics community is relatively small, the way academic-industry partnerships operate within sports science may be unique to other disciplines.

2.4 Translating Biomechanics Knowledge to Practice in Ice Hockey (Action Cycle)

Knowledge users are unlikely to utilize research evidence for which the application has not been clearly identified, therefore, there is a need for sports science to break the tradition of focusing on outcomes that do not explicitly acknowledge how the research will be applied (Bishop, 2008; Holt, Pankow, Camiré, et al., 2018; Kilic & Ince, 2015; Kubayi et al., 2019). Integrated knowledge translation (iKT) applies the principles of KT to the entire research process rather than focusing solely on the dissemination or application of research findings, as with an end-of-grant KT approach (CIHR, 2015). Emphasis in iKT is placed on a collaboration between researchers and knowledge users to develop research more relevant to knowledge users and therefore more likely to be adopted into practice.

2.4.1 Integrated Knowledge Translation and Fostering Relationships

When creating and utilizing the partnerships developed for iKT projects, a multidisciplinary and/or interdisciplinary approach may be used. One way a multidisciplinary approach can be defined is people from different disciplines working together, each drawing on their particular disciplinary knowledge. One example of a multidisciplinary approach to iKT in action is the integration of life skills into Golf Canada's youth programs (Kendellen et al., 2017). Researchers and Golf Canada staff members collaborated to develop and integrate the life skills curriculum using their respective strengths. Researchers primarily applied their disciplinary knowledge (e.g., life skills and intervention development; program evaluation) to the methods and Golf Canada staff applied their disciplinary knowledge (e.g., the mission of Golf Canada) to the application of researcher knowledge within the Golf Canada context. The research team identified that fostering effective communication throughout the entire process was critical to maintaining a strong and successful partnership.

Many projects employ a combination of multidisciplinary and interdisciplinary approaches as KT is generally considered to be interdisciplinary and multidirectional at its core. The Sport Injury Prevention Research Centre (SIPRC) is one example of a group that utilizes an interdisciplinary approach to KT, incorporating key knowledge users such as parents, coaches, athletes, referees, clinicians, policymakers, and researchers into the KT process (Richmond et al., 2014). With the ultimate goal of influencing policy and practice to reduce sport injuries in youth hockey, research proposals were developed in conjunction with local, provincial, and national associations and community stakeholders. These partners also assisted in adapting research for maximum relevance, identifying barriers to uptake, and developing dissemination plans. Similar to Kendellen et al. (2017), Richmond et al. (2014) highlights the importance of regular communication between researchers and stakeholders. Using an interdisciplinary approach to collaborate with knowledge users/stakeholders is useful in maximizing the public impact of sport science research (Richmond et al., 2014).

One final example of iKT in sport science is the development of the PYDSportNET by Holt, Camiré, et al. (2018). PYDSportNET set out to achieve the following objectives: a) systematically review positive youth development (PYD) through sport research to consolidate the evidence base; b) create knowledge products for PYD through sport; c) examine stakeholders' perceptions of research problems and barriers/challenges/opportunities associated with using research findings. These objectives accounted for knowledge creation and action cycle components to the KTA framework, on which the project was based, while also creating a network for knowledge exchange and dissemination for PYD through sport. Key takeaways from this lofty research endeavour thus far include the importance of using a KT framework to guide research and dissemination/implementation activities and the benefit of creating meaningful partnerships (e.g., social media "network of networks") to increase the potential impact of research findings.

Co-developing and tailoring sports biomechanics knowledge to meet the needs of knowledge users can provide the field with more avenues for expansion and exposure. Despite the potential for positive impact on sport such as improving movement patterns, biomechanics is still a relatively lesser-known science (DeVita, 2018). To tailor sport biomechanics knowledge to meet community needs is not only to expand the influence and impact of this research, but to increase accessibility of the discipline of sports biomechanics and the broader study of sports science.

2.4.2 Remote Biomechanical Analysis

Sports science support has been proven to improve athletic performance (Reade, Rodgers, & Spriggs, 2008) and biomechanics is at the root of this with research largely driven by the goals of reducing injury and improving performance (Bartlett, 2008). Biomechanical interventions have been shown to improve athletic performance at various athletic levels in a number of sports, and ease of access increases with the popularity of the field (Nelson et al., 2014). Coaches seeking out information on their own tend to have limited access to biomechanics knowledge that is often distributed via scholarly journals and not always written with end users (coaches) in mind (Knudson, 2007). However, elite and non-elite coaches alike can take advantage of biomechanical knowledge as is beneficial to their team through establishing a level of consultation and cooperation with sports science researchers (Williams & Kendall, 2007). Coaches and researchers working side by side using an integrated KT approach allows for knowledge to be adapted to local contexts and applied to meet the needs of the team and community.

Bolstering existing sports programs in communities removed from urban centres can be challenging for a number of reasons, and limited access to elite sports performance coaches or training centres can lead to barriers for athletes pursuing high-performance careers. One method for bridging the gap between sports science researchers and coaches in remote communities is the implementation of remote video analysis software and biomechanical analysis into coaching practices. Remote analysis software has been shown to be powerful for qualitative analysis and comparison of multiple trials of movement activities when compared against the "gold standard" (Garhammer & Newton, 2013). 2D video analysis results have been rated by users as better explained than 3D results, likely because 2D results are often delivered with accompanying video footage (Fenton et al., 2007). The ability to use this technology remotely also makes it a powerful tool in this setting, as sport scientists do not need to physically be present in rural communities for the program to carry on. Though biomechanical analysis (with the help of remote analysis software) has proven to be valuable to sports science, more information on implementing remote video analysis in communities partnered with sport scientists needs to be established.

The process of implementing a remote analysis and consultation program within a remote community has not been evaluated in ice hockey but has previously been employed in healthcare via telemedicine. One study by Holt et al. (2019) found that the implementation of remote presence robotic technology had a significant cost benefit, allowed for direct connection between all end users and stakeholders, and improved community access to specialized healthcare. It was also well-received by the community, as community leaders had been involved in the planning process and implementation. Tailoring the implementation of a tool such as remote analysis to a specific community has great potential for improving outcomes, including within sport, and the knowledge-to-action process could prove useful in guiding program development. Given the popularity of ice hockey in rural communities in Canada, applying this program to connect rural ice hockey coaches remotely with sports scientists provides a perfect opportunity to examine the utility of remote analysis in sport. Furthermore, the assessments by the research team would include tailoring ice hockey knowledge specifically to the end users (i.e., coaches and athletes), and would highlight another key component to the knowledge-to-action process.

2.5 Summary of Knowledge Gaps

Sports science researchers tend to rely academic channels to disseminate research findings, but the translation of sports science research to end users involves consideration at each step in the process. At the knowledge creation stage, a combination of identifying knowledge gaps in existing literature and working with stakeholders to determine directions for knowledge inquiry is ideal for conducting relevant research. Working directly with stakeholders and knowledge users can increase the relevance of sports science research, though these relationships require deeper investigation. Understanding the dynamics of collaborative stakeholder groups like academic-industry research partners is necessary to facilitate effective relationships, reduce identified barriers, and foster improved knowledge translation. Much of the existing research in this area focuses on output rather than inter-personal relationships, which may have implications for the success of academic-industry research partnerships.

When considering knowledge creation in ice hockey, identifying gaps in the existing literature is as important in guiding new research as understanding what is relevant to knowledge users. Although there has been some investigation comparing skating kinematics based on sex and skill level, the findings do not provide a comprehensive understanding of skating mechanics. Joints tend to be studied in isolation but understanding how the body coordinates segments and how these parts are integrated to achieve task specific goals can provide useful information about locomotion. Given that inter-segment coordination appears to be task-specific, different based on skill level, and that males and females may utilise different coordinative strategies, further investigation through first-generation knowledge inquiry is warranted (Boyer et al., 2017).

Considering that, on average, a seventeen-year gap exists in healthcare research between evidence being produced and its eventual application, working with knowledge users is especially important for knowledge application (Bekker et al., 2017; Morris et al., 2011). The knowledge-to-action process has not previously been evaluated for the implementation of a remote analysis program to bridge sports scientists and ice hockey coaches in rural communities. The knowledge-to-action process provides a guide for each step of the knowledge translation process, and the flexibility of the model may give it utility for sports science knowledge translation in a variety of settings and situations.

Chapter 3: Differences in intersegment coordination of high- and low-calibre ice hockey players during forward skating (Objective 1 – Knowledge Creation)

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Published by *Sports Biomechanics.* Volume 22(10), 1303-1318.

doi: 10.1080/14763141.2020.1797151

3.1 Preface

The knowledge creation component of the Knowledge-to-Action framework is utilised in this chapter through the knowledge inquiry phase. Forward skating is one of the most investigated skating tasks, but lower body intersegment coordination had not previously been evaluated for ice hockey skating. High- and low-calibre athletes have previously been compared to determine ideal movement patterns for various sporting tasks, so this study sought to determine whether coordinative differences existed between these groups. Information from the knowledge inquiry phase may not always be necessary to translate to all audiences but is still essential and the threshold for dissemination varies for different knowledge users (Straus et al., 2013). In this case, findings about intersegment coordination may not be directly applicable to athletes or industry research and development teams but can provide further context to kinematic findings and potentially inform training protocols, thus adding to the wealth of knowledge available. Peer reviewed publication and conference presentations (considered traditional end-of-grant KT methods) were used to disseminate findings to the appropriate audience.

3.2 Abstract

The objective was to compare lower extremity inter-segment coordination between high-calibre and low-calibre ice hockey players during forward full stride skating. A 10-camera Vicon motion capture system collected kinematic data on male high-calibre (n=8) and low-calibre (n=8) participants. Continuous relative phase (CRP) was calculated for shank-*sagittal*/thigh-*sagittal*, shank-s*agittal*/thigh-*frontal*, and foot-*sagittal*/shank-*sagittal* segment pairs. Principal component analysis (PCA) was used to extract features of greatest variability of the CRP and hierarchical linear model investigated relationships between principal components and skill level. High-

calibre players demonstrated more out-of-phase coordination (higher CRP) of shank-*sagittal*/thigh-*sagittal* throughout glide/push-off (p = 0.011) as well as a delay in the transition to more in-phase coordination during early recovery phase (p = 0.014). For shank-*sagittal*/thigh-*frontal* (p = 0.013), high-calibre players had more out-of-phase coordination throughout the entire stride. High-calibre players were also associated with an earlier transition to more out-of-phase coordination of the foot-*sagittal*/shank-*sagittal* during push-off (p = 0.007) and a smaller difference in CRP between mid-glide/early recovery (p = 0.016). Utilising more out-of-phase modes of coordination may allow players to more easily adjust to optimal modes of coordination throughout skating strides. Skating drills incorporating varying speed, directionality, and external stimuli may encourage the development of more optimal coordination during skating.

3.3 Introduction

Ice hockey is one of the most popular team sports with over 1.7 million registered players in more than 70 countries during the 2017/2018 season (International Ice Hockey Federation [IIHF], 2018). Biomechanical analysis of ice hockey tasks such as measures of player's body kinematic patterns can highlight elements related to optimal technique and performance. For example, a whole-body kinematic analysis of hockey players' wrist shots has been used to identify movement factors affecting shooting accuracy (Michaud-Paquette, Magee, Pearsall, & Turcotte, 2011), while kinematic studies of forward skating starts have found specific hip, knee, and ankle joint movement differences between males and females (Budarick et al., 2018; Shell et al., 2017). Hence, kinematic analysis, as a supplementary evaluation tool, can yield relevant information to guide coaches and trainers in providing the most appropriate training techniques for their athletes. Additionally, identifying factors governing the locomotion of skating can reveal important information about coordination (Krasovsky & Levin, 2010). As skating is such an integral component of ice hockey, establishing an in-depth understanding of this task is warranted.

Differences in high- and low-calibre hockey players have been evaluated in previous studies to establish what characteristics of skating may lead to improved performance. For example, in a study of skating starts, high-calibre players' quicker start times corresponded with kinematic measures of higher lateral accelerations, higher stride rates, and shorter skate contact time during the first four running steps compared to low-calibre players, even though both groups had similar lower body strength (Renaud et al., 2017). Similarly, in another study by Buckeridge, LeVangie, Stetter, Nigg, and Nigg (2015), they identified that high-calibre skaters have an overall greater range of motion (ROM) of the hip and higher knee extension velocity during propulsion, both thought to contribute to a more effective push-off and increased skating speed. Lower body joint angles of high- and low-calibre players during full stride forward skating were compared on both a skating treadmill and regular ice. In both conditions, high-calibre players showed greater hip flexion throughout stride, and greater knee extension, external rotation, and ankle inversion during push off (Robbins, Renaud, & Pearsall, 2018; Upjohn, Turcotte, Pearsall, & Loh, 2008). These differences between skill levels offer insight into a more effective skating technique, but do not consider the coordination between lower limb segments.

Skating, much like walking or running, is a complex, dynamic movement which requires considerable coordination (Longworth, Chlosta, & Foucher, 2018). Inter-segment coordination can be defined as the relationship and relative timing between different body segments throughout a task (Krasovsky & Levin, 2010). One way to quantify coordination is by using continuous relative phase (CRP), which allows the relation between body segments to be quantified by constructing and comparing phase planes of each respective segment based on kinematic data (Eggleston, Landers, Bates, Nagelhout, & Dufek, 2018; Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2013). Previous research has used CRP to evaluate coordination in a variety of sports providing a wide range of insight. In distance running, out-of-phase coordination has been associated with transitions throughout the gait cycle, and it has been suggested that this coupling pattern may allow for an easier and faster switch to a new coupling pattern in response to perturbations (Dierks & Davis, 2007). Seifert, Leblanc, Chollet, and Delignières (2010) compared inter-limb coordination of recreational swimmers to competitive swimmers and found that recreational swimmers used largely in-phase elbow-knee coordination. Alternatively, a study on coordination and skill level in gymnastics longswing identified that elite gymnasts utilised more in-phase hip-shoulder coordination while successful novices tended to demonstrate more out-of-phase coordination (Williams, Irwin, Kerwin, Hamill, Van Emmerik, & Newell, 2016). Also, stronger attraction to in-phase and anti-phase patterns (more absolute coordination rather than more transitional out-of-phase patterns) may be assumed in cross-country skiing than during walking (Cignetti, Schena, Zanone, & Rouard, 2009). These discrepancies in coordination suggest that the use of in-phase or out-of-phase coordination within a movement is highly task-specific, therefore highlighting the need to identify coordination patterns in forward skating and gain deeper understanding of the fundamental elements that define high-level athletic performance.

Although the mechanics of forward skating between high- and low-calibre ice hockey players have been studied previously, no study has assessed inter-segment coordination in skating which may have implications for more efficient and effective movement patterns. Thus, the objective of this study was to compare lower extremity inter-segment coordination between high- and low-calibre ice hockey players during forward full stride skating. Lower extremity body segments included shank versus thigh in the sagittal plane (shank-sagittal/thigh-sagittal); shank in the sagittal versus thigh in the frontal plane (shank-sagittal/thigh-frontal); and foot versus shank in the sagittal plane (foot-sagittal/shank-sagittal). It was hypothesised that high-calibre players would demonstrate more out-of-phase movement as this mode of coordination may allow for an easier and faster switch to a new coupling pattern and it has been suggested that a flexible coupling pattern is associated with high-standard performance in sprinting (Bradshaw et al, 2007) which bears similarities to forward skating.

3.4 Methods

3.4.1 Participants

Sixteen male ice hockey players participated in this study and were classified as high or low-calibre (Table 3.1). High-calibre players (n=8) had played at the major junior level or higher and were recruited from the university varsity team. Low-calibre players (n=8) had played hockey at a level lower than major junior and were recruited from local teams. Players who had experienced major lower limb injuries within the year prior to data collection were excluded. Data collection took place from November 2014 to January 2015 alongside previously published studies focusing on joint angles during skating starts (Renaud, et al., 2017) and full stride skating (Robbins, et al., 2018). Due to the technical difficulty and cost of collecting data on an ice surface, sample size was limited. Approval from the McGill University Research Ethics Board was obtained, and all players provided written informed consent prior to participation.

Table 3.1 Means (standard deviation) for group demographics and speed.

Variable	High Calibre (n=8)	Low Calibre (n=8)	*p* value*
Age (y)	24 (3)	24 (3)	0.752
Height (m)	1.84 (0.06)	1.79 (0.03)	0.089
Weight (kg)	86.8 (5.6)	81.3 (8.4)	0.143
Body mass index (kg/m^2)	25.7 (1.3)	25.2 (2.4)	0.656
Playing Experience (y)	19 (4)	9 (6)	0.001
Average Speed (m/s)	6.01 (0.37)	5.51 (0.61)	0.064
Peak Speed (m/s)	7.39 (0.49)	6.71 (0.72)	0.043

*p value from independent t-test

3.4.2 Data Collection

Participant age, height, mass, and self-reported playing experience in years were recorded. A 10-camera motion capture system (Vicon Motion Systems Ltd., Oxford, UK; 8 MX3+ cameras, 2 T40S cameras) was used to collect forward skating data on an indoor ice surface. Data were sampled at a rate of 240 Hz and the system was calibrated prior to each session. The same two researchers attached 24 passive retro-reflective markers to each player following a modified Helen Hayes marker set-up, as previously described (Collins, Ghoussayni, Ewins, & Kent, 2009; Robbins, et al., 2018). All players wore Bauer MX3 skates with standard boots, which they were told to lace as they would for a game. Skate blades were sharpened by the same technician before every data collection session to a 3/8-inch hollow with a 9.5 radius. In addition to test skates, all players wore compression clothing, a helmet, hockey gloves, and were given a hockey stick to carry while skating to replicate game-situation skating. Players were allotted a 5-minute warm-up period on the ice outside of the capture area. Using a foot template to ensure consistent foot placement between participants, a static standing trial was collected with the joints in a neutral position (Robbins, et al., 2018). Five trials of maximum effort forward skating starting in a hybrid-v stance were captured per participant (Renaud, et al., 2017). Of the total 19.5 m goal line to blue line skating area, participants had the first 6.1 m to accelerate prior to entering the capture area.

3.4.3 Data Processing

Similar to Robbins, et al. (2018), marker data were filtered with a low pass, recursive, 4^{th} order Butterworth filter with a cut-off frequency of 6 Hz to remove unwanted noise or movement artefact. Gap filling was completed using Vicon IQ (Version 2.5, Vicon Motion Systems Ltd., Oxford, UK). Thigh, shank, and foot segment angles were calculated about the global coordinate system and derived from YXZ Cardan angles with the following ordered rotations: flexion, abduction, and rotation. Skate contact (i.e. initial ice contact) events were determined by automatic identification of peak vertical acceleration of the heel markers and manually checked to confirm accuracy (Hreljac & Marshall, 2000; Robbins, et al., 2018). The derivative of the posterior superior iliac spine marker positions was used to determine skating speed and was averaged across each skating trial; peak speed for each trial was also determined. Visual3D (Version 5.01, C-Motion Inc., Germantown, USA) was used for filtering, segment angle determination, event detection, and skating speed calculations. Skating stride can be divided into two main phases: support phase where the leg is in contact with the ice, and swing phase where the leg is off the ice taking the next step. Support phase consists of glide (0 to ~40% of the stride cycle) and push-off (~40-60% stride cycle), while swing phase constitutes recovery (~60-100% stride cycle).

Due to limited capture area, complete skate strides were not able to be consistently measured on both sides. Although bilateral marker placement meant data were available for both limbs, the limb with the greatest number of strides with complete segment data was chosen as the limb of interest. If there were an equal number of strides for both sides, the limb was chosen at random without regard for limb dominance. For high-calibre participants the left limb was chosen twice and the right limb was chosen six times. For low-calibre participants, the left limb was chosen three times and the right limb was chosen five times. Each participant had two to five trials for each segment pair (n = 51 for each pairing). For shank-*sagittal*/thigh-*sagittal* and shank-*sagittal*/thigh-*frontal* pairings the high-calibre group had 28 total trials and for foot-*sagittal*/shank-*sagittal* the high-calibre group had 27 total trials.

3.4.4 Continuous Relative Phase

Phase angles were computed for the foot, shank, and thigh using the Hilbert transform approach. The Hilbert transform allows for a clear assessment of the phase difference through the transformation of a real signal into a complex, analytic signal (Ippersiel, Robbins, & Preuss, 2018; Lamb & Stöckl, 2014). A double reflection method was employed to pad the signal to address issues with data distortion associated with Hilbert transform (Ippersiel, Preuss, & Robbins, 2019). Next, CRP was calculated by determining the absolute difference in the phase angles between body segments (proximal minus distal) in specific planes (Burgess-Limerick, Abernethy, & Neal, 1993) including shank versus thigh in the sagittal plane (shank-*sagittal*/thigh-*sagittal*); shank in the sagittal versus thigh in the frontal plane (shank-*sagittal*/thigh-*frontal*); and foot versus shank in the sagittal plane (foot-*sagittal*/shank-*sagittal*). These segments generally produce the largest amplitudes in those specific directions during skating. A value of 0 degrees indicates the segments are moving completely in-phase with one another (e.g. windshield wipers moving side to side together), while 180 degrees indicates the segments are moving completely anti-phase (e.g. windshield wipers rotating to the centre at the same time). Values closer to 0 or 180 may be relatively in-phase or anti-phase, respectively (Oullier, Bardy, Stoffregen, & Bootsma, 2002). Cubic spline interpolation was used to normalise CRP waveforms to 100% of stride from first ice contact within the capture area to the successive ice contact of the same skate. CRP calculations were performed using Matlab (version R2018a, MathWorks Inc., Natick, USA). Phases of skating stride throughout 0-100% of stride cycle are defined in Appendix Figure 1.

3.4.5 Statistical Analysis

Descriptive statistics were calculated for group demographics, average speed, and peak speed. Independent t-tests were used to compare these variables between high- and low-calibre groups.

Principal Component Analysis

Separate Principal Component Analyses (PCA) were conducted on the CRP waveforms for each segment pair (shank-*sagittal*/thigh-*sagittal*; shank-*sagittal*/thigh-*frontal*; foot-*sagittal*/shank-*sagittal*). This analysis was used to extract important characteristics from the CRP waveforms and summarise the most important information in the data (Deluzio & Astephen, 2007). Data were entered into a n by p matrix (**X**) where n is the number of trials for all participants and p is the 101 data points over the stride cycle. Matrices sizes for all three segment pairs were 51x101. Eigenvectors, also called principal components (PC), which describe characteristics of the waveforms (e.g. amplitude, time shift), were extracted from the covariance matrix and eigenvalues indicated the amount of variation in the data explained by each eigenvector. Since the first few eigenvectors tend to explain the majority of the variation in the data, the first three eigenvectors were analysed. *PC-scores* (*PC-scores* = ($\mathbf{X}$-$\bar{\mathbf{X}}$)*eigenvectors) were determined to represent the extent to which a waveform matches the eigenvector shape/waveform characteristics and were used in statistical analyses. Eigenvectors will henceforth be referred to as PC. PCA was performed using Matlab (version R2018a, MathWorks Inc., Natick, USA).

Hierarchical Linear Model

Hierarchical linear models (HLM) were used to address the study objectives; HLM allows for an uneven number of observations between players by accounting for variability within a participant. Separate models were constructed for each *PC-score*, which were the dependent variables. Individual trials clustered with-in participants allowed the variability to be partitioned both within and between participants (Tirrell, Rademaker, & Lieber, 2018). For each analysis, two separate models were constructed: a speed model which statistically controlled for speed, and a non-speed model which did not. This was done in order to account for differences that may have been due to skating speed rather than high- or low-calibre group distinction. For the non-speed model, the intercept and trial number were entered in the first step, and group was entered in the second step (categorical – high-calibre = 1; low-calibre = 0). The speed model incorporated trial number and intercept (continuous) into the first step, followed by the average speed over the trial. Group was entered in the third step followed by a group x speed interaction. The interaction term was only maintained in the model if it statistically significantly contributed to the model. Different stages of model development were evaluated using a – 2 log-likelihood and critical values for chi-square statistic. Slope coefficients were also examined and reported with 95% confidence intervals with associated p values from the Wald statistic. Full-maximum likelihood was chosen for every model. Statistical significance was set at $p < 0.05$. All statistical analyses were conducted using SPSS Statistics (version 24.0, IBM Corp, Armonk, USA).

3.5 Results

Demographic variables were not significantly different between groups with the exception of playing experience which was significantly greater for the high-calibre group (Table 3.1). Peak speed was significantly greater for high-calibre players (p = 0.043), though average speed between groups was only approaching statistical significance (p = 0.064). Regression coefficients (i.e. slope) are provided in Table 3.2. Interpretations and the explained variance for each *PC-score* are provided in Table 3.3. CRP group means for each segment pair are shown in Figure 3.1. Group means for thigh, shank, and ankle segment angles are shown in Appendix Figure 2.

Table 3.2 Regression coefficients estimates (95% confidence intervals) for non-speed and speed hierarchical linear models.

Segment pair	*PC*	Non-Speed Model Regression Coefficients	Speed Model Regression Coefficients		
		Group*	Speed	Group	Interaction**
Shank-*sagittal* vs. Thigh-*sagittal*	1	104.57 (41.17, 167.97)	73.12 (-20.30, 125.93)	66.51 (9.05, 123.98)	N/A
	2	12.17 (-21.62, 45.96)	-38.10 (-69.34, -6.86)	31.33 (-3.04, 65.71)	N/A
	3	10.09 (-15.09, 35.28)	21.46 (-2.33, 45.26)	-0.28 (-26.17, 25.61)	N/A
Shank-*sagittal* vs. Thigh-*frontal*	1	104.90 (0.93, 208.88)	117.10 (25.18, 209.01)	46.15 (-52.83, 145.13)	N/A
	2	-34.10 (-110.13, 41.91)	67.82 (-6.24, 141.89)	-67.45 (-148.05, 13.13)	-196.26 (-313.63, -78.88)
	3	57.48 (-0.96, 115.94)	31.60 (-26.58, 89.79)	41.64 (-23.01, 106.29)	N/A
Foot-*sagittal* vs. Shank-*sagittal*	1	36.10 (-3.92, 76.13)	-16.39 (-56.57, 23.77)	44.40 (-1.12, 89.93)	N/A
	2	13.33 (-11.52, 38.20)	29.67 (9.23, 50.12)	-1.66 (-24.38, 21.05)	N/A
	3	-25.12 (-45.07, -5.17)	-12.57 (-31.97, 6.82)	-18.55 (-10.08, 2.96)	N/A

* Low-calibre participants were coded 0 and high-calibre participants were coded as 1.
** Interactions were only included in the model if they were significant
N/A: not applicable, no interaction existed; PC: principal component

Table 3.3 Principal component (PC) descriptions and explained variance.

Variable	*PC*	Description	Higher *PC-scores*	Variance (%)
Shank-*sagittal* vs. Thigh-*sagittal*	1	Overall amplitude and shape	Higher CRP throughout glide and push-off	71.4
	2	Phase shift in timing	Delay in CRP decrease during push-off/early recovery	14.2
	3	Difference operator	Greater change in CRP during early glide	9.0
Shank-*sagittal* vs. Thigh-*frontal*	1	Overall amplitude and shape	Higher CRP throughout stride	54.5
	2	Difference operator	Greater change in CRP from glide to recovery	23.3
	3	Difference operator	Greater change in CRP from early glide to late glide/early recovery	13.3
Foot-*sagittal* vs. Shank-*sagittal*	1	Overall amplitude and shape	Higher CRP throughout stride	47.1
	2	Phase shift in timing	Earlier increase in CRP during push-off	20.9
	3	Difference operator	Greater change in CRP during glide to recovery	16.9

PC-scores: Principal component scores
CRP: Continuous Relative Phase

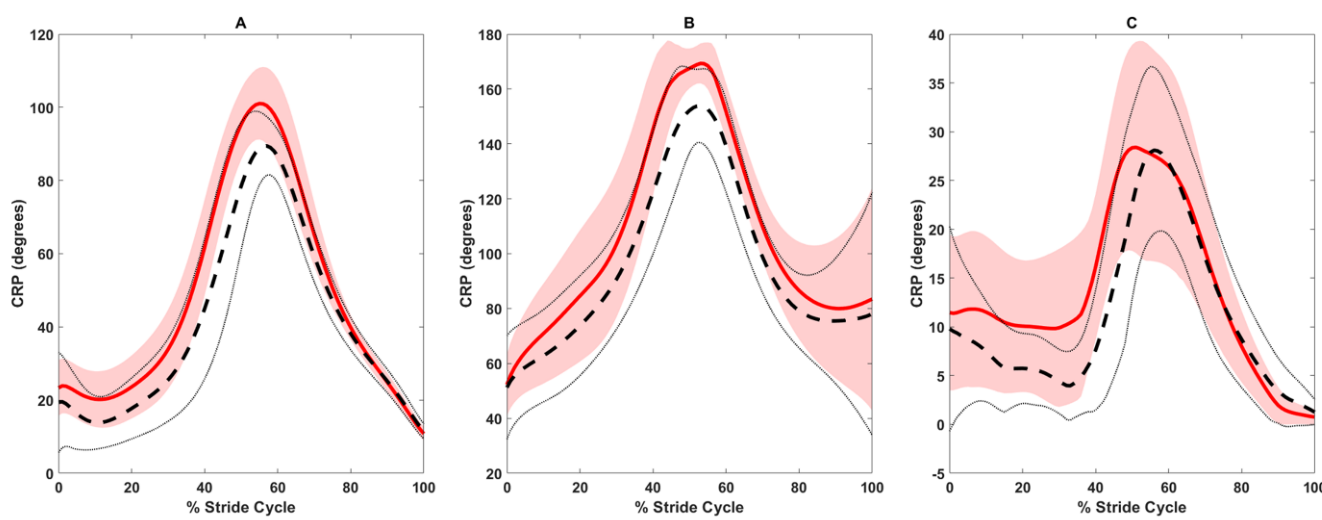

Figure 3.1 Group means for (A) shank-sagittal/thigh-sagittal, (B) shank-sagittal/thigh-frontal, and (C) foot-sagittal/shank-sagittal during a full stride for high-calibre (red, solid lines) and low-calibre (black, dashed lines) groups. The pink shaded area represents one standard deviation for the high-calibre group and the dotted lines represent one standard deviation for the low-calibre group.

3.5.1 Shank-sagittal versus Thigh-sagittal

For shank-*sagittal*/thigh-*sagittal PC1-scores*, adding group significantly improved the non-speed model (*-2LL* change = 9.3, p = 0.002). Adding group also significantly improved the speed model (*-2LL* change = 6.4, p = 0.011), however, adding the group x speed interaction did not improve the model (*-2LL* change = 0.6, p = 0.446), demonstrating that the relationship between *PC-scores* was related to skill level (group). The high-calibre group had higher *PC1-scores*, which indicated they had more out-of-phase coordination throughout the glide and push-off phases of skating (Figure 3.1A, Figure 3.2).

For shank-*sagittal*/thigh-*sagittal PC2-scores*, adding group to the non-speed model did not significantly improve the model (*-2LL* change = 0 .6, p = 0.452), though adding group to the speed model did cause a significant improvement (*-2LL* change = 6.1, p = 0.014) signifying that the relationship between *PC-scores* was related to skill level. This *PC2* represented a time delay of the CRP decrease during push-off/early recovery (Figure 3.2). The high calibre group had higher *PC2-scores* which indicated a delay in the transition to more in-phase coordination during this time (Figure 3.1A).

For remaining shank-*sagittal*/thigh-*sagittal* analyses, there were no other significant relationships between group and *PC-scores*.

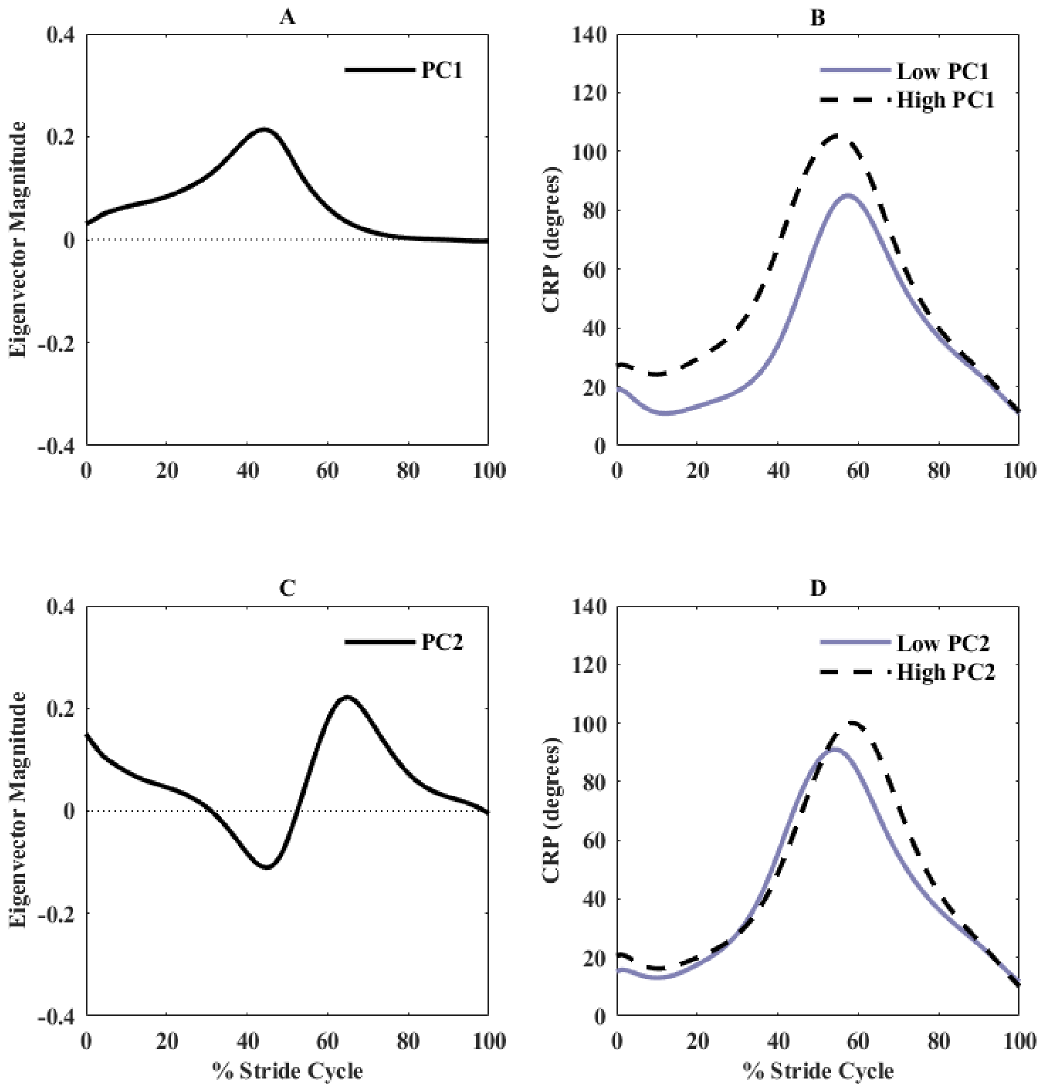

Figure 3.2 Principal components (PC) for shank-sagittal/thigh-sagittal. (A) shank-sagittal/thigh-sagittal PC1 and (B) a subset of participants that had high and low PC1-scores indicate that this PC captures higher CRP throughout glide and push-off. (C) shank-sagittal/thigh-sagittal PC2 and (D) a subset of participants that had high and low PC2-scores indicate that this PC captures a delay in CRP decrease during push-off/early recovery.

3.5.2 Shank-sagittal versus Thigh-frontal

For shank-*sagittal*/thigh-*frontal PC1-scores*, the relationship between *PC*-scores was dependent upon skill level, as adding group significantly improved both the non-speed (*-2LL* change = 4.1,

p = 0.042) and speed (*-2LL* change = 6.2, p = 0.013) models. The high-calibre group was associated with higher *PC1-scores*, which indicated they were more out-of-phase for shank-*sagittal*/thigh-*frontal* coordination throughout the stride (Figure 3.1B, Figure 3.3).

For shank-*sagittal*/thigh-*frontal PC2-scores*, adding group did not significantly improve the non-speed model (*-2LL* change = 0.9, p = 0.347). Adding group approached significance in the speed model (*-2LL* change = 3.7, p = 0.056) while adding group x speed interaction significantly improved this model (*-2LL* change = 8.1, p = 0.004; Table 3.2), demonstrating that the relationship between shank-*sagittal*/thigh-*frontal PC2-scores* and speed depended on the group. Higher *PC2-scores* indicated a greater change in CRP from glide to recovery (Figure 3.1B, Figure 3.3). In the low-calibre group, higher *PC2-scores* were also related to faster skating speeds, demonstrating that faster skaters were more out-of-phase during the recovery phase (Figure 3.1B, Figure 3.4). This relationship did not exist for the high-calibre group.

For remaining shank-*sagittal*/thigh-*frontal* analyses, there were no other significant relationships between group and *PC-scores*.

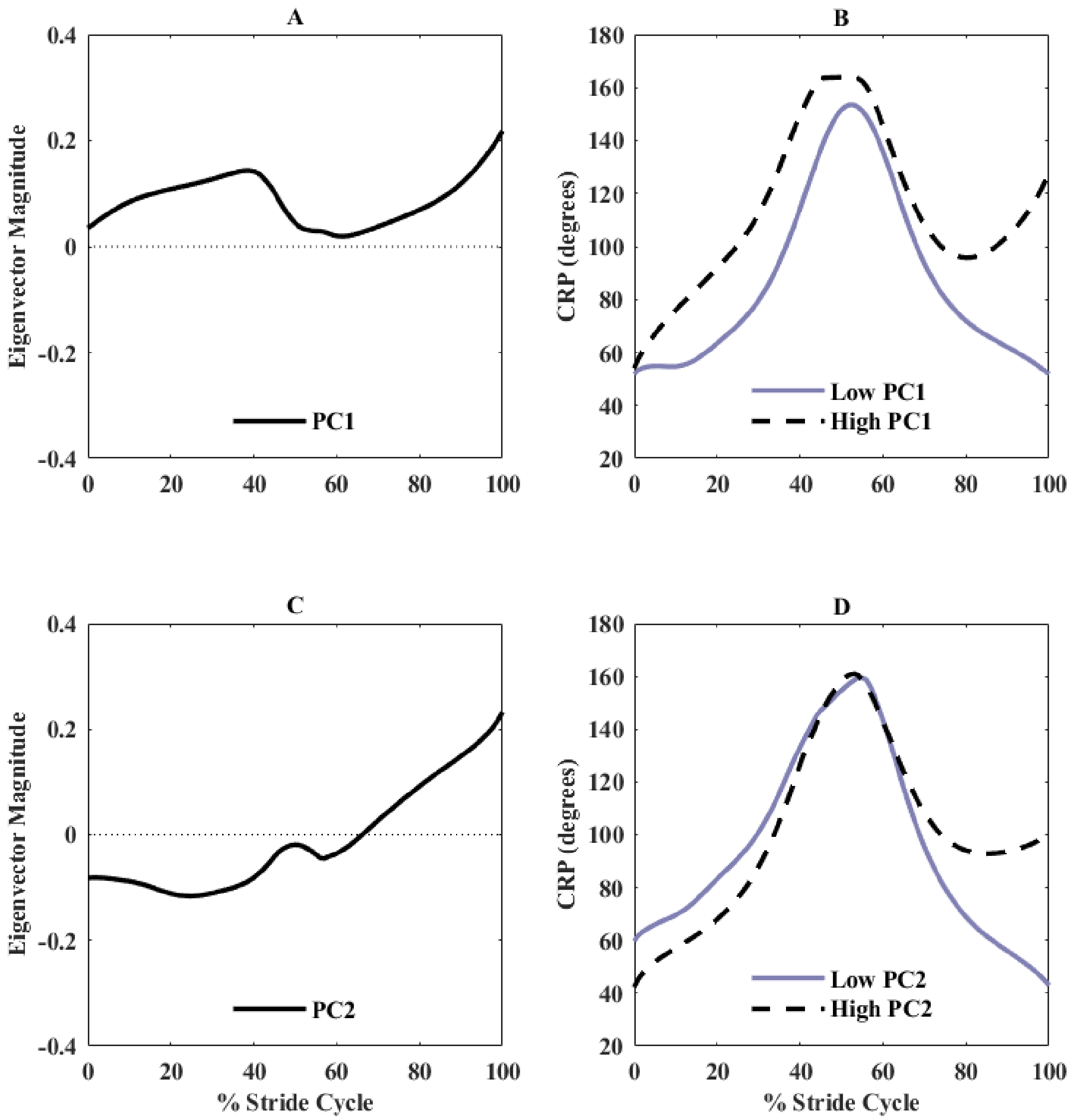

Figure 3.3 Principal components (PC) for shank-sagittal/thigh-frontal. (A) shank-sagittal/thigh-frontal PC1 and (B) a subset of participants that had high and low PC1-scores indicate that this PC captures higher CRP throughout entire stride. (C) shank-sagittal/thigh-frontal PC2 and (D) a subset of participants that had high and low PC2-scores indicate that this PC captures a greater change in CRP from early glide to late glide/early recovery.

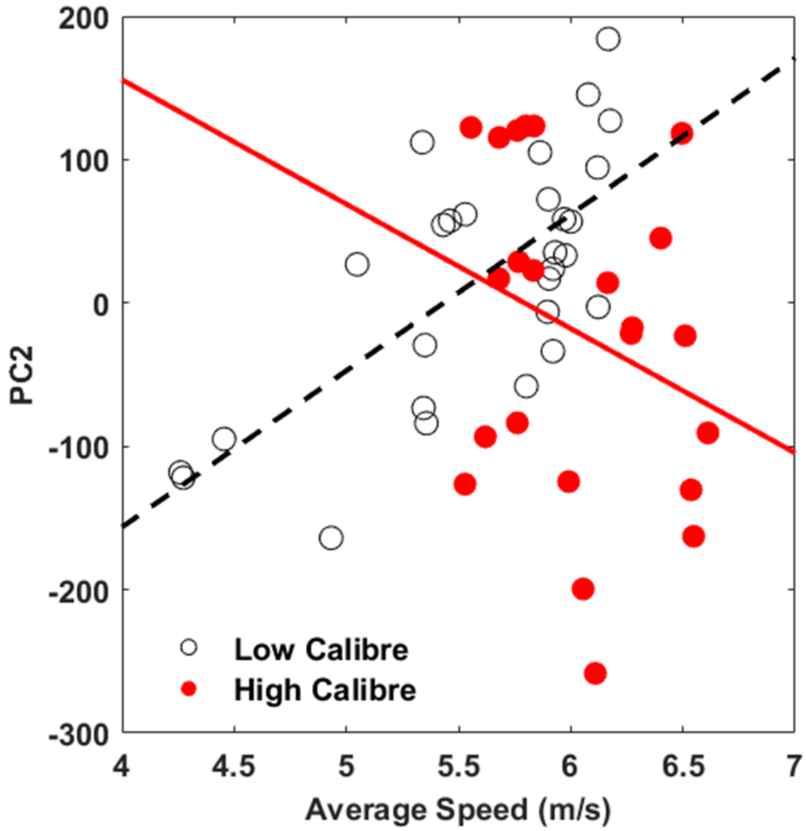

Figure 3.4 The relationship between average speed and shank-sagittal/thigh-frontal PC2-scores for high- and low-calibre participants. High-calibre participants are represented by red, filled dots and low-calibre participants are represented by black, unfilled dots. The lines of best fit for the high- (red, solid) and low- (black, dashed) calibre groups are also represented.

3.5.3 Foot-sagittal versus Shank-sagittal

For foot-*sagittal*/shank-*sagittal PC2-scores*, adding group to the non-speed model did not significantly improve the model (*-2LL* change = 1.2, p = 0.271). Adding group significantly improved the speed model (*-2LL* change = 7.4, p = 0.007) denoting that *PC-scores* were dependent on skill level. This *PC2* represented a time delay in the increase in the CRP during push-off/early recovery (Figure 3.5). High-calibre players had higher *PC2-scores* which indicated an earlier increase in CRP (more out-of-phase) during push-off/early recovery (Figure 3.1C).

For foot-*sagittal*/shank-*sagittal PC3-scores*, the non-speed model was significantly improved by adding group (*-2LL* change = 5.9, p = 0.016), though the speed model was not (-*2LL* change = 1.9, p = 0.169). Higher *PC3-scores* indicated a greater change in CRP from mid-glide to early recovery (Figure 3.5). The high-calibre group was related to lower *PC3-scores,* meaning they had a smaller difference in CRP between these times (Figure 3.1C). The differences in the non-speed and speed models demonstrate that this relationship is dependent upon skating speed.

For remaining foot-*sagittal*/shank-*sagittal* analyses, there were no other significant relationships between group and *PC-scores*.

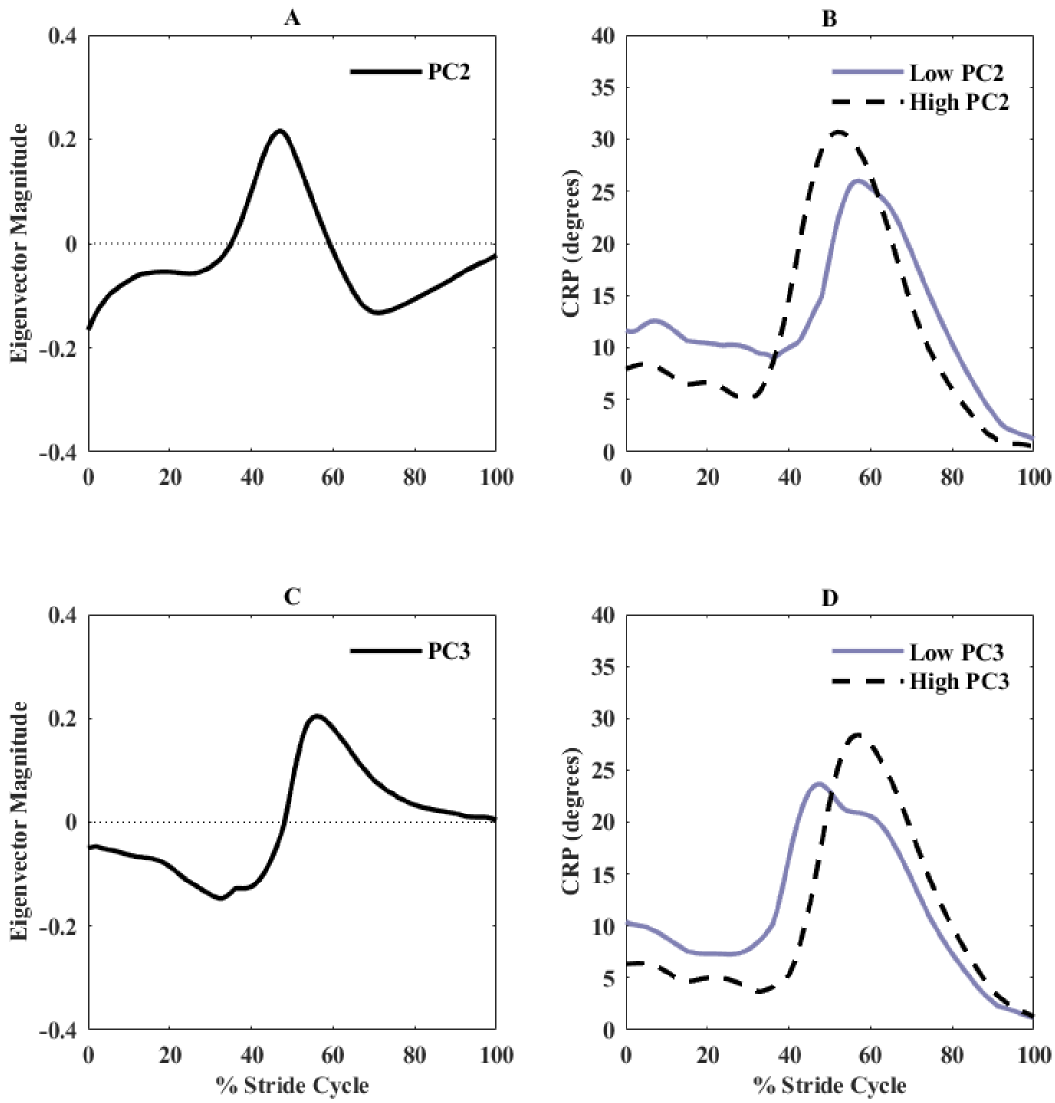

Figure 3.5 Principal components (PC) for foot-sagittal/shank-sagittal. (A) foot-sagittal/shank-sagittal PC2 and (B) a subset of participants that had high and low PC2-scores indicate that this PC captures a time delay in the increase in CRP during push-off/early recovery. (C) foot-sagittal/shank-sagittal PC3 and (D) a subset of participants that had high and low PC3-scores indicate that this PC captures a change in CRP between early/mid-glide and late-glide/early recovery.

3.6 Discussion and Implications

This study was the first to compare lower extremity inter-segment coordination between high- and low-calibre ice hockey players during forward full stride skating. The results largely support the hypothesis that, throughout forward full stride skating, high-calibre players demonstrate less in-phase coordination patterns in thigh/shank and shank/foot segment pairs. Greater peak speeds in the high-calibre group could be attributed to coordination differences with out-of-phase coordination being a more effective mode of coordination. Having lower extremity segments be out-of-phase with one another results in more efficient strides as this may allow for better use of the forces present in the system.

3.6.1 Shank versus Thigh

High-calibre players were associated with more out-of-phase coordination, represented by higher CRP, throughout the entire stride (shank-*sagittal*/thigh-*frontal*) and throughout glide and push-off (shank-*sagittal*/thigh-*sagittal*). More out-of-phase coordination, which is considered more variable, may allow players to switch more easily between modes of coordination (Dierks & Davis, 2007). This may mean that players will be more readily able to adjust to outside forces, such as changes in the ice surface or contact with other players, by altering their mode of coordination to one more optimal for their needs. Additionally, high-calibre players had a delay in the transition to a more in-phase mode of coordination for shank-*sagittal*/thigh-*sagittal* (*PC2*) during the early recovery phase and thus remained out-of-phase for longer. More time spent out-of-phase may promote a more restful recovery phase for high calibre players by taking advantage of the forces generated (Temprado, Della-Grasta, Farrell, & Laurent, 1997).

In the low-calibre group, faster skating speeds were associated with more out-of-phase coordination of shank-*sagittal/*thigh-*frontal* during recovery. More out-of-phase coordination during recovery may be related to faster movement from hip extension during push-off to hip flexion during recovery, which has been associated with faster skating speeds (Robbins, et al., 2018).

3.6.2 Foot versus Shank

High-calibre players were associated with an earlier transition to a more out-of-phase mode of coordination (increase in CRP) during push-off for foot-*sagittal*/shank-*sagittal* segments. A more out-of-phase mode of coordination may be optimal for push-off to account for and adapt to changes in ground reaction force and friction as the player pushes against the ice. High-calibre players were also associated with a smaller change in CRP during mid-glide to early recovery. This is likely due to having more out-of-phase coordination (higher CRP) during glide, meaning high-calibre athletes remained more out-of-phase over this time. Similar to shank-*sagittal*/thigh-*sagittal* coordination, operating in a more out-of-phase mode of coordination may allow players to more easily adjust to changes in the ice surface or other outside forces. The overall CRP for foot-*sagittal*/shank-*sagittal* segments is more in-phase throughout the stride than the other segment pairings (Figure 3.3). An increased need for stability at the foot and shank during skating may dictate that an overall more in-phase mode of coordination for this segment pairing is more advantageous than at the shank/thigh.

3.6.3 Implications

High-calibre players tend to use a more out-of-phase mode of coordination which, we speculate, may allow them to more easily alter their coordination. Because high-calibre players have significantly more experience than low-calibre players (Table 3.1), this has likely allowed them to create and develop an adaptive system that allows for optimal movement (Vereijken, van Emmerik, Whiting, & Newell, 1992). Segment couplings that begin as more in-phase in the learning stages gradually shift through practice to more out-of-phase to effectively utilise external forces and increase efficiency (Temprado, et al., 1997). The findings of the present study suggest that a consistent incorporation of a diverse collection of skating drills may help players strengthen the ability to more effectively alter their coordination and achieve efficient modes of coordination faster. The use of varied skating drill contexts may assist skaters in establishing more overall adaptive coordination and completion of these drills regularly may reinforce developed coordination patterns. For example, drills should incorporate varying combinations of speed, directionality, and external stimuli (obstacles, other players, etc.) to encourage the development of optimal coordination in a wide range of skating conditions. These proposed drills and their impact on inter-segment coordination are speculative and should be examined in experimental studies.

3.6.4 Limitations

There are several limitations of the present study. The sample size was small, and generalisability is limited to male hockey players with similar levels of experience. Participants used equipment that was provided for them, including a standard skate to control for potential effect of skate design, with a relatively brief amount of time to acclimate to the equipment. This may have affected their comfort level, and generalisability of the findings of this study are limited to this skate model. Players did not skate with full equipment (shoulder pads, hockey pants, etc.) which could potentially influence their segmental coordination and overall performance. Additionally, motion of the trunk and upper extremities, which would have provided additional information, were not captured. The capture area was too small to obtain information on both limbs and thus side to side differences could not be compared. Movement variability could also not be examined because additional trials would have been required.

3.7 Conclusion

In conclusion, differences exist in lower extremity inter-segment coordination between high- and low- calibre ice hockey players during full forward stride skating. High-calibre players demonstrate more out-of-phase coordination. This may allow them to more easily adjust to optimal modes of coordination throughout skating strides. Implementation of a diverse selection of skating exercises regularly may encourage the development of adaptive, more optimal coordination. Future studies should examine potential skating interventions and determine the extent to which a skating intervention will improve forward full stride skating coordination. Future studies should also examine movement variability during skating as it may provide deeper insight into optimal skating coordination.

3.8 Acknowledgements

This work was supported by the Natural Sciences and Engineering Research Council of Canada under grant CRDPJ 453725-13 and Bauer Hockey Ltd. This company also provided the skates and assisted with developing the research question. They had no additional role in the study. The authors would like to thank Jaymee Shell, Adrien Gerbé, and Spencer Paveck for their assistance with data collection.

3.9 Disclosure Statement

Bauer Hockey Ltd. provided some of the funds for this study. None of the authors had a financial or personal conflict of interest.

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Chapter 4: Differences in intersegment coordination of high-calibre male and female ice hockey players during forward skating starts (Objective 2 – Knowledge Creation)

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Manuscript under review with *Research Quarterly for Exercise and Sport.*

4.1 Preface

Chapter 4 utilised the knowledge inquiry component of knowledge creation to further investigate intersegment coordination during ice hockey skating. The biomechanics of female ice hockey players have been examined significantly less than their male counterparts. Additionally, lower limb coordination had not previously been investigated during forward skating starts. Forward skating starts are a critical skill for dynamic gameplay, and kinematics (e.g., step widths) vary greatly from the initial steps to more steady-state strides (Budarick et al., 2018). This suggests that skating start coordination may also differ from steady-state skating and warrants additional investigation. As with the previous chapter, findings from this chapter may not have direct applications for athletes or industry research and development teams, but establishing foundational biomechanics knowledge is a necessary step to gain a more thorough understanding of sport-specific skills. Knowledge dissemination for chapter 4 consisted of traditional end-of-grant KT methods including peer reviewed publication (under review) and conference presentations. Given the foundational nature of this research, traditional dissemination methods were deemed appropriate for reaching the most suitable audience for these findings.

4.2 Abstract

Coordination in ice hockey skating has been minimally investigated, particularly in females. The objective was to compare lower-extremity inter-segment coordination of high-calibre male and female ice hockey players during forward skating starts. An 18-camera Vicon motion capture system collected kinematic data on high-calibre male (n=9) and female (n=10) participants. Continuous relative phase (CRP) was calculated for shank-*sagittal*/thigh-*sagittal*, shank-*sagittal*/thigh-*frontal*, and foot-*sagittal*/shank-*sagittal* segment pairs. Principal component

analysis (PCA) extracted features of greatest variability of the CRP and relationships between principal components and sex were investigated using hierarchical linear model. Males demonstrated more out-of-phase coordination (higher CRP) for side one ($p=0.01$) and side two ($p<0.01$) shank-*sagittal*/thigh-*sagittal* as well as side one shank-*sagittal*/thigh-*frontal* ($p<0.01$) segment pairs throughout each step. Females demonstrated a greater change in CRP from late stance/early swing to late swing/early stance on side two for shank-*sagittal*/thigh-*frontal* segments ($p<0.01$). For side two shank-*sagittal*/thigh-*frontal* segments, faster males utilised more out-of-phase coordination throughout each step whereas faster females utilised more in-phase coordination ($p<0.01$). Males and females may employ different coordinative strategies to achieve faster skating speeds. Males tend to utilise more out-of-phase coordination of the shank and thigh throughout strides, although coordinative differences of the shank and foot were not found between sexes. Further investigation is needed to examine the relationship between lower limb strength and coordination as well as the effect of targeted training protocols on lower extremity coordinative patterns.

4.3 Introduction

Women's ice hockey has seen steady growth since it gained status as a full medal sport in the 1998 Olympic Winter Games. The number of female registered players increased from 153,665 in 2007 to over 230,000 in 2020 (IIHF, 2020). As popularity has grown, research surrounding women's ice hockey has also increased, though only a small number of these studies have compared on-ice performance of male and female players. Rather than assuming female players skate and play hockey the same as their male counterparts, male and female ice hockey players should be compared to ensure that training protocols, equipment, game rules and strategies, etc. are appropriate.

Kinematics of accelerative skating (i.e., skating starts) of male and female high-calibre players have been contrasted to establish technical characteristics that may explain performance differences and guide training techniques. For instance, males had greater peak speeds during forward skating starts than females, with forward centre of mass (COM) accelerations in the first two strides having the greatest effect on final speed (Budarick et al., 2018; Shell et al., 2017). Greater forward acceleration is generated throughout the first four steps by males compared to females, though both groups have similar stride-by-stride accelerations thereafter (Budarick et al., 2018). Additionally, females demonstrate lower hip abduction angles throughout skating stance and greater knee extension at initial ice contact during accelerative steps (Shell et al., 2017). This, along with decreased leg strength, may impact the forces generated during push-off, resulting in lower skating speeds for females (Budarick et al., 2018; Shell et al., 2017). The multiple identified differences between male and female skaters demonstrate a need to take sex into consideration for skating tasks.

Although there has been some investigation into the skating kinematics of high-calibre male and female players, the findings do not provide a comprehensive understanding. Inter-segment coordination is an important aspect of locomotion that refers to the relative behaviour of two body segments in relation to one another (Chardonnens et al., 2013). Multiple degrees of freedom enable different solutions for a particular task, and coordination has been considered mastering redundant degrees of freedom involved in a particular movement (Bernstein, 1967; Turvey, 1990). Much like single joint or segment data, patterns of relative motion can be important indicators of performance and understanding inter-segment coordination may have implications not only for more tailored training techniques, but a deeper overall understanding of human locomotion. Identifying coordinative patterns may highlight differences in the control mechanisms used by males and females in skating and understanding segmental differences can lead to more informed training interventions such as tailored strength training or skating drills. Locomotive coordination can be quantified using continuous relative phase (CRP) to construct and compare phase planes for body segments based on kinematic data (Eggleston et al., 2018; Robertson et al., 2013). CRP has been used to examine coordination during walking and running gait, forward full stride skating, and other sporting tasks and can have utility in identifying coordinative patterns for various tasks and groups (Chardonnens et al., 2013; Cignetti et al., 2009; Hamill et al., 1999; Mazurek et al., 2023).

A number of differences in lower-body inter-segment coordination patterns have previously been identified between males and females. During walking, older males have exhibited more in-phase coordination at the shank-foot in the sagittal plane while older females tended to be more in-phase at the pelvis-thigh (Ghanavati, Karimi, et al., 2014). In contrast, in a study conducted by Chow and Stokic (2015), there were no meaningful differences in walking coordination between healthy males and females at various gait speeds, though speed impacted the coordinative relationship. Females have also demonstrated significantly less coordination variability for thigh abduction-adduction/leg abduction-adduction segment coupling during an unanticipated cutting manoeuvre (Pollard et al., 2005). It has been suggested that decreased variability in segment couplings may be related to less flexible coordination patterns with more in-phase coordination thought to be more stable (Dierks & Davis, 2007; Hamill et al., 1999). Flexible coordination patterns may be useful for skaters to adjust to changes in the ice surface or other perturbations.

Inter-segment coordination of females has, to our knowledge, not yet been investigated during forward skating. Joints tend to be studied in isolation but understanding how the body coordinates segments and how these parts are integrated to achieve task specific goals can provide useful information about locomotion. Given that inter-segment coordination appears to be task-specific coupled with the possibility that males and females may utilise different coordinative strategies, further investigation is warranted (Boyer et al., 2017). The objective of this study was to compare lower extremity inter-segment coordination between high-calibre male and female ice hockey players during forward skating starts on a real ice surface. Coordinative differences between male and females have been previously identified in a number of tasks, therefore it was hypothesised that significant differences would exist between males and females in lower extremity inter-segment coordination at each segment pairing, with female players likely being more in-phase at the shank-thigh segment pairings than males.

4.4 Methods

4.4.1 Participants

Ten high-calibre female and nine high-calibre male ice hockey players participated in this cross-sectional study (Table 4.1). Players were considered 'high-calibre' if they had played hockey at the university varsity (Canadian Interuniversity Sport league) level or higher and participants were selected based on convenience sampling. Players who had experienced major lower limb injuries within the year prior to data collection were excluded. Approval from the McGill University Research Ethics Board (REB #463-0515) was obtained, and all players provided written informed consent prior to participation. Data collection took place alongside a previously published study focusing on forward skating start kinematics in high-calibre male and female hockey players (Shell et al., 2017). Due to the cost and technical difficulty of collecting data on an ice surface, the sample size for this study was limited (n=19).

Table 4.1 Means (standard deviation) for group demographics and performance variables.

Variable	Female (n=10)	Male (n=9)	*p*-value*
Age	21 (1)	22 (1)	0.452
Playing experience (y)	14 (1)	16 (2)	0.016
Body height (m)	1.72 (0.07)	1.81 (0.08)	0.011
Body mass (kg)	71.2 (10.4)	81.5 (8.4)	0.031
Lower limb length (m)	0.93 (0.05)	0.97 (0.05)	0.148
Peak speed (m/s)	6.98 (0.31)	7.60 (0.28)	0.001
Task completion time (s)	1.94 (0.18)	1.82 (0.12)	0.130

**p*-value from independent t-test

4.4.2 Data Collection

Participant age, height, mass, and self-reported playing experience in years were recorded. An 18-camera motion capture system (Vicon Motion Systems Ltd., Oxford, UK; 2 T40S cameras, 8 T20 cameras, and 8 T10 cameras) was used to collect forward skating start data on an indoor ice surface. Data were sampled at a rate of 240 Hz and the system was calibrated prior to each session. The calibrated capture area was approximately 3 m wide by 15 m long and 2 m high and captured the first six steps of acceleration. All participants wore tight fitting compression clothing to allow passive retroreflective markers to be placed as closely as possible to anatomical landmarks. Eighty-one total markers were used including four on the hockey stick, twelve fixed to the skates, and sixty-seven markers placed on anatomical landmarks as previously described by Shell et al. (2017). Markers on the body were based on previous work (Collins et al., 2009; Leardini et al., 2011; Leardini et al., 2007). Relevant to the current study, markers on the pelvis and legs included clusters of four non-collinear markers on both thighs and shanks as well as single markers on posterior superior iliac spines, anterior superior iliac spines, greater trochanters, medial and lateral femoral epicondyles, tibial tuberosities, and femoral heads (Shell, 2016).

Players wore Bauer Vapor 1X skates that were provided for them in their size and sharpened to a 3/8-inch hollow with a 9.5 radius (standard) by the same technician prior to data collection. Players were given five minutes to warm-up on the ice to adjust to the skates and get accustomed to the ice surface. A five second static calibration was captured with the subject standing in a T-pose and holding the hockey stick. During skating trials, participants skated with a hockey stick to replicate game-situation skating. Beginning at the blue line in an athletic stance, participants were instructed to perform a forward start without a cross over on the side they felt most comfortable starting with. Participants were instructed to skate to the next blue line (distance of 15.3 m) using maximal effort. Each participant completed five trials.

4.4.3 Data Processing

Marker data were filtered with a low pass, recursive, 4th order Butterworth filter with a cut-off frequency of 8 Hz to remove unwanted noise or movement artifact. Skate ON refers to the when the skate contacted the ice and was determined by the moment of maximum vertical acceleration of the heel marker. Skate OFF refers to when the skate left the ice and occurred at the maximum anterior-posterior (direction of skating) acceleration of the toe marker (Hreljac & Marshall, 2000; Robbins et al., 2018). These skate contact events were manually checked to confirm accuracy. The leg that first stepped forward was ‘side one’, regardless of whether this was the participant’s right or left leg, and included ‘step 0,’ ‘step 2,’ and ‘step 4.’ ‘Side two’ refers to the contralateral side and included ‘step 1,’ ‘step 3,’ and ‘step 5’ (Figure 4.1). Steps zero and five are not complete steps, with step zero including only the swing phase, and step five including only the stance phase. Thigh, shank, and foot segment angles were calculated about the global coordinate system and derived from XYZ Cardan angles with the following ordered rotations:

flexion, abduction, and rotation. Visual 3D (Version 5.01, C-Motion Inc., Germantown, USA) was used for filtering, determining segment angles, event detection, and calculation of skating speed.

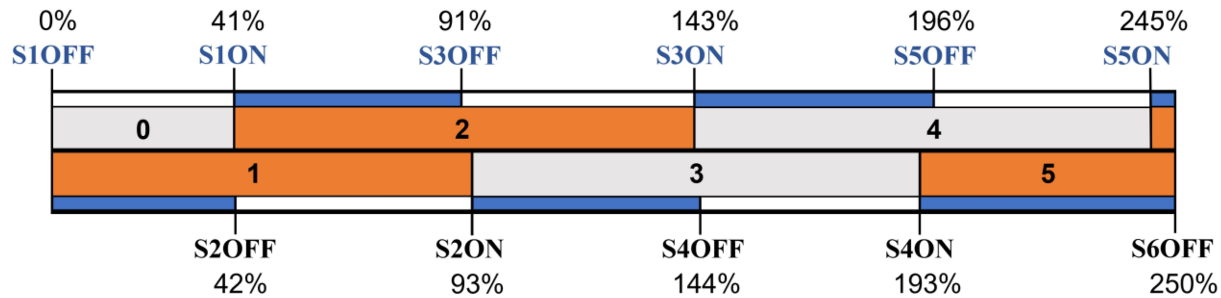

Figure 4.1 Side one and side two step event breakdown. Side one information, including steps zero, two, four, and six, are displayed on the top side of the figure (blue font). Side two information including steps one, three, and five are displayed on the bottom side of the figure (black font). Periods where the skate is on the ice are denoted by a blue bar, periods where the skate is off the ice are denoted by a white bar. Percent of task values provided for each event are averages for all participants. Grey and orange bars are used to identify individual steps.

Continuous Relative Phase

Continuous relative phase (CRP) allows for the quantification of coordination through constructing and comparing phase planes of each respective segment based on kinematic data (Eggleston et al., 2018; Robertson et al., 2013). Phase angles were computed for the foot, shank, and thigh using the Hilbert transform approach as described in a previous study on lower-limb coordination during steady stride forward skating (Lamb & Stöckl, 2014; Mazurek et al., 2023). Issues with data distortion associated with Hilbert transform were addressed through the use of a double reflection method to pad the signal using 100 data points (Ippersiel et al., 2019). CRP was then calculated by determining the absolute difference in the phase angles between body segments (proximal minus distal) (Burgess-Limerick et al., 1993; Lamb & Stöckl, 2014) for shank versus thigh in the sagittal plane (shank-*sagittal*/thigh-*sagittal*); shank in the sagittal plane versus thigh in the frontal plane (shank-*sagittal*/thigh-*frontal*); and foot versus shank in the sagittal plane (foot-*sagittal*/shank-*sagittal*). The majority of propulsive movement during skating takes place at these pairings and the largest amplitudes tend to be produced by these segments in these specific directions. CRP values may fall between 0 and 180 degrees with 0 degrees indicating segments moving completely in-phase (e.g., windshield wipers moving side to side together) and 180 degrees indicating segments moving completely anti-phase (e.g., windshield wipers rotating to the centre at the same time). For the purposes of this paper, values closer to 180 degrees are considered "out-of-phase." Cubic spline interpolation was used to normalise CRP waveforms to 250% of task from S1OFF (first skate off the ice surface) to S6OFF (the contralateral side skate off the ice surface following step five stance phase). Normalising to 250% allowed for two and a half steps on each side to be included without being separated into individual steps, which would vary greatly as the player accelerated and transitioned towards more steady-state skating. CRP calculations were performed using Matlab (version R1018a, MathWorks Inc., Natick, USA).

Principal Component Analysis

Separate Principal Component Analyses (PCA) were conducted on the CRP waveforms for each segment pair (shank-*sagittal*/thigh-*sagittal*; shank-*sagittal*/thigh-*frontal*; foot-*sagittal*/shank-*sagittal*) as described in a previous study on lower-limb coordination during steady stride forward skating (Mazurek et al., 2023). This analysis was used to extract important characteristics from the CRP waveforms and summarise the most important information in the data (Deluzio & Astephen, 2007). Data were entered into a n by p matrix (**X**) where n is the number of trials for all participants and p is the 251 data points over the multi-stride cycle. Matrices sizes were 57x251 for all segment pairs. Eigenvectors, also called principal components (PC), describe waveform characteristics (e.g., amplitude, time shift) and were extracted from the covariance matrix. Eigenvalues indicate the amount of variance in the data explained by each eigenvector. The first three eigenvectors were analysed as they tend to explain the majority of variation in the data. *PC-scores* (*PC-scores* = ($\mathbf{X}$-$\bar{\mathbf{X}}$)*eigenvectors) represent the extent to which a waveform matches the eigenvector shape (waveform characteristics) and were used in statistical analyses. Eigenvectors will henceforth be referred to as PC. PCA was performed using Matlab (version R2018a, MathWorks Inc., Natick, USA).

4.4.4 Statistical Analysis

Descriptive statistics were calculated for group demographics, peak speed, and time to task completion. Timing for step events were normalized to 250% of task and averaged across all available trials for each participant. Independent t-tests were used to compare these variables between males and females.

Hierarchical Linear Model

Hierarchical linear models (HLM) were used to address the study objectives. Variability was partitioned both with-in and between participants by entering available data at the individual trial level into the models and clustering individual trials with-in participants (Tirrell et al., 2018). *PC-score*s were the dependent variable with separate models constructed for each *PC-score.* A model controlling for speed was constructed for each analysis to account for differences in speed between trials. For the model, intercept (continuous) and trial number were entered into the first step, the peak speed over the trial entered in the second, and group (male vs. female) entered in the third step, followed by a group x speed interaction. The interaction term was maintained in the model only if it statistically significantly contributed to the model. Full-maximum likelihood was chosen for every model. Stages of model development were evaluated using critical values for chi-square statistic and a – 2 log-likelihood (Peugh, 2010). Regression coefficients were examined and reported with 95% confidence intervals with associated p values from the Wald statistic (Table 4.2 and Table 4.3). Statistical significance was set at $p < 0.05$ with all statistical analyses conducted using SPSS Statistics (version 24.0, IBM Corp, Armonk, USA).

4.5 Results

Males had significantly more years of experience playing hockey ($p = 0.016$) and were also significantly taller ($p = 0.011$) and heavier ($p = 0.031$) than female players (Table 4.1). Ages ($p = 0.452$) and task completion time ($p = 0.130$) were not significantly different between groups. Peak speed was significantly greater for male players ($p < 0.001$) though timing for step events as a percent of task was not significantly different between groups (Table 4.4). CRP group means for each segment pair are shown in Figure 4.2 for side one and Figure 4.3 for side two. Interpretations and the explained variance of the *PC-scores* are provided in Tables 4.5 and 4.6. Although five trials were collected for each participant, due to the temperature of the data collection environment, some participants' raw data showed more marker occlusion than others, and some trials needed to be excluded. For all segment pairings, females had a total of 32 trials and males had a total of 25 trials, with an average of three trials per participant. Data from all analyses are available in Tables 4.2 and 4.3.

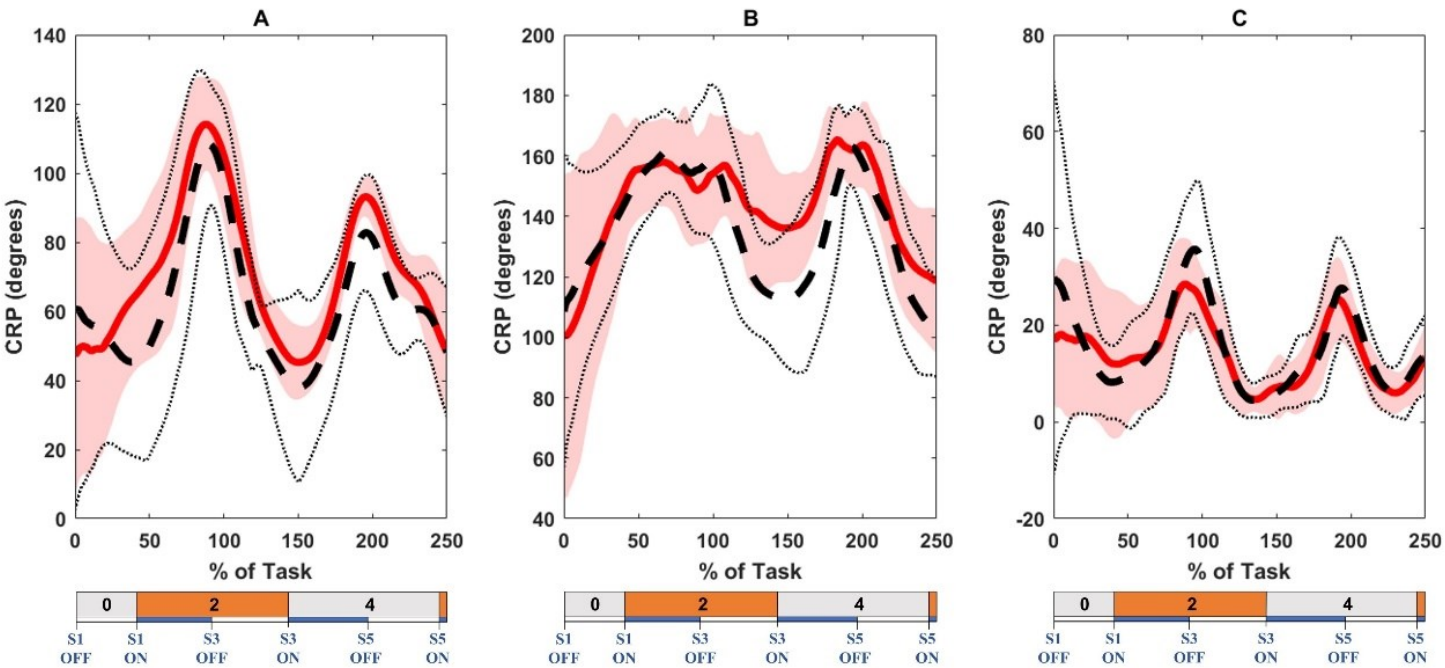

Figure 4.2 Group means for (A) shank-sagittal/thigh-sagittal, (B) shank-sagittal/thigh-frontal, and (C) foot-sagittal/shank-sagittal during all accelerative steps on **side one** for male (red, solid lines) and female (black, dashed lines) groups. The pink shaded area represents one standard deviation for the male group and the dotted lines represent one standard deviation for the female group. Corresponding step number and event information is provided under each graph.

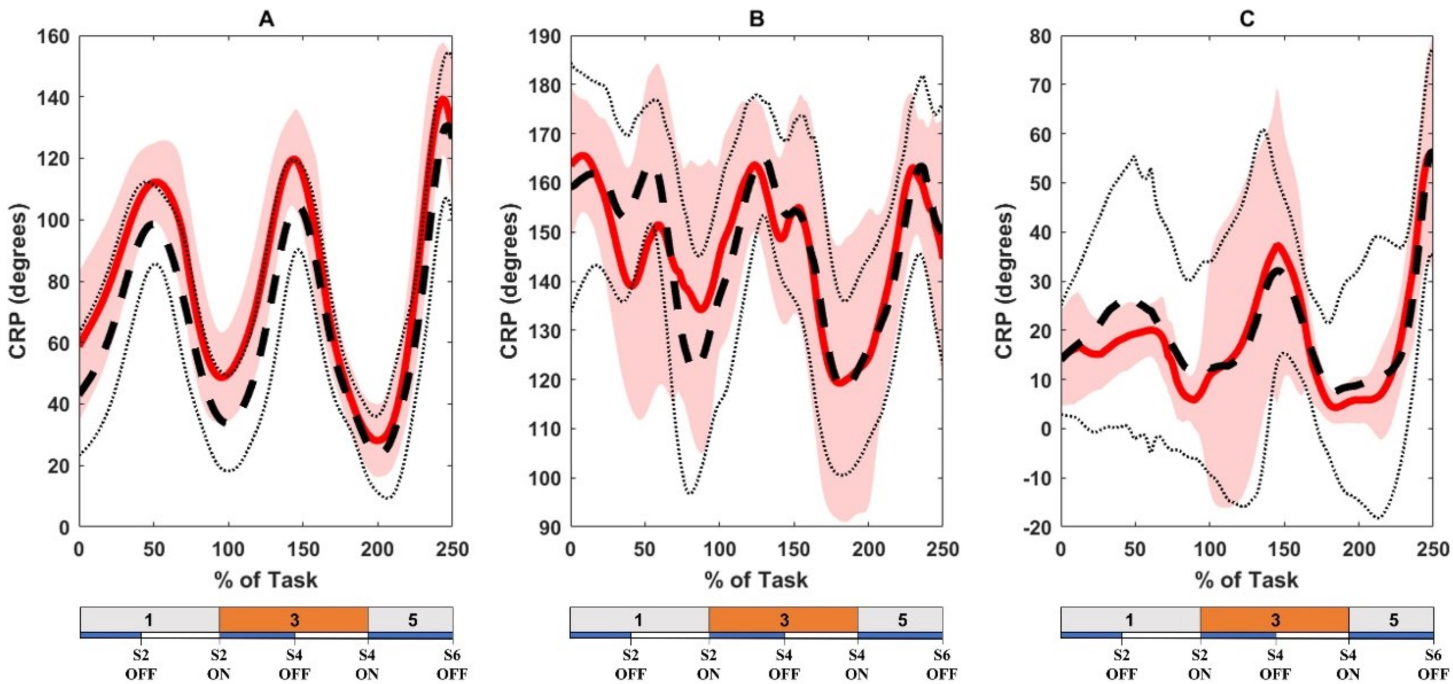

Figure 4.3 Group means for (A) shank-sagittal/thigh-sagittal, (B) shank-sagittal/thigh-frontal, and (C) foot-sagittal/shank-sagittal during all accelerative steps on **side two** for male (red, solid lines) and female (black, dashed lines) groups. The pink shaded area represents one standard deviation for the male group and the dotted lines represent one standard deviation for the female group. Corresponding step number and event information is provided under each graph.

Table 4.2 Regression coefficients estimates (95% confidence intervals) for hierarchical linear model for **side one** segment pairs.

Segment pair	*PC*	Model Regression Coefficients		
		Speed	Group*	Interaction**
Shank-*sagittal* vs. Thigh-*sagittal*	1	-159.24 (-283.37, -35.12)	**184.58 (55.12, 314.05)**	N/A
	2	28.99 (-107.35, 165.34)	-7.23 (-148.51, 134.05)	N/A
	3	-90.50 (-15.88, -165.12)	**94.85 (172.98, 16.72)**	N/A
Shank-*sagittal* vs. Thigh-*frontal*	1	5.34 (-137.61, 148.30)	-50.23 (-196.62, 96.16)	N/A
	2	-76.51 (-180.21, 27.18)	**227.64 (119.85, 335.43)**	N/A
	3	-25.36 (-124.99, 74.27)	-9.58 (-124.11, 104.95)	N/A
Foot-*sagittal* vs. Shank-*sagittal*	1	37.16 (-35.36, 109.67)	-42.81 (-117.18, 31.56)	N/A
	2	2.07 (-49.32, 53.47)	-29.42 (-103.23, 44.39)	N/A
	3	36.53 (-6.12, 79.18)	-42.93 (-91.32, 5.47)	N/A

* Female participants were coded 0 and male participants were coded as 1
** Interactions were only included in the model if they were significant
Statistically significant values are **bolded**
N/A: not applicable, no interaction existed; PC: principal component

Table 4.3 Regression coefficients estimates (95% confidence intervals) for hierarchical linear model for **side two** segment pairs.

Segment pair	*PC*	Model Regression Coefficients		
		Speed	Group*	Interaction**
Shank-*sagittal* vs. Thigh-*sagittal*	1	-262.11 (-348.16, -176.06)	**316.56 (209.66, 423.45)**	N/A
	2	80.76 (-11.26, 172.79)	27.37 (-107.25, 161.99)	N/A
	3	-1.00 (-91.92, 89.92)	-42.20 (-140.58, 56.17)	N/A
Shank-*sagittal* vs. Thigh-*frontal*	1	244.88 (137.69, 352.06)	**-179.12 (-316.77, -41.47)**	N/A
	2	44.57 (-51.35, 140.49)	-76.23 (-175.90, 23.45)	**278.69 (135.78, 421.59)**
	3	8.53 (-80.71, 97.78)	-5.00 (-114.15, 104.16)	N/A
Foot-*sagittal* vs. Shank-*sagittal*	1	-156.85 (-360.20, 46.50)	26.15 (-199.58, 251.88)	N/A
	2	-34.18 (-111.30, 42.94)	58.15 (-20.84, 137.14)	N/A
	3	49.10 (4.84, 93.36)	-9.44 (-54.78, 35.90)	N/A

* Female participants were coded 0 and male participants were coded as 1
** Interactions were only included in the model if they were significant
Statistically significant values are **bolded**
N/A: not applicable, no interaction existed; PC: principal component

Table 4.4 Mean % of Task by Step Event

	Step Event and % of Task					
SIDE ONE	**S1 OFF**	**S1 ON**	**S3 OFF**	**S3 ON**	**S5 OFF**	**S5 ON**
Combined (n=57)	0	40.9	91.5	143.0	196.5	244.6
Females (n=32)	0	38.9	92.0	142.2	198.1	244.6
Males (n=25)	0	43.5	90.8	144.1	194.4	244.6
SIDE TWO	**S2 OFF**	**S2 ON**	**S4 OFF**	**S4 ON**	**S6 OFF**	
Combined (n=57)	41.7	93.3	144.0	192.7	250	
Females (n=32)	41.2	91.5	144.3	192.7	250	
Males (n=25)	42.2	95.7	143.7	192.6	250	

n = # of trials

4.5.1 Shank-sagittal versus Thigh-sagittal

Side One

For shank-*sagittal*/thigh-*sagittal PC1-scores*, adding group to the model did cause a significant improvement (*-2LL* change = 6.9, p = 0.01). The group x speed interaction was not significant (-*2LL* change = 0.1, p = 0.77) and was not included in the final model. *PC1* was related to the overall CRP amplitude and shape for each step on side one (Figure 4.4). Males had higher *PC1-scores*, indicating that they had higher overall CRP (more out-of-phase) throughout each step on this side (Figure 4.2A).

For shank-*sagittal*/thigh-*sagittal PC3-scores*, adding group did significantly improve the model (*-2LL* change = 5.5, p = 0.02). A group x speed interaction did not significantly improve the model (*-2LL* change = 0.8, p = 0.36). *PC3-scores* were related to CRP amplitude throughout step two late swing to step four mid-stance (~130-170%) on side one (Figure 4.4). Male skaters had higher *PC3-scores*, demonstrating higher CRP (more out-of-phase) during this transitional period (Figure 4.2A).

For the remaining side one shank-*sagittal*/thigh-*sagittal* analyses, there were no other significant relationships between group and *PC-scores*.

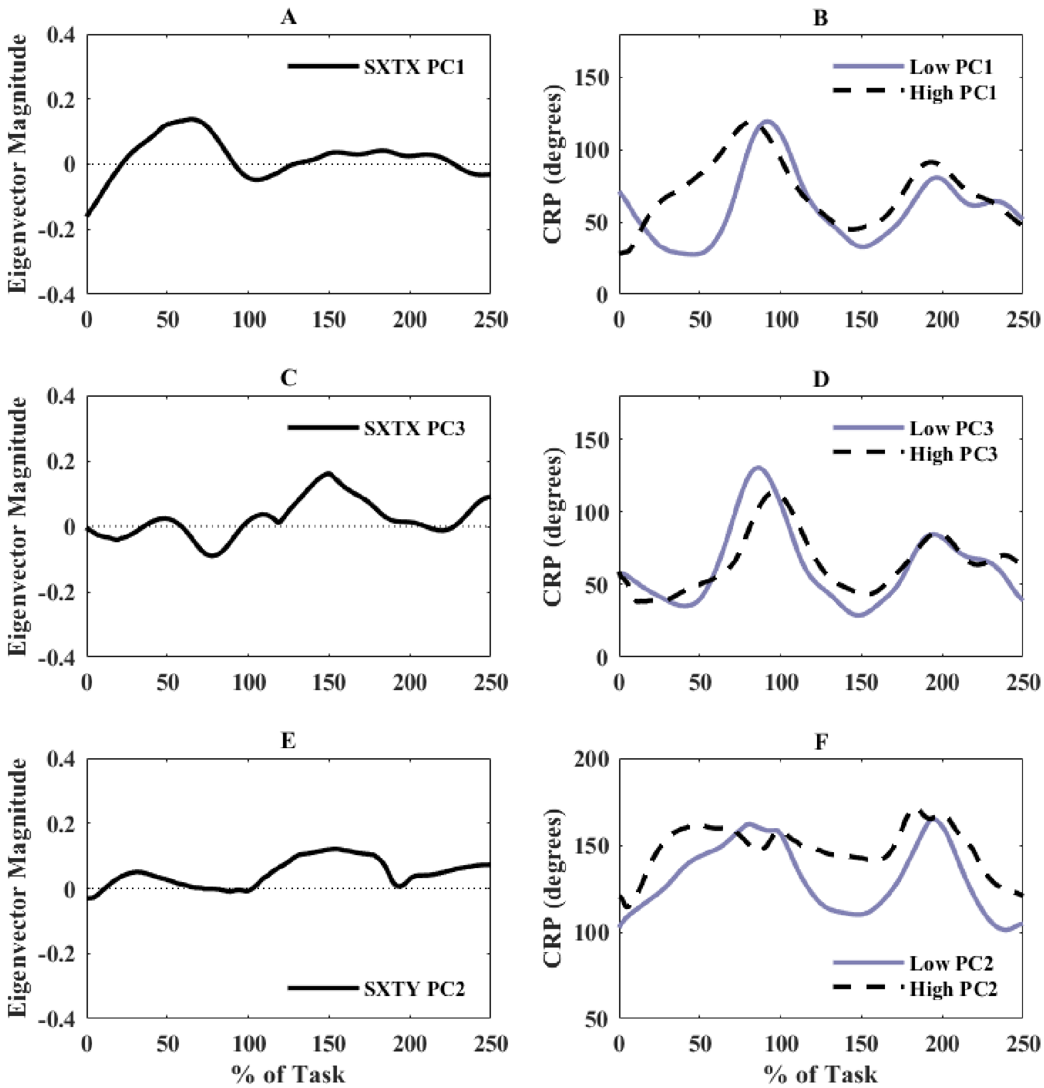

Figure 4.4 Principal components (PC) for **side one**. (A) shank-sagittal/thigh-sagittal PC1 and (B) a subset of participants that had high and low PC1-scores indicate that this PC captures higher CRP throughout each step on side one. (C) shank-sagittal/thigh-sagittal PC3 and (D) a subset of participants that had high and low PC3-scores indicate that this PC captures a higher CRP during step two late swing through step four mid-stance (~130-170%). (E) shank-sagittal/thigh-frontal PC2 and (F) a subset of participants that had high and low PC2-scores indicate that this PC captures higher CRP throughout each step on side one.

Side Two

For shank-*sagittal*/thigh-*sagittal PC1-scores*, adding group significantly improved the model (-*2LL* change = 21.6, p < 0.01), while the group x speed interaction did not significantly improve the model (*-2LL* change = 0.2, p = 0.65). *PC1* was related to the overall CRP amplitude and shape for each step on side two (Figure 4.5). Males had higher *PC1-scores*, indicating that they had a higher overall CRP (were more out-of-phase) throughout each step on side two (Figure 4.3A).

For the remaining side two shank-*sagittal*/thigh-*sagittal* analyses, there were no other significant relationships between group and *PC-scores*.

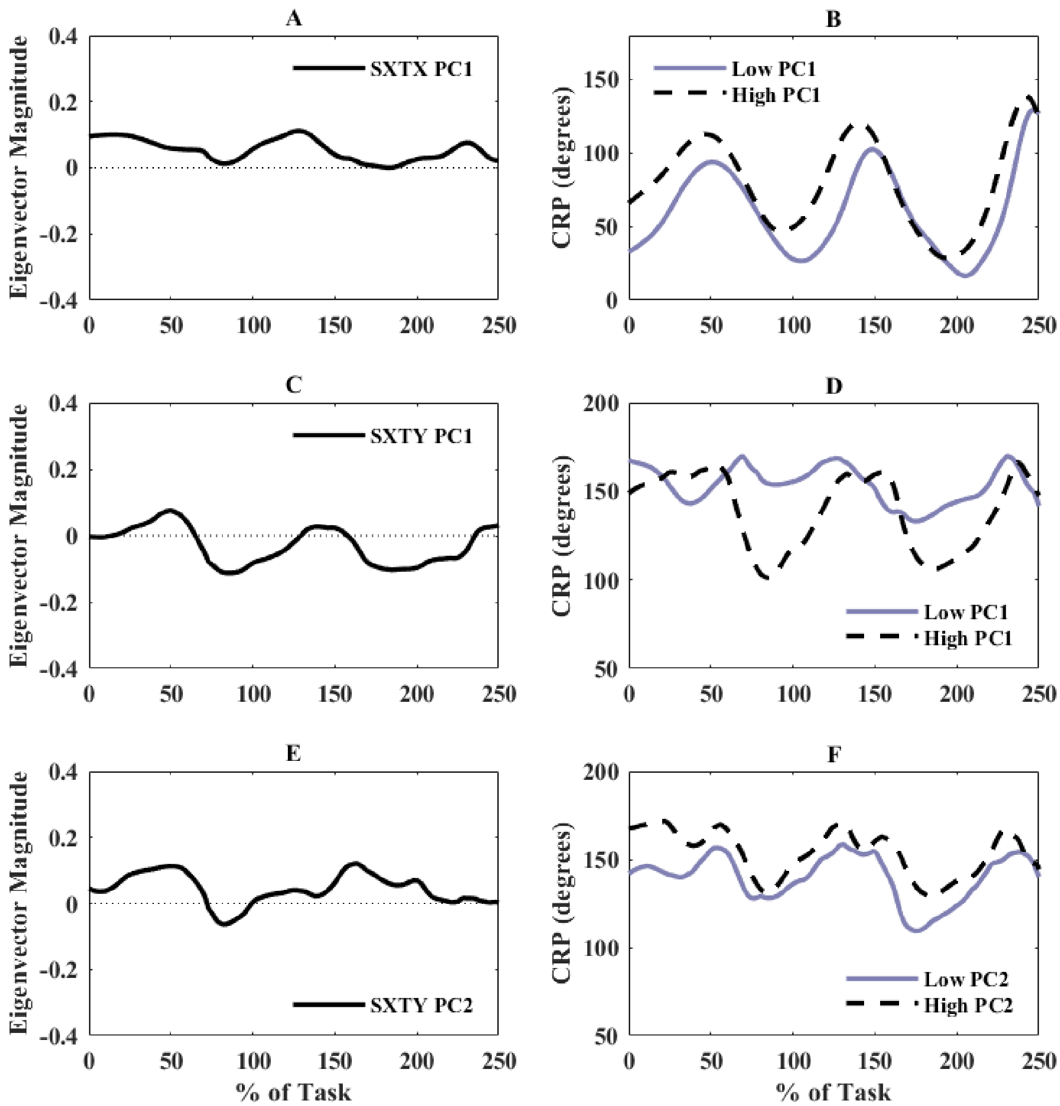

Figure 4.5 Principal components (PC) for **side two**. (A) shank-sagittal/thigh-sagittal PC1 and (B) a subset of participants that had high and low PC1-scores indicate that this PC captures higher CRP throughout each step on side two. (C) shank-sagittal/thigh-frontal PC1 and (D) a subset of participants that had high and low PC2-scores indicate that this PC captures a greater change in CRP from late stance/early swing of step one (~45-55%) and step three (~140-155%) to late swing/early stance of steps three (~85-100%) and five (~175-200%). (E) shank-sagittal/thigh-frontal PC2 and (F) a subset of participants that had high and low PC2-scores indicate that this PC captures higher CRP throughout each step.

4.5.2 Shank-sagittal versus Thigh-frontal

Side One

For shank-*sagittal*/thigh-*frontal PC2-scores,* adding group to the model did cause a significant improvement (*-2LL* change = 11.6, $p < 0.01$). The group x speed interaction was not significant (*-2LL* change = 0.8, $p = 0.39$). *PC2* was related to the overall CRP amplitude and shape for each step on side one (Figure 4.4). Males had higher *PC2-scores*, indicating that they had higher overall CRP (more out-of-phase) throughout each step (Figure 4.2B).

For the remaining side one shank-*sagittal*/thigh-*frontal* analyses, there were no other significant relationships between group and *PC-scores*.

Side Two

For shank-*sagittal*/thigh-*frontal PC1-scores*, adding group to the model resulted in a significant improvement (*-2LL* change = 21.6, $p = 0.01$) and adding a group x speed interaction to the model approached significance (*-2LL* change = 3.7, $p = 0.06$). *PC1-scores* were related to change in CRP from late stance/early swing of step one (~30-55%) and step three (~135-155%) to late swing/early stance of steps three (~85-100%) and five (~175-200%) on side two (Figure 4.5). Females had higher *PC1-scores*, demonstrating they had greater changes in CRP from late stance/early swing (more out-of-phase) to late swing/early stance (more in-phase) than males (Figure 4.3B).

For shank-*sagittal*/thigh-*frontal PC2-scores*, adding group did not significantly improve the model (*-2LL* change = 2.0, $p = 0.16$), though a group x speed interaction was significant (*-2LL* change = 12.2, $p < 0.01$). An outlier was identified in the data; however, the results were similar when running the model with the outlier removed, including the significance of a group x speed interaction (*-2LL* change = 9.8, $p < 0.01$). Therefore, it was concluded that the outlier was not driving the model and was included in the analysis. This interaction demonstrated that the relationship between shank-*sagittal*/thigh-*frontal PC2-scores* and speed depended on the group. Higher shank-*sagittal*/thigh-*frontal PC2-scores* indicated a higher overall CRP amplitude (more out-of-phase) throughout each step (Figure 4.5). For males, higher *PC2-scores* (higher CRP amplitude) were related to higher peak skating speed, whereas for females, lower *PC2-scores* (lower CRP amplitude) were related to higher peak skating speed (Figure 4.6).

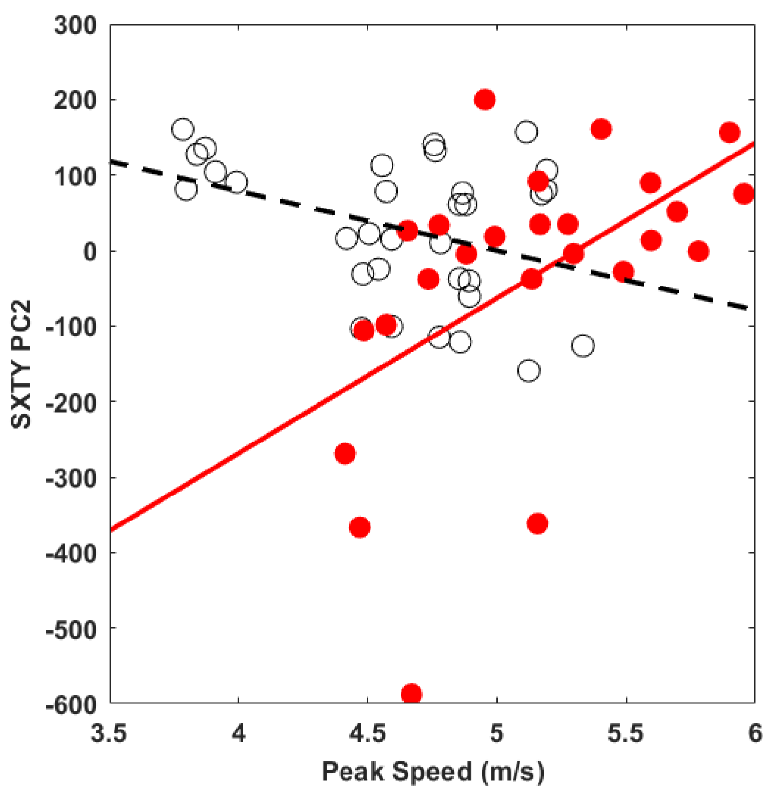

Figure 4.6 The relationship between peak speed and shank-sagittal/thigh-frontal PC2 on side two for each group. Male participants are represented by red, filled dots and female participants are represented by black, unfilled dots. The lines of best fit for male (red, solid) and female (black, dashed) groups are also represented. Note: outlier was included in the analysis as it was concluded they were not driving the model.

For the remaining side two shank-*sagittal*/thigh-*frontal* analyses, there were no other significant relationships between group and *PC-scores.*

4.5.3 Foot-sagittal versus Shank-sagittal

There were no significant relationships between group and *PC-scores* for foot-*sagittal*/shank-*sagittal* analyses on side one or side two.

Table 4.5 Principal component (PC) descriptions and explained variance for **side one.**

Variable	*PC*	Description	Higher *PC-scores*	Variance (%)
Shank-*sagittal* vs. Thigh-*sagittal*	1	Overall amplitude and shape	Higher CRP amplitude throughout each step	34.4
	2	Amplitude during step zero	Higher CRP amplitude throughout step zero (0-41%)	29.0
	3	Amplitude during transition from step two to step four	Higher CRP amplitude during step two late swing through step four mid-stance (~130-170%)	10.6
Shank-*sagittal* vs. Thigh-*frontal*	1	Amplitude during step zero	Higher CRP amplitude throughout step zero (0-41%)	33.0
	2	Overall amplitude	Higher CRP amplitude throughout each step	21.8
	3	Phase shift in timing	Delay in CRP peaks throughout the entire stride cycle	11.9
Foot-*sagittal* vs. Shank-*sagittal*	1	Overall amplitude and shape	Higher CRP amplitude during swing phases in step zero (~0-41%), step two (~91-143%), and step four (~196-230%)	39.4
	2	Phase shift in timing	Delay in CRP peaks during late stance/early swing phase for steps two (~80-105%) and four (~180-205%)	18.7
	3	Difference operator	Greater change in CRP from late stance/early swing in steps two (~75-95%) and four (~185-200%) compared to late swing/early stance in steps two (~125-145%) and four (~225-245%)	10.8

PC: Principal Component
CRP: Continuous Relative Phase

Table 4.6 Principal component (PC) descriptions and explained variance for **side two.**

Variable	*PC*	Description	Higher *PC-scores*	Variance (%)
Shank-*sagittal* vs. Thigh-*sagittal*	1	Overall amplitude and shape	Higher CRP amplitude throughout each step	42.3
	2	Phase shift in timing	Delay in CRP peaks throughout the entire stride cycle	17.3
	3	Difference operator	Greater change in CRP from early recovery of step one (~42-55%) compared to early stance of step three (~93-105%)	15.4
Shank-*sagittal* vs. Thigh-*frontal*	1	Difference operator	Greater change in CRP from late stance/early swing of step one (~30-55%) and step three (~135-155%) compared to late swing/early stance of steps three (~85-100%) and five (~175-200%)	29.5
	2	Overall amplitude	Higher CRP amplitude throughout each step	17.7
	3	Amplitude during step one	Higher CRP amplitude throughout swing phase of step one (~42-93%)	12.6
Foot-*sagittal* vs. Shank-*sagittal*	1	Overall amplitude and shape	Higher CRP amplitude throughout stance and early swing phases for steps one (0-70%), three (~93-165%), and five (~193-250%)	68.5
	2	Difference operator	Greater overall change in CRP from late swing (~75-93%) of step one compared to late stance/early swing (~135-155%) of step three	13.8
	3	Phase shift in timing	Delay in CRP peak during step three late stance/early swing phase (~130-155%)	6.3

PC: Principal Component
CRP: Continuous Relative Phase

4.6 Discussion

To our knowledge, this study was the first to compare lower extremity inter-segment coordination between male and female ice hockey players during forward skating starts. The results partially supported the hypothesis that differences in lower-extremity inter-segment coordination would exist, with females likely being more in-phase at the shank-thigh segment pairings than males. However, there were no significant differences identified between males and females at the shank-foot segment pairings.

4.6.1 Shank versus Thigh

Male hockey players demonstrated more out-of-phase coordination (higher CRP) than females for both side one and side two shank-*sagittal*/thigh-*sagittal* as well as side one shank-*sagittal*/thigh-*frontal* segment pairings throughout each step. Utilising a more out-of-phase mode of coordination may allow for a more efficient energy transfer and better use of the forces present in the system and therefore may be more advantageous in this segment pairing (Bernstein, 1967; Schenau, 1989; Temprado et al., 1997). Females, on the other hand, demonstrated a greater change in CRP for shank-*sagittal*/thigh-*frontal* pairing on side two. Females transitioned from more out-of-phase in late stance/early swing to more in-phase in late swing/early stance. It is possible that females may utilise a more in-phase mode of coordination to achieve increased stability surrounding ice contact in the transition from swing (recovery) to stance phases. Smaller changes in CRP throughout the stride cycle for males are likely due to them tending to stay more out-of-phase throughout all strides on both sides.

For shank-*sagittal*/thigh-*frontal* segment pairing on side two, faster males utilised more out-of-phase coordination (higher CRP) while faster females utilised more in-phase coordination (lower CRP), further exhibiting differences in coordinative strategies employed by males and females for achieving faster skating speeds. There are no previous skating coordination comparisons between sexes, or any studies to our knowledge that have examined female skating coordination. However, during walking, males exhibited more in-phase coordination at the shank-foot in the sagittal plane, while older females tended to be more in-phase at the pelvis-thigh (Ghanavati et al., 2014). Females have also displayed decreased CRP variability – thought to be associated with more in-phase coordination patterns – at the thigh-shank during running compared to males (Hannigan & Chou, 2019). Speculation that males and females may adopt different control mechanisms during walking and running suggests that this may be true for skating tasks as well. Further investigation is required to determine whether targeted training protocols impact coordinative patterns and to what extent particular coordination strategies relate to better performance outcomes.

Despite similar skating stride length, stride rates, and task completion times between male and female skaters in this cohort, males reached greater peak speeds, had greater stride width, and longer off-ice single leg jumps than females (Shell et al., 2017). Strength differences may not only play a role in kinematic differences, but also differing coordination patterns by sex, as they have been shown to significantly alter coordination of the lower-limb during weight-bearing dynamic tasks such as walking and hopping (Smith et al., 2014). We speculate this may also be pertinent to skating tasks and that significantly greater leg strength in males may be a factor in the use of different coordinative methods to achieve stability between sexes (Shell et al., 2017). More in-phase behaviour is thought to reduce the control effort necessary for motor control, so female skaters may use more in-phase coordination of the shank-thigh to counteract decreased lower-body strength and better control skating performance (Ghanavati, Salavati, et al., 2014). Additionally, an increased lower extremity injury rate for females at all ages and levels of play could result in a greater need for stability at the shank-thigh segment pairing as a protective measure (MacCormick et al., 2014). Female skaters demonstrated possible protective measures including decreased knee flexion and a brief knee extension cessation at ice contact and initial stance; the use of more in-phase coordination may be another protective strategy, as in-phase coordination is considered more stable (Dierks & Davis, 2007; Hamill et al., 1999; Shell et al., 2017). Increased emphasis on lower body strength could be beneficial in decreasing the need for protective measures and achieving more efficient coordination patterns, particularly in females. This relationship should be investigated further as it could have direct implications for athlete training.

4.6.2 Foot versus Shank

No significant differences were found at the foot-*sagittal*/shank-*sagittal* segment pairings. Given the unique demands of on-ice locomotion with hockey skates, it is possible that out of necessity, coordinative patterns at these segment pairings are optimised earlier in skill development than shank/thigh segment pairings during forward skating starts. Both high-calibre male and female skaters may have achieved optimal coordinative patterns at the shank/foot. Based on these findings, we speculate that it may be more beneficial for coaches to focus on shank/thigh segment coordination through the incorporation of diverse skating drills and strength training, as more ideal coordinative patterns may require more practice and reinforcement to develop. Future studies should examine the relationship between lower-limb coordination and the implementation of skating drills and strength training.

4.6.3 Limitations

The results of this study should be interpreted with several limitations taken into consideration. First, despite the elite level of both groups, males had significantly more years of playing experience than females; it is possible that differences between groups may have been influenced by playing experience. Additionally, the use of compression clothing and a standard skate model as well as not wearing protective equipment while skating may have resulted in differences in inter-segment coordination and overall performance compared to in-game skating. The use of a standard skate controlled for the potential effect of skate design, though this may have affected overall comfort and generalisability of the findings. The sample size was small, and there were not enough trials to examine coordination variability.

4.7 Conclusion

Coordinative differences of the shank and thigh were identified between high-calibre male and female hockey players during forward skating starts. Males tend to utilise more out-of-phase modes of coordination throughout strides on both sides of the body. Females tend to have a greater change in mode of coordination between transitional ice contact events and utilise more in-phase coordination, possibly as a protective measure. Additional studies should examine the relationship between lower limb strength and coordination as well as the effect of incorporating diverse skating drills on shank/thigh coordinative patterns.

4.8 Acknowledgements

The authors would like to thank Jaymee Shell, Adrien Gerbé, David Greencorn, Aleksandra Budarick, and Daniel Boucher for their assistance with data collection.

4.9 Funding

This work was supported by the Natural Sciences and Engineering Research Council of Canada under Grant [CRDPJ 453725-13] and Bauer Hockey Ltd. under Grant [CRDPJ 453725-13].

4.10 Disclosure Statement

Bauer Hockey Ltd. provided some of the funds for this study. None of the authors had a financial or personal conflict of interest.

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Chapter 5: Knowledge translation with an industry partner: a deeper look at academic-industry research collaboration in sports science (Objective 3 – Knowledge Creation: tailoring knowledge)

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In preparation for submission to *The Journal of Technology Transfer*

5.1 Preface

Staying within the knowledge creation component of the Knowledge-to-Action cycle, chapter 5 examines how knowledge (and knowledge creation) is tailored to meet the needs of knowledge users. Within sports science, there are a multitude of knowledge users to take into consideration when conducting sports biomechanics research. Industry research teams often look to apply research results to product development, and partnerships with academic teams can help strengthen the research process. Previous research in this area has focused on output from the partnership (e.g., performance, funding, etc.) and there is minimal research investigating such partnerships within sports science. This chapter will instead investigate the relationship between academic and industry research teams, the process of creating mutually beneficial research projects, and the impact of this research on product development in sports biomechanics. Analysing the way stakeholders co-create and co-develop knowledge can provide a deeper understanding of knowledge translation in sport.

5.2 Abstract

Academic-industry research partnerships in sports science have not been adequately investigated from the perspectives of all participants (i.e., students, academic staff, and industry staff). The objective was to explore the relationship between sport science researchers and industry partners and how they collaborate to guide the research process in the interest of product development. This study was an instrumental multiple-case study informed by social constructivist paradigm with focus groups and interviews conducted with academic staff (n = 4), students (n = 7), and industry (n = 8) separately for each partnership. Interviews and focus group transcripts were analysed using thematic analysis. Patterns of distinctive institutional logics across academic and

industry groups were shown and can be divided into competing and reconciling logics. Competing logics included differences in time cycles, contrasting goal orientations, and emphasis placed on different learning needs, which were demonstrated during often frustrating contract negotiations. Partnered academic and industry research groups can develop new, shared institutional logics over time through dialogue and active participation, leadership and guidance, and structuring (reconciling logics). The presence of former academics on industry research teams, commitment to regular dialogue (both informal and formal), and engaging students in both partnership and research activities were beneficial to overall feelings of perceived success by partnership participants.

5.3 Introduction

Public-private research partnerships, like those of academic-industry partnerships, have been demonstrated to advance the efficacy and uptake of new innovations in a number of fields, including agriculture, medicine, engineering, and other sciences (Chandrasekaran et al., 2014; Hingle et al., 2019; Spielman et al., 2010). Such partnerships can drive innovation, increase opportunities for students, and enhance the diffusion of knowledge by allowing academic and industry researchers to work concurrently to bridge the gap between, for example, the laboratory and product (Chai & Shih, 2016; Prigge, 2005; Tumuti et al., 2013). Research into academic-industry partnerships has increasingly focused on the tension between retaining the authenticity of a particular domain with the benefits of cross-sector collaboration, but the relationship between industry and academia is often portrayed in terms of relatively fixed positions (Barnes et al., 2002). There is little research on how perspectives coalesce around institutional positions on both sides, and how they might be reconciled.

Sport might offer a fruitful domain in which to explore this problem because sport has a major community component as well as a commercial-professional component, characterized by learning and interaction at multiple levels. Further, different industries utilise different channels of knowledge transfer between university and industry as well as different technological and market knowledge, highlighting a need to evaluate specific industries individually (Bekkers & Freitas, 2008). Academic-industry research partnerships in sport have demonstrated growth, though there is an established gap in research examining these research interactions (Zaharia, 2017). Although these partnerships have the potential to shape sport performance through product development, they often operate as a "black box" in which inputs and outputs may be known but the internal workings cannot be observed. There is considerable information available on how some groups identify industry partners and create such partnerships, as well as research looking at their effectiveness; however, there has been limited research investigating academic-industry partnerships in sports science and even less examining participant perspectives.

Previous studies examining academic-industry partnerships in sports management, sports statistics, and cooperative education programs in sport and recreation highlight the utility of such partnerships within the realm of sport (Fleming & Hickey, 2013; Kovalchik & Reid, 2019; Zaharia, 2017). Kovalchik and Reid (2019) assert that implementing academic-industry partnerships in sport is not only feasible, but an effective method for knowledge translation. Academic and industrial partners are thought to operate from their own set of cultural beliefs and rules which shape their behaviour (Dunn & Jones, 2010). This suggests that a level of cooperation is required for partners from different institutions to successfully work together. Veletanlic and Sá (2019) identified misalignments in academic and industry cultural beliefs and goals (e.g., fundamental research vs. applied work). Trust, communication, and the use of intermediaries can help facilitate knowledge transfer in university–industry research partnerships, though more exploration into the perspectives of industrial participants is particularly necessary (De Wit-de Vries et al., 2019).

Investigating the perspectives of different stakeholder groups can shed light on how partnerships may operate despite conflicting institutional logics. For example, Fleming and Hickey (2013) interviewed industry supervisors, academic supervisors, and students within cooperative education programs and found that, while all participants agreed the partnership was mutually beneficial, students and industry stakeholders (who worked directly together) both emphasized clear communication as a necessity for a productive partnership. Another study by Barnes et al. (2002) on the perceptions of key participants in collaborative university–industry research projects on factors influencing project success found that– in addition to effective communication– good project monitoring, commitment, and clearly defined objectives were commonly mentioned. These organizational perspectives are insightful, but it may not be appropriate to assume they apply to all domains, as it was found that cases differed substantially within, but especially beyond, the same industry (Barnes et al., 2002). The diversity of academic-industry research partnerships and their objectives requires the consideration of strategies unique to particular industries, making a "one size fits all" approach to these partnerships inappropriate (D'este & Perkmann, 2011; Spielman et al., 2010). Consequently, further investigation into the perspectives of key stakeholders in partnerships that apply sports science research (e.g., sports biomechanics) to industry products is necessary.

Substantial differences exist in the overarching missions of academic and industry research teams, as well as the way these entities operate. A greater collective understanding of the personal experiences of those directly participating in academic-industry research partnerships may counter these differences and lead to a more effective balance between academic and commercial interests (Veletanlic & Sá, 2019). Therefore, the objective of this study was to explore the relationship between sport science researchers and industry partners and how they collaborate to guide the research process in the interest of product development. More specifically, this study was guided by the following research questions: (1) What strategies are engaged to guide the development of research questions that benefit both teams and what level of involvement do all participants in the partnership have? (2) In what ways (if any) does product design and development benefit from the collaboration with an academic research team and how is this impacted by barriers experienced by academic and industry researchers? (3) What are participants' perspectives on the way the academic-industry partnership in sport science functions, including perceived strengths and weaknesses?

5.4 Methods

Investigating the way individuals perceive experiences and how the processes of negotiating and conducting a partnership happen rely on speaking with people (Denzin & Lincoln, 2011). This implies the use of qualitative methods – a language-based strategy. The imperative to examine different perspectives suggests that there might be different views on academic-industry research partnerships, and one way of conceptualizing collective views that different stakeholders may have is the idea of "institutional logics". An institutional logic is a group of ideas that form a coherent set, and which a particular group of people share that is distinguishable from another institutional logic shared by others and come about through interaction by which people influence each other (Friedland, 1991). Straightforward examples include the shared beliefs and behaviours that centre on an organization being devoted either to education, humanitarian work, or profit. Summarily, institutional logics can be defined as "socially constructed patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality" (Thornton & Ocasio, 1999, 2008). The idea that there are competing logics rests on a constructivist assumption that there is more than one reality to the world (Bloomberg & Volpe, 2016; Kim, 2001). Using an institutional logics perspective allows for a better understanding of how the beliefs and behaviours of partnered academic and industrial institutions working in sport (i.e., both a research domain and a community) overlap or contrast.

This study was conducted as a multiple-case study informed by social constructivist paradigm in which emphasis is placed on understanding social phenomena from a context-specific perspective. The central assumption of social constructivism is that reality is socially constructed, and individuals establish subjective meanings of their personal experience which results in multiple meanings (Bloomberg & Volpe, 2016; Guba & Lincoln, 1994). Collective (multiple) case study involves studying multiple cases simultaneously or sequentially to generate a broader appreciation of a particular issue or a larger collection of cases (Sparkes & Smith, 2013; Yin, 2009). Therefore, this sample included participants from several academic-industry partnerships and at various levels of involvement within the partnership in order to establish a comprehensive and more transferable understanding. Approval from the McGill University Ethics Research Board (REB #22-04-086) was obtained, and all participants provided written informed consent prior to participation.

5.4.1 Sample and Participants

Participants who are currently or were previously involved in an academic-industry research partnership centred on sports science were targeted. Specifically, members of industry research and development teams and their partnered academic research teams, including both graduate students and supervisors were recruited. Academic and industry teams were questioned separately, with students and academic supervisors additionally considered separately to allow for a better understanding of how positionality may impact experience. In order to understand the processes and individual perceptions of people involved in these partnerships, it was important to sample a range of groups. Participants were purposively sampled, which involves identifying and selecting groups that are experienced with a specific phenomenon of interest as well as available and willing to participate in the research (Creswell & Clark, 2017; Palinkas et al., 2015). Once the purposive categories were established particular participants were approached on the basis of convenience sampling and snowball sampling, which involved collecting data from accessible and appropriate participants and using participants to identify other cases of interest based on people they know, respectively (Palinkas et al., 2015). Students (n = 7), staff (n = 4), and industry researchers (n = 8) from four distinct sports science partnerships operating from varied locations in Canada and the United States participated in this study. This provided the opportunity for more transferable results as findings would not be relevant to only one specific region within North America. Individual participants were eligible if they worked with the partnered research team for at least one year.

5.4.2 Data Collection

Semi-structured focus groups were conducted to collect relevant information on the topic while facilitating an interactive and in-depth dialogue in which participants were able to more flexibly report their own perceptions and experiences (Sparkes & Smith, 2013). Individual interviews were employed in the event of having only one person available at that level of the partnership (e.g., only one academic supervisor). Where there were multiple participants in the same organization, focus groups were organized to optimize insight that would build on previous participants' responses, thus providing a deeper understanding of the relationships between roles (Atkinson, 2011). Focus groups were divided according to stakeholder positions, i.e., separated by academic and industry group distinctions, as well as into supervisor/student subgroups to optimize distinctiveness of perspectives according to hierarchical role. All focus groups andinterviews were conducted via Zoom video calls and the average duration was roughly 39 minutes.

The interview and focus group guides were created and refined by the research team to collect information regarding general impressions of the research partnership, perceived strengths and weaknesses of the partnership, and suggestions for improvement. Interview guides (Appendix A-C) were initially the same for stakeholders within the same subgroups; however, interview guides were revised throughout the project to include new themes and topics that came up in discussion but were not previously addressed in the guides, resulting in some slight differences between groups. As examples, questions included: "What are your feelings about the current processes in place for communication between the academic and industry research teams?" and "What changes do you think would be beneficial to the relationship between the academic and industry research teams?"

5.4.3 Data Analysis

Data collected from interviews and focus groups were audio recorded, transcribed verbatim, and analysed using thematic analysis. This approach allowed us to move beyond explicit words and phrases to generate common themes from patterns within the data (Tumuti et al., 2013). The six-steps of conducting thematic analysis as defined by Braun and Clarke (2006) included familiarization, coding, generating themes, reviewing themes, defining and naming themes, and writing up the analysis. A detailed "audit trail" of coding definitions, decisions, and categories was recorded to enhance transparency and provide information on the analysis process (Bloomberg & Volpe, 2016). The codes and themes were flexible and open to change in order to allow new themes to be identified. Space was left for development because realities are socially, culturally, and historically constructed and therefore multiple realities can exist (Bloomberg & Volpe, 2016; Guba & Lincoln, 1994).

Interview and focus group recordings were automatically transcribed by Zoom software and manually checked against the audio recordings to ensure accuracy and increase familiarity with the data. Transcripts were then read repeatedly while searching for meanings and patterns as prescribed by Braun and Clarke (2006) above. Initial codes were generated manually by two researchers to help optimize alignment and enhance relatively plausible coverage of initial categories. This step was considered accomplished when refinements were not contributing new codes, but merely slightly different examples of existing codes. Reading, re-reading, and re-examining of the data and codes by multiple researchers continued until no new themes were identified across all data as documented in our "audit trail" (Bloomberg & Volpe, 2016; Lincoln & Guba, 1985). Theme maps and other visual representations were used to develop themes, followed by reviewing the representation of the thematic map to the data set. Once a thematic map was determined, themes were defined and named, and a detailed analysis was written for each individual theme. After these steps were completed and a set of themes were delivered, the thematic analysis was written up to provide a coherent account of the story told by the data within and across themes. A journal was kept throughout the research process in order to help develop balanced perspectives among different researchers and increase credibility of the research (Braun & Clarke, 2006). "Peer debriefing," which involves having a colleague examine field notes and ask questions to help examine assumptions or view the data differently was used to improve research credibility (Bloomberg & Volpe, 2016; Crowe et al., 2011).

5.5 Results

The results show patterns of distinctive institutional logics across academic and industry groups. These were evident as distinctive sets of ideas and beliefs that reflected the social or organizational positions of the participants. These sets of beliefs can be divided into competing and reconciling logics, as described in the following sections.

5.5.1 Competing Logics

Time Cycles

For a start, academic research timelines tend to be longer in duration than in industry research, which appeared to have consequences for collaboration across the academic-industry divide. The misalignments of these research timelines were mentioned at all levels of the partnership as a potential source of friction, but none more than by the industry teams. Industry frustration on this subject could be summed up by the following:

> *I think if I could wave a magic wand and research with the university could be faster, then that would be great. (Industry 2A)*

Longer-term timelines were explained to be more challenging to manage for the industry teams, particularly when expected timelines would be additionally delayed, as it could be difficult to explain to the other teams on the industry side (such as the production team). However, industry partners with longer standing partnerships expressed a learned understanding of how to use the timeline differences to their advantage:

> *Sometimes it is a challenge to get everyone aligned, but on our end, being in such a long working relationship, we've kind of learned through the years as to set the expectations properly for both parties where we're typically gonna do things with [university partner] that we know are longer term, and maybe are sometimes like seeds we're planting to see what's gonna come out versus having them do things that we absolutely need in a timely manner. So, we've been kind of adjusting everyone's schedule to make sure that everyone kind of gets what they need for the projects. (Industry 3B)*

Another difficulty of timeline differences occurred when industry partners were unable to meet the needs of the academic team, particularly in ensuring they had the necessary resources to complete the research. Industry partners may not have sufficient control of when products are available and can be sent to the academic team. Academic partners also expressed frustration at having materials provided that were not "up to standard" for data collection, resulting in a need to repeat data collection sessions, or concerns about forcing research to be conducted in an inappropriately fast timeline.

Students highlighted that "the biggest strain was how much time we wanted the research to take," noting the desire to take more time to "make sure this is exactly correct," compared to industry wanting "to move really quickly." On the other hand, some of the academic staff found benefits to both sides of the timeline differences:

> *I think– as I said, what I like most about it is being able to see both sides of it and it's fun to sometimes be on a timeline and really help out [the industry partner] really quick[ly], but it's also working with the students who have a longer timeline and different aspirations and different goals. Yeah, my position is really fun in that sense. (Academic Staff 3A)*

Goal Orientations

The type of research that was most beneficial for each research team was another sticking point in the relationship between academic and industry teams, reflecting competing views that were collectively held and mutually reinforced by their institutional positions. Researchers from both sides pointed out that the primary goal of academic research is publishing, which often involves more theoretical research, compared to the more practical goals of industry research that tends to be geared towards tangible products. This goal discrepancy can make the partnership challenging, as described by one industry researcher:

> *It can be hard finding the balance between just wanting something that's beneficial for us and then them wanting something that's publishable. (Industry 1A)*

This difficulty is increased for academic staff who also need to consider the interests of student researchers. How groups handle this may vary depending on timing and the needs of the industry partner. Some academic groups mentioned times where potential incompatibilities with student interests were limited by bringing students in for specific projects that industry partners had already agreed to. Sometimes, students were more involved in project development as the industry partner gave a more general research direction to the academic team.

> *Sometimes a company has very specific things they would like to work on, which is great. That kind of gives us a really good– "okay we know you want to work on this; we'll try to build a project that works for you as well as the student." Sometimes they're kind of like "we're kind of interested in this and that," and they'll give us a little bit of leeway to figure out… "we're trying to figure out this general theme, but we don't know exactly how to do it," and they'll give us a lot of creative freedom to kind of come up with a project.*

> *Obviously, we come back to them and get approvals and stuff and make sure everyone is on the same page, but it depends on the year. (Academic Staff 3A)*

Many groups recognized a need for “give and take” between academic and industry research. While partnerships may choose to approach this challenge differently, it typically came down to reaching a compromise between the goals of each group. One academic supervisor summed up the relationship by saying:

> *I’m not in the business of doing [product] testing for [industry partner]. I am in the business of doing science, and we both know that. I feel like they fund a little bit more fundamental stuff than is necessarily good for them, and I do a little bit more product evaluation than is necessarily good for me.(Academic Staff 1A)*

Learning Needs

The partnership offers learning opportunities for everyone who participates in it, but the primary modes of learning for academic and industry teams can be at odds with one another, again reflecting cultural differences that derive from differing institutional locations. For students, the most meaningful learning from academic-industry partnerships comes from the process of conducting the research, as well as gaining some industry experience.

> *I think the biggest benefit there is that my students get a lot out of it. That is different than just me doing publishable fundamental research. It’s also about [them] getting their experience. They get the experience, and they can move on into jobs like that at companies where they do more specific products research. (Academic Staff 1A)*

On the industry side, the primary concern is typically what they learn from the outcomes of the research and how it can be applied to the product moving forward. However, one industry team did note that “learning from every project” can be applied into more than just product, but potentially into testing processes or new technologies that have been developed. Industry teams must also balance student learning with their own learning needs:

> *So usually we'll come up with, like, "these are the things we'd like to address or that we'd like to investigate, and then how can [academic partner] add things to these to make sure that that work is valuable for [academic partner] as a research endeavor so that the students learning something, going through the process of learning how to do research and everything?" So that's why I think sometimes it can be challenging to fit both bills. But that's on our end to be able to … manage the expectations internally ... to what the research partner is gonna be able to do and provide at the end. (Industry 3B)*

With student learning at the forefront of the benefit of academic-industry research partnerships, students expect to take hands-on roles in their research projects. The amount of involvement the students felt they had in the project directly contributed to their level of satisfaction with the research partnership. Industry desires for high-quality research can lead to expectations that the academic supervisor will be heavily involved in the project, sometimes resulting in students feeling less "in-charge" of their projects, and further highlighting the industry focus on outcomes rather than the research process. One student stated:

> *I feel like a lot of times the communication [from industry partner] doesn't go directly to me. I sort of hear about it afterwards from [my supervisors], whereas, I'm kind of seeing it from my perspective, like, this is my project, my thesis, so a lot of it I want to be in control of. (Student 3C)*

Contracts

Legal contracts such as research agreements are one source of conflict between the academic and industry research teams that tends to highlight the differences between these groups. Contracts are often completely outside of the respective research teams' control, making it a clear example of how competing institutional logics manifest as institutionally circumstantial, rather than features of individual personality or intention. Both academic staff and industry teams recalled negative experiences with contract negotiations:

> *So that experience was incredibly frustrating because we knew what [the university partner] wanted and then [industry partner] on the lower levels knew what we wanted, and then getting the legal teams to agree on that was just a nightmare. It took months. (Academic Staff 2A)*

Each group has different needs that require consideration in contract negotiations but expressed an understanding of the needs of their research counterpart (e.g., academics needing the ability to publish research, but industry being consulted about what is published). Despite generally negative comments about the process of dealing with legal procedures, both sides appreciated the necessity of contracts to manage their institutionally distinctive perspectives and roles.

> *…I dislike it, but it's a necessary process because that's how people get burned if it's not done properly. (Academic Staff 4A)*

5.5.2 Reconciling Logics

Dialogue and Active Participation

Collaboration and communication between research teams were unanimously identified as the most important components for fostering a satisfying and successful partnership. This takes active work and commitment to discussion and exchanging of ideas. Participants identified that an important first step in project collaboration is to determine overlap between goals and provide a clear direction to the research partner:

> *What we've done in the past is just have a brainstorming session with our [academic] partners. So, they come to the table with research areas that they're interested in exploring, and then we come to the table with new*

> *concepts, research ideas, or directions that we're interested in exploring, and then we see where they overlap. (Industry 1A)*

Students appreciated having explicitly defined goals from their industry partner in terms of comfort in their role in the partnership and their confidence in meeting the expectations of the industry team. Pre-determined goals also helped projects remain as beneficial to both groups as possible. However, an active commitment to direct and consistent communication (i.e., "talking as doing") tended to be necessary to work towards a shared logic of work. Although face to face communication was preferred when possible for "more important" meetings such as presentation of findings, all the groups stated that virtual communication via video meetings and email were vital throughout the research process. Given the distance between some partnered research teams making face to face meetings unreasonable, the frequency/consistency of communication was presented as more important than the means of communication. As increased communication was related to improved trust between research groups, the opposite was also true. One group conveyed the consequences of breakdowns in communication:

> *I think … it happened a few times, where there's a disconnect between our expectation and the [academic] lab's expectation or direction. A couple times through these different collaborations, like we've felt that if we're not meeting regularly enough, we're kind of going off [on] two different tangents, where we think the [academic] research partner is going there, but they're actually going over there just because either they decided along the project to change direction for different reasons. (Industry 3B)*

More consistent communication and determining shared goals also fostered mutual learning through effective research and relationships. Students were able to learn from industry in addition to their academic supervisor(s). Students learned not only information about their research topic and how to conduct research, but about how industry works and how to foster and negotiate the sometimes-treacherous waters of working relationships. The industry teams had opportunities to learn from the academic supervisors as well, who tended to be brought in as "experts" in their respective subject:

> *There were times where…you know, I'm new to the industry, and so I appreciate getting a different perspective on things. So, it was great to kind of pick [academic supervisor's] brain a little bit more and get what [their] perspective is on certain things. So, I walked away with more knowledge than I walked in with, so that that was something positive I took away. (Industry 2B)*

Having roles and expectations well-defined and effectively communicated between the teams was seen to contribute to building a bridge across institutional logics, increasing the overall satisfaction in the partnership by industry teams and academic teams, especially students. Students expressed feelings of enjoyment and appreciation for the opportunities provided by the partnership, especially when students had felt adequately involved in the projects and knew what they were supposed to contribute to the team. Students also expressed wanting more involvement from the industry partner, not only through their own projects, but potentially through internships or other training opportunities:

> *Let's say the relationship was more of an internship style, […] like that collaborative relationship builds a better study and also gives you the experience of, like, what industry would do, not just what the university would do to interpret the results, right? That's, like, one small example of how an … internship style relationship would be even more valuable. (Student 3B)*

Leadership and Guidance

The importance of having a nominated academic supervisor within the partnerships was frequently mentioned by members of all groups. From the industry perspective, academic supervisors often play something between a "consultant" and "lead collaborator" role:

> *We have a lot of those kind of consulting meetings with [academic staff] where we'll go through the data and pitch new concepts and get feedback on them, and then really use [their] feedback a lot. (Industry 1A)*

In addition to having their direct input on how most effectively to conduct research, students discussed following the lead of their supervisors in how they interacted with the industry team. Having the students involved in or witness most interactions between the industry team and the academic supervisors was stated to be a prime learning opportunity. Academic supervisors are also largely responsible for ensuring the students are adequately prepared for conducting the research and have been trained in the necessary skills. If the academic supervisor did not perform their role sufficiently or "you realize that the student actually didn't have the skill set they needed to execute on," it led to rifts between the academic and industry teams.

On the other hand, when the industry team took a more hands-on approach to their guidance with the students, it tended to greatly increase the perceived success of and satisfaction with the projects. One industry team stated that working side by side with the students early in the project's development was useful in preventing problems later in the project:

> *…some of … the mentorship things, like our ability to be on site with [the students] at times was, I think, really critical; and kind of teaching some of the students who maybe hadn't done a project on [sport biomechanics] for example – to teach them in person and to catch things that are maybe going wrong earlier than like, when all the data was collected and looking at it after the fact. (Industry 2D)*

Structuring

Given that institutional logics emerge according to institutional positioning or circumstances, and are fostered by interaction, the sustainability of shared logics relied on structures being put in place. The existing structures for input and participation play direct roles in the overall experience of the partnership for people at each level. The informal norms and expectations that come with the various positions (e.g., student vs. staff, academic vs. industry) ultimately dictated some of the participants' behaviour. For example, students commented that they "felt like the lowest rung" and did not always know where and how to voice concerns, or feel entitled to do so (i.e., "…you don't really want to bite the hand that feeds you…") which resulted in breakdowns in communication. Clear chains of command on certain projects were recommended to alleviate situations such as one student describes:

> *As a student it's not super clear who you go to, right? Do you go to [industry partner] or you're going to your lab to say, "I think our project should be more focused." You know what I mean? It's not really clear whose fault either that would be if you ever had a complaint. (Student 3B)*

Academic supervisors and industry team members both share control over the project in meaningful ways. Industry often supplies funds or equipment to meet goals they have often defined, and academic supervisors act as a main guide for the students and project. Coordination between the academic staff and industry team to maximize student learning as well as project success was recognized as beneficial for everyone in the partnership, and academic staff tended to play the role of "middleman" between groups. However, one feature that was deemed especially crucial to the success of the partnership was having industry team members with academic backgrounds to help bridge the gaps between the two settings and reduce friction.

> *They [industry partner] were really great about understanding where we were coming from, and I think it helps that they all come from academia as well. So, they understand what is going on on our [academic] side as well. (Student 2A)*

At all levels of the partnership structure, the degree of collaboration taking place was directly related to the perceived levels of satisfaction. With a better understanding being fostered between the groups, a "real team effort" could be made:

> *It's kind of been much more, I would say, collaborative of a back and forth between like, this is what we're interested in, and I think is important, and had me personally anyway, kind of more interaction with their students that are working on the project and things like that. (Industry 2D)*

5.6 Discussion

This study sought to demonstrate the factors represented in negotiation and conduct between three organizational perspectives (2 academic, 1 industry) of academic-industry research partnerships in sport, and what factors contribute to their effectiveness. The relatively under-researched domain of sport is an ideal setting to explore academic-industry partnerships as dynamic and circumstantial, given that sport is a widely shared activity in society that is not solely commercial-professional. Further, it has been established that despite some general commonalities, the characteristics of partnerships between different industries can vary enough to warrant specialized investigation (Barnes et al., 2002).

The present study showed that competing institutional logics are represented by different perspectives on time cycles, goals, and learning needs, and represented dramatically in preparing and agreeing on contracts. These findings are similar to previous literature examining culture differences between academic and industry research partners in other domains. Academic-industry partnerships tend to be managed informally and irrationally, based on high levels of trust (De Wit-de Vries et al., 2019), and this was partially true for the cases included in this study. Despite formal contracts, some teams relied on informal reporting practices that were often dictated by feelings of necessity and sometimes resulted in greater disconnects later in the projects. Barnes et al. (2002) suggested that teams should only hold meetings when there is significant progress to report, though similarly reported that intermediate communication between meetings is useful which further highlights the importance of clearly defined communication practices. Misalignment of organizational goals (e.g., students wanting to learn and publish vs. industry wanting fast and tangible results) and task uncertainty (particularly for student participants) were frequently mentioned as barriers to perceived success in the partnerships, and have been demonstrated to negatively impact project control and coordination (Morandi, 2013). With the emphasis for industry research teams centred around product outcomes and, for the academic research team, centred around collective learning, the need for establishing common ground between research teams is paramount. The structure of partnerships tends to dictate the nature of collaboration, and teams employed a number of strategies within their respective partnerships to enhance its effectiveness.

The study showed that institutional logics can be bridged – indeed a new, shared institutional logic, can be forged by dialogue and active participation, leadership and guidance, and structuring. Although active participation has been considered challenging to maintain (Chandrasekaran et al., 2014), it is achievable if participants commit to talking regularly. Stakeholders need to participate in shared dialogue – a common position from mutual empathy – that becomes structured and routine. As such, and since collaboration only comes from shared perspectives, “talking” needs to be, and comes to be, seen as equally productive and practical as “doing”. Trust is an important factor in and predictor of organizational innovation and tends to be tied directly to collaborative success (Ellonen et al., 2008; Hardwick et al., 2013; Oliver et al., 2020). Demonstrating continued commitment to the partnership by attending regularly scheduled meetings and actively participating in group engagements appeared to play a significant role in trust being built between teams. It has previously been suggested that industrial partners prefer a supporting or "observing" role in research projects (Barnes et al., 2002), although industry partners in the present study tended to be more involved in the ongoing research process. The trust that emerges from dialogue and active involvement in the partnership allows recognition of unforeseen commonalities in time cycles, for example, unforeseen shared goals, and promotes preparedness to compromise where necessary.

Reconciling academic-industry partnerships in sport, indeed generally, relies on developing social structures of collaborative dialogue. It is significant that the experience of students emerged as central to convey the dynamics of academic-industry partnerships in sport. Institutional logics are founded on dynamic learning relationships where institutional positions are role-modelled and reinforced, depending on one's role or organizational position. In a dynamic environment in which logics are learned, students who witness negotiations by academic and industry leaders are role-modelled as bridge-builders in academic-industry partnerships. Valuing dialogue as equal to "practical work" creates norms of behaviour, which create expectations of behaviour, and hence structures. Students who were more involved in the relationship with the industry team tended to feel more positively about the success of the project and the partnership overall, displaying the importance of the learning that takes place outside of the research itself. On the industry side, the presence of academics who had transitioned into industry research roles was also key to managing expectations on all sides of the partnership and allowed the industry researchers to act somewhat as intermediaries. Business managers and university scientists and administrators alike have previously complained that their counterpart does not understand or appreciate the goals/culture/constraints of the other (Siegel et al., 2003), which can be mitigated by positioning (former) academics in industry research and development roles. Their behaviour within the partnership is guided by their first-hand experience of both the academic and industrial structures and ultimately contributes to more effective structuring and leadership within the partnership.

The perspectives of industry participants have been perhaps the least investigated in academic-industry research partnerships despite the potential for learning from their business-driven approach to the partnerships (De Wit-de Vries et al., 2019). Responses from industry participants in this study demonstrated that some of the conflicting logics experienced between groups can be reconciled by simply using them to the advantage of the industry partner. For example, multiple industry participants referenced utilizing the partnership to address more theoretical goals that may influence product decisions down the road, which is made possible by longer research timelines and improved resources via the partnership. Industry teams who had worked with their partnered academic team for longer seemed to have a better understanding of how to generate mutually beneficial research, which implies that over time these groups may have developed their own shared culture and institutional logic within their partnership. Researchers on either side of the partnership who had an established relationship with a partnered researcher also had a more positive impression of the partnership's success, though it is unclear whether this is the result or product of trust in the relationship. This was especially true for industry professionals coming from an academic research background, further validating the benefit of having former academics in industry roles. The relatively small size of the involved industry and academic research teams may also have impacted the ease with which new, shared logics could be established, as larger groups with more separation between the teams may cling to their existing group logics more readily.

5.6.1 Limitations

This study has several limitations; first, this study analysed only four research collaborations. Research partnerships are not often made readily available, making participant recruitment challenging, even with snowball sampling. Although the inclusion of academic staff, students, and industry staff provided a more complete understanding of these partnerships, these perspectives were limited in instances where only one participant was available for a group (e.g., one student). Future studies may consider following ongoing partnerships over a longer period of time to include more students and staff. Additionally, generalisability is limited to Canada and the United States. Extending the sample to other geographical regions would strengthen the general applicability of the findings.

5.7 Conclusion

Academic-industry research partnerships function not only to impact product outcomes, but also to improve the learning of students and the knowledge of researchers in both academia and industry. These partnerships are challenging to navigate largely due to the vast cultural differences and the conflicting institutional logics that each party operates from. In the sport science partnerships included in this study, the established conflicting logics included differences in time cycles, contrasting goal orientations, and emphasis placed on different learning needs, which were demonstrated during often frustrating contract negotiations. However, partnered academic and industry research groups can develop new, shared institutional logics over time through dialogue and active participation, leadership and guidance, and structuring. The presence of former academics on the industry research teams was beneficial to the implementation of practices that helped forge more effective shared institutional logics for the group. To maximize the perceived success by participants, partnered academic and industry research teams should emphasize a commitment to regular dialogue (both formal and informal), establish clear leadership roles and mutual goals, and engage students in partnership activities as well as research activities.

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Chapter 6: Using Knowledge-to-Action to guide the implementation of a remote biomechanical analysis program in a rural First Nation community (Objective 4 – Action Cycle)

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In preparation for submission to *Implementation Science.*

6.1 Preface

Chapters 3-5 pertain to the knowledge creation component of the Knowledge-to-Action process without participating in the action cycle: the process by which knowledge is implemented (Straus et al., 2013). Chapter 6 discusses the implementation of a biomechanical analysis program, focusing on the application of the KTA process and its utility for translating sports biomechanics knowledge to support Indigenous governance in sport. Rural Indigenous communities offer a unique setting for applying sports biomechanics knowledge and Remote Presence Sporting Technology (RPST) given their distance from urban training hubs and ongoing experiences with colonial systems that create barriers of access to science and technology in sport governance. The KTA process provides a flexible KT framework and has been considered valuable in some First Nations contexts, though only the knowledge creation component has been previously investigated in Indigenous sport. This chapter will showcase the process of applying sports biomechanics knowledge in action as well as critique the KTA process for use in a remote Indigenous sport setting. It is important to consider the needs of specific communities when discussing knowledge translation in sports biomechanics rather than simply assuming a "one size fits all" mentality for applying knowledge.

6.2 Abstract

Biomechanical analyses can be used to support Indigenous sport governance and athlete training by supporting coaches to implement tailored training programs specific to athlete and team needs. Knowledge translation, which refers to the process by which research can be developed, implemented, and maintained over time to improve the applicability and effectiveness of research findings to end users, can help facilitate the implementation of such programs. The

objectives of this paper are: (1) to propose that KT can be used to leverage sports science knowledge and remote presence sporting technology to support Indigenous governance in sport; and (2) to describe lessons learned by applying the KTA process to translate sports science and technology knowledge to the coaches of a rural First Nation hockey team. Ten U18 male athletes and four coaches participated in the biomechanical analysis component of this project and the role of the KTA process in the implementation of the testing program with the coaches is the primary focus of this manuscript. The KTA process provided a flexible framework that allowed for adaptability and for community-based knowledge and local contexts to be incorporated into the project design. However, the KTA does not have tools or steps outlined for consideration of the complex navigation of multiple knowledge systems and colonial power dynamics or translating knowledge in Indigenous contexts. While the KTA process showed utility within the context of implementing remote biomechanical analysis with a remote First Nation hockey team, it is recommended that researchers incorporate additional appropriate frameworks, such as Indigenous science, technology, and society (Indigenous STS), to help facilitate knowledge translation by centring Indigenous governance.

6.3 Background

In 2015, the Truth and Reconciliation Commission of Canada made clear the powerful role that sport must play in restoring the country's broader goal of reconciliation between Indigenous and non-Indigenous peoples. However, recent years have witnessed the corrosion of Indigenous control over sport governance as elite-level athletes are required to leave home to pursue training opportunities in major urban centres (e.g., places where athletes can gain access to elite-level coaching, personalized fitness and training regimes, and high-tech sporting infrastructure). This rural-to-urban pipeline presents several challenges in terms of both youth, community, and athlete development; e.g., high financial costs and potentially dangerous travel conditions, diminished educational outcomes due to prolonged periods away from home/school, enhanced anxiety related to family separation, and ruptures in family and community identity and cohesion—all challenges that are exacerbated by the cultural disconnect and systemic racism and sexism experienced by many young Indigenous athletes upon leaving their home communities to pursue sport (Postl, et al., 2010; Robidoux, 2004, 2012).

This project sought to help resolve many of these long-standing issues by empowering Indigenous youth through access to elite-level training and skill development in their home communities and, thus, by giving them the choice to remain home while still pursuing their sporting dreams. We pursued this goal in solidarity with our community partners in northern Québec through the co-development of locally relevant and community-controlled sporting applications that we have labelled Remote Presence Sporting Technology (RPST). In committed partnership with the community's hockey program, we used biomechanical analyses to help coaches to implement training programs tailored to the needs of individual athletes and their teams. Remote analysis methods– including Dartfish software– are effective tools for conducting qualitative movement and performance analysis (Garhammer & Newton, 2013). RPST can provide rural athletes access to elite-level sporting technologies and skills development by partnering sports science researchers and coaches. However, biomechanics and sports performance research findings are not always disseminated in a way that is effective for end users (Martindale & Nash, 2013). Therefore, methods of knowledge translation require further consideration to improve the effectiveness of communication and access between researchers, coaches, and athletes.

Knowledge translation (KT) refers to the process by which research can be developed, implemented, and maintained over time to improve both the applicability and effectiveness of research findings to end users (Straus et al., 2009). Various frameworks, models, and theories, including the Knowledge-to-Action (KTA) framework, have been established to assist researchers in taking a more intentional and systematic approach to the KT process. The KTA process consists of two primary phases: 1) the knowledge creation funnel where knowledge can be created and synthesized, and, 2) tailored; and the action cycle in which knowledge is applied to, and implemented with a group of end-users (Graham et al., 2006). Whether utilized in full or simply as a reference, the KTA process provides a flexible framework for fitting local circumstances and needs. The KTA process has been demonstrated as beneficial in several settings and has been successfully applied in sport (Field et al., 2014; Holt et al., 2018; Kosmenko et al., 2019).

KT has been employed in Indigenous research contexts to help improve health outcomes, but seldom are the KT processes adequately documented or shared transparently (Morton Ninomiya et al., 2022). Moreover, given the fact that academic institutions have, in many ways, played harmful roles in colonial societies, KT methods must be specifically developed and evaluated within Indigenous research contexts to answer calls for Indigenous governance over research (Battiste et al., 2002; Smylie et al., 2004). In a sporting context, Kosmenko and colleagues (2019) called for tailoring of the KTA model to Indigenous contexts and making the process more culturally relevant through recommendations such as ensuring participant engagement is consistent (e.g., research-related events do not overlap with other commitments) and dedicating a participant-directed phase to identifying, locating, and recruiting project resources. However, these recommendations were focused on the knowledge creation component of the KTA process, which suggests that further investigation into the action cycle is necessary. In addition to adjusting KT processes to be more relevant for Indigenous communities, a systematic review of KT in Indigenous health research stresses that effective KT should be directed, governed, and/or led by Indigenous rightsholders (Morton Ninomiya et al., 2022).

The objectives of this paper are: (1) to propose that knowledge translation can be used to leverage sports science knowledge and remote presence sporting technology to support Indigenous governance in sport; and (2) to describe lessons learned by applying the Knowledge-to-Action process to translate sports science and technology knowledge to the coaches of a rural First Nation hockey team. Specifically, we seek to discuss the utility of using the KTA process in this setting and identify strengths and limitations of this knowledge translation method. Given that the benefits of scientific knowledge production have not been proportionately experienced by Indigenous communities in Canada, we approached this work through a framework of Indigenous science, technology, and society (Indigenous STS), which asserts that Indigenous peoples have a stake in governing the sciences and technologies that produce knowledge about and affect them (Kolopenuk, 2020).

6.4 Coaching Intervention

Ten U18 male athletes and four coaches participated in the first iteration of this project. Project development was guided by a multidisciplinary team of Indigenous and non-Indigenous researchers and hockey coaches and community leaders in charge of local sports programming. The overarching goal of this project was not to study Indigenous bodies through biomechanical analysis, but to support community sport governance and athlete training. Athlete testing was divided into two phases: off-ice and on-ice. Off-ice data collection included anthropometric measures of height and weight, grip strength, long jump, seated medicine ball throw, and a Y-balance test. These tests were used as baseline measures to be re-tested following off-ice and on-ice training programs. On-ice tests included forward skating accelerations (from blue line to blue line), wrist shots, and slapshots. On-ice tests were captured using an iPad 11 pro (Apple Canada Inc., Toronto, Ontario) and analysed using the Dartfish mobile software (Dartfish USA, Alpharetta, Georgia). Each participant performed three trials of each test. Timing for skating accelerations were recorded using Brower timing gates (Brower Timing Systems LLC, Draper, Utah, USA), and wrist shot and slapshot velocity was measured using a HS Extreme Hockey Radar (Hockeyshot, Mississauga, Ontario). Videos collected during on-ice testing were uploaded to the DartfishTV channel (Dartfish USA, Alpharetta, Georgia) and analysed by a team of ice hockey coaches and biomechanics specialists to provide individual feedback and establish group training themes. For the purpose of this paper, the role of knowledge translation in the implementation of the testing program with coaches will be the focus.

6.4.1 Community Engagement & Program Development

Perhaps the most important aspect of integrated knowledge translation is the relationship between researchers and the community in which knowledge is being translated. The direction of this translation goes both ways as partners learn with and from each other. This is especially true when developing research with, by, and for Indigenous communities in which relationality and social networks are not only foundational to research, but closely tied to many diverse Indigenous lifeways (Morton Ninomiya et al., 2022).

With respect to this specific project, initial community engagement/relationship building began well before the first visit to the community. Through a social sport setting, the lead researcher created contact with one of the Indigenous community members who conveyed interest in remote performance analysis for the community ice hockey teams. These conversations continued for roughly 18 months which created the initial framework and direction of the project proposal. Once funding was secured, plans were made for the first of four visits to the community. The lead researcher and research assistant travelled for the initial visit to the community (June 2019). This two-day trip focused on meeting multiple community elders and stakeholders including band council chief, band council recreation manager, ice hockey program coordinator and coaches. Meetings with band council members were the first priority upon arrival in the community. Informal presentations were given on the project and its goals. These meetings were important in obtaining band council/community buy-in and acceptance of the project, and to understand the needs of the community with regards to athlete performance analysis. Once band council approval was gained, meetings with ice hockey program stakeholders took place. Similar informal presentations were given to these stakeholders, with more focus on the detailed outlines of the performance analysis protocols. Within these conversations, the needs of the specific teams and athletes were discussed, which helped to tailor the eventual performance analysis protocols i.e. on ice and off ice testing parameters. This first trip was short in its duration, but invaluable in developing the initial community relationship, engagement with and acceptance of the project.

The second trip to the community (August 2019) focused on reconnecting with certain community stakeholders (band council recreation manager, ice hockey program coordinator and coaches) previously met during the initial visit, to gain further insight into the detailed logistics and scheduling of the ice hockey programs. In addition, this visit was helpful in touring the ice hockey facilities to understand the infrastructure and equipment needs for the project, which enabled the research team to create an equipment list needed for the upcoming visits. Conversations with the hockey coaches also allowed the research team to determine, with the help of the coaches themselves, which on-ice and off-ice testing protocols would best suit their program needs. By the end of this second visit, details about hockey practice/game schedule and team needs i.e. performance analysis equipment and testing protocols needed, were obtained to allow for the planning of the first data collection (third overall) trip.

After this second trip, the research team met multiple times and brought in other coaching experts to help develop the on-ice and off-ice testing protocols to best cater to the needs of the community hockey program. From the information provided by the hockey program director and coaches, the research team created a testing protocol including four off-ice tests and three on ice tests. The tests were chosen because they could be easily set up in a short time and would allow for test/retest capability in order to track player performance progress by the coaches themselves. Once the testing protocols were established, equipment was ordered and preparations for the third community trip were underway.

Another important consideration outlined within the Knowledge-to-Action framework is to assess barriers to knowledge use. Potential barriers identified by the research team were assessed by collaborators and the program was adapted to limit them. Barriers were considered at the coach, athlete, and community-level. The biggest barrier at all three levels was effectively communicating the value of the biomechanical intervention that would increase athlete buy-in. To meet this challenge, the research team consistently engaged and built rapport with the team, was open to any questions or feedback, and proved information about the benefits of biomechanical analysis. Other notable potential challenges included a lack of confidence in procedural knowledge (coaches), uncertainty or lack of desire to incorporate intervention into routine (coaches), and negative emotions towards being analysed/critiqued (athletes).

6.4.2 Implementing the Analysis Program

The university research team travelled to the community for four days during phase one of the program to meet with the coaching staff, team, parents, and community members. Phase one also included relationship-building with athletes, describing the purpose of the project, and conducting on and off-ice testing. The research team met with the coaching staff in advance of the scheduled practice to get better acquainted with one another and familiarised with practice protocols, to answer any questions, and to create a general plan for testing and data collection. It was collectively decided to hold data collection during regular practice times (90 minutes) to maximize player attendance. During the data collection sessions, coaches acted as an intermediary between the research team and the athletes and parents. Their role as leaders in the project was important for demonstrating that this research project was not about studying Indigenous youth, but rather, was meant to increase their access to athletic training in a way that supported local control and community governance. The leadership of community partners at every aspect of the project was paramount in prioritizing the research team's primary goal of supporting community sport governance and athlete development.

Phase two of this project involved training the coaches to conduct data collection and analysis. The university research team travelled to the community for a second visit and provided training on all data collection procedures. The research team also provided demonstrations of an off-ice training program for the athletes to engage in during their off-season. First, the research team met with the coaches to familiarize them with the equipment and explain testing protocols. The coaches conducted data collection with athletes during the regularly scheduled practice time while the research team was present and able to assist with any questions. This data collection session also allowed for initial testing to be done with athletes who were not present at the phase one testing session. Accounting for exercise preferences and available equipment as advised by coaches and a small group of athletes, the off-ice training program was developed based on findings from individual athlete and team analyses during phase one. In-person review of each exercise as well as a bank of instructional videos were provided to the coaches and team.

In addition to data collection procedures, coaches were provided instructions for uploading videos to the shared "DartfishTV" channel that both the research team and coaching team had access to. Uploading the videos from data collection sessions would allow for them to be analysed. Depending on the needs of the coaches, the research team could analyse the videos to answer specific questions or provide feedback. The coaching staff could also use the analysis tools within the software on their own. Coaches walked through how to use these features in the Dartfish software with the research team and were able to practise on their own. In-person meetings were deemed to be the most appropriate method for transmitting this knowledge to the coaching staff to allow for real-time questions to be answered, hands-on practice, and to strengthen the relationship between researchers and coaching staff.

A major tenet of knowledge translation is that interventions should be tailored to meet the needs of the community (Graham et al., 2007). Throughout the implementation phases, it became apparent that barriers to knowledge use needed to be reassessed as necessitated by the community and circumstances. First, available in-person time (or lack thereof) posed a challenge not only for completing the data collection sessions during the visits, but also for expecting coaches to conduct subsequent sessions. Both coaches and athletes had many other responsibilities beyond hockey, limiting practice time that could be sacrificed for testing. Internet availability/speeds in the community were also a significant barrier to more effective implementation of the analysis program, as uploading the videos collected during a session took about three times longer than in an urban centre. Colonial inequities in digital connectivity is a broader systemic challenge faced by many rural and remote Indigenous communities (Duarte, 2017; Wemigwans, 2018). Another notable barrier to knowledge use was the changeover of coaching staff involved with the team. Coaches had many other roles and responsibilities within the community, resulting in occasional staffing changes that highlighted the need for coaches to have access to training materials rather than relying solely on training visits by the research team. It would be helpful to add that longer or more frequent in-person visits would benefit this overall process, but that there are structural limitations in place on the academic side (e.g. funding, teaching responsibilities on campus, etc.) that are especially felt in the context of Indigenous community-based research.

6.4.3 Program Evaluation & Sustainability

Due to the timing of the Covid-19 Pandemic, not only was monitoring knowledge use and evaluating outcomes not possible, but the whole program was forced to halt indefinitely. However, it is important to note that this project was designed with these steps in mind. Equipment provided to the community was theirs to keep, so data collection materials are always available to them for any new tasks they would like to evaluate or retesting they would like to do. Additionally, the academic research team remained in contact with the community and coaching staff, checking in regularly to see if/how the materials are being used or if there is any data the team wants assessed. It is important to note that the original purpose of the project was to increase access to elite level training for hockey players through remote delivery. The pandemic created circumstances that revealed the necessity for projects like these. The coaches' training in which they learned how to collect, upload, and analyse data was crucial to project sustainability with coaches able to conduct future testing and analysis on their own time and without needing to coordinate with researchers.

Since the research team originally visited the community and conducted athlete testing, there have been many changes in the community, including among the coaching staff and community knowledge champions. This has led the research team to re-evaluate the sustainability of the project. A website with pertinent information as well as an educational course on sports science and biomechanics has since been developed that may ultimately improve knowledge sustainability. In-person visits back to the community have not yet taken place as the community recovers from the pandemic and attends to other immediate governance issues.

6.5 Benefits of Using KTA to Implement Biomechanical Analyses

The KTA process provides a flexible framework that can be continually adapted and improved throughout the research process. When implementing biomechanical analysis with a remote Indigenous community, unique challenges and demands result in a need for a flexible approach to knowledge application. The KTA process has steps built into the action cycle that encourage adjustment of the knowledge translation process so that the applied knowledge fits the desired setting as best as possible. This is particularly useful for the implementation of biomechanical analyses with a remote hockey team given the application of technological aspects (e.g., accessibility of internet, use of hardware and software, ongoing virtual partnership with the research team), the details of which depend largely on the specific community. Knowledge of equipment use, foundational sport science knowledge, and plans for sustainability were able to be tailored as a fundamental feature of the action cycle. The flexibility of KTA also helped allow for the program to be adapted to challenges completely out of the research team and community partners' control, including the Covid-19 Pandemic and subsequent lockdowns.

Although the KTA process does not have Indigenous-specific steps or recommendations, the openness of the knowledge creation funnel and the action cycle (particularly the adapting knowledge to local context step) allows for community-based knowledge and local contexts to be incorporated into project design. This includes not only the specific knowledge being applied, but the application process itself. Furthermore, emphasis on the involvement of community members, rightsholders, and stakeholders is intended to ensure that local knowledges and contexts are integrated rather than ignored or misinterpreted by researchers. The Bodies of Power, Nations of Strength project holds Indigenous governance as a central priority. We were able to absorb the KTA process into this priority rather than have it drive the process itself. Another benefit of using the KTA process is that it includes considerations for much of the application process from problem identification to sustainability, creating a useful path for researchers to follow. However, it is worth noting that selection of community members, rightsholders, or stakeholders to be involved in the research process is not a specified step in the KTA process and may be a potential limitation of its use in this setting.

6.6 Challenges of Using KTA to Implement Biomechanical Analyses

Employing information positioned largely in scientific systems such as biomechanical knowledge and technology within Indigenous contexts should be done in a way that critically considers Indigenous stakes in research and training and is guided by Indigenous knowledge and community interests. Rather than present the biomechanical knowledge and technology to the community as “the right way” to improve athlete performance, the goal was to provide the community with additional tools to incorporate into their existing athlete development systems, provide exposure to increasingly common athlete development practices and technologies, and support Indigenous governance. While the flexibility of the KTA process technically allows for the complex navigation of multiple knowledge systems (e.g., community-based, scientific social scientific) the KTA cycle does not realistically have tools or steps outlined for such consideration.

Like previous critiques surrounding the use of KT processes within Indigenous research and training contexts, the research team noted that while the KTA process provides a flexible and adaptable framework, critical steps for translating knowledge in Indigenous contexts are missing (Kosmenko et al., 2019; Morton Ninomiya et al., 2017; Smylie et al., 2004). Most notably, guidance for establishing relationships within the community as well as ensuring academic researchers take steps to learn about the community and its history, protocols, activities, etc. are necessary additions to KT models in Indigenous contexts. Despite these missing components, the research team engaged with the community and integrated project components into existing community protocols as previously outlined within the community engagement and program development section of the coaches' intervention.

Another key challenge faced by the research team was maintaining community buy-in and, as a result, program sustainability. Although the research team was able to establish relationships with the initial group of coaches, athletes, and community leaders, the sustainability of the project was challenged as the people in these roles changed over time. The Covid-19 Pandemic created special challenges in this regard, but also quickly exposed a limitation of the KTA process in this project. Despite there being a step in the action cycle specifically for sustaining knowledge use, there are no guidelines or recommendations on how to do so or things to consider. Maintaining community buy-in is more likely when there is an overlap of partners from the community as the project carries on who can champion the program over time and share their experiences with incoming partners. The KTA process is abstracted from the real-world contexts whereby research interfaces with life in a remote First Nation community. It is a methodological tool available to researchers, but, like all research processes, should be engaged only if and when the Indigenous community involved deems it appropriate.

6.7 Conclusions

The KTA process showed utility within the context of implementing remote biomechanical analyses with a remote First Nation hockey team. Specifically, the call for tailoring knowledge in the knowledge creation funnel as well as the flexibility of the action cycle are critical for ensuring relevance of the project to the community. However, to maximise the relevance of knowledge translation to Indigenous communities, we recommend researchers incorporate additional appropriate frameworks such as Indigenous STS. Indigenous STS, as an example, specifically considers how Indigenous engagement with science and technology fields can support Indigenous peoples in shaping these fields rather than being subject to them (Kolopenuk, 2020). In addition to establishing connection, considerations of existing Indigenous knowledge and community history and protocols are of the utmost importance not only for implementing biomechanical analyses but for undertaking any knowledge translation with Indigenous communities.

Another key takeaway from this project was the importance of considering the structural limitations experienced by community members and knowledge users. The realities of remote Indigenous communities (e.g., decreased connectivity such as the internet or long distances from urban centres) can drastically alter the way a project is carried out compared to one in an urban setting. The experience of the research team in adapting the project to structural limitations was made easier by the established community connections but is a recommendation that should not be taken lightly when tailoring a program for a remote community as these limitations could render an intervention useless if not properly accounted for. While this project sought to address limits on access to elite-level training for hockey players by testing remote presence sporting technologies, we learned that a significant investment of in-person time is needed to set up the conditions of effective use and translation. The onus of accounting for any structural limitations should be on the research team rather than the community.

Finally, when using knowledge translation to implement sports science in rural Indigenous communities, researchers should keep in mind that training programs for new skills that can be applied in various capacities as needed may be a more beneficial approach than isolated interventions. Programs with built-in means for passing along the new information and providing additional options for application may ultimately give Indigenous communities more control. While this recommendation may not be appropriate for all contexts, biomechanics knowledge and technologies certainly fit into the category of interventions where a training program with avenues for sustainability and continued training can be much more useful in supporting Indigenous governance than a single intervention or solitary knowledge set. With the necessary considerations, the knowledge-to-action process can be used to leverage sports science knowledge and remote presence sporting technology to support Indigenous sport governance.

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Chapter 7: General Discussion

7.1 Key Findings of this Dissertation

Chapters 3-6 report findings related to forward skating coordination in ice hockey, relationships between partnered academic and industry research teams in sports science, and using KTA to implement a remote biomechanical analysis program with coaches in a rural Indigenous community. The position of these specific findings within the broader topic of knowledge translation in sports biomechanics will be discussed in subsequent sections.

Major findings from chapters 3-6 can be summarized as follows:

1. High-calibre ice hockey players tend to use more out-of-phase coordination of the shank-thigh segments than low-calibre players during forward full-stride skating. *(Chapter 3)*
2. Coordination of the foot-shank segments in the sagittal plane is more in-phase for both high- and low-calibre male skaters than the shank-thigh segments during forward full-stride skating. *(Chapter 3)*
3. High-calibre male ice hockey players tend to use more out-of-phase modes of coordination for the shank-thigh segments throughout forward skating accelerative strides on both sides of the body than high-calibre females. *(Chapter 4)*
4. High-calibre female ice hockey players tend to have a greater change in their mode of coordination between transitional ice contact events and use more in-phase modes of coordination than high-calibre males for thigh and shank segment pairings. *(Chapter 4)*
5. Coordination of shank and foot segment pairings does not significantly differ for high-calibre male and female ice hockey players during forward skating starts. *(Chapter 4)*
6. Academic and industry research partners in sports science contend with competing institutional logics, namely differences in time cycles, goals, and learning needs that can hinder feelings of satisfaction in these partnerships. *(Chapter 5)*

7. Academic and industry research partners can create a new, shared, and mutually beneficial institutional logic through dialogue and active participation, leadership and guidance, and structuring. *(Chapter 5)*
8. Knowledge translation can be used to leverage sports science knowledge and remote presence sporting technology to support Indigenous governance in sport. *(Chapter 6)*
9. The knowledge-to-action process should be employed alongside the necessary considerations (e.g., structural limitations, community history) for each specific community and/or with additional appropriate frameworks (e.g., Indigenous STS) to maximise relevance for First Nations communities. *(Chapter 6)*

7.2 Integration of Findings

Each chapter of this dissertation highlighted a different aspect of the Knowledge-to-Action process. In addition to the novel findings of each respective chapter, the research process within the broader scope of knowledge translation in sports biomechanics will be discussed.

7.2.1 Knowledge Creation

Knowledge Inquiry

Of the knowledge-to-action process, knowledge creation is the component most engaged in, with knowledge inquiry being the primary focus for many researchers in sports science. Chapters 3 and 4 investigated lower extremity intersegment coordination during various modes of forward skating in ice hockey, which had previously not been studied. The findings of these chapters suggest that demands for lower-extremity skating coordination may differ along the kinetic chain, with an increased need for stability at the foot-shank segments and increased adaptability at the shank-thigh segments. Shank and foot segment pairings did not differ between high-calibre males and females, but significant timing differences were found between high-calibre males and low-calibre males. At the shank-thigh segments, greater differences were found during both accelerative skating strides between high-calibre males and females and during steady state forward skating between high- and low-calibre males. It is possible that more in-phase modes of coordination may offer improved stability compared to more out-of-phase modes of coordination that may offer more adaptability on the ice. The more in-phase coordination of the foot-shank segment pairing compared to other segment pairings supports this theory, as the ankle may need greater stability due to the demands of navigating a thin blade along a slick ice surface than joints located farther up the kinetic chain. Greater adaptability rather than emphasis on stability may also contribute to faster skating speeds.

Shifts to more in-phase modes of coordination as tasks become more complex have been demonstrated during sidestepping tasks (Weir et al., 2019). Similarly, the findings of chapters 3 and 4 suggest that as skaters become more experienced, their coordination tends to be more out-of-phase throughout both accelerative and steady state strides. Coordination has been considered mastering redundant degrees of freedom to complete a task, so as hockey players "master" skating, they therefore shift to more out-of-phase modes of coordination to allow for greater adaptability. High-calibre females may utilise more in-phase coordination than high-calibre males as a protective measure or to account for decreased lower-body strength by reducing the control effort necessary for motor control.

The findings of chapters 3 and 4 are novel and have implications for future research, but their limited direct application draws attention to the constraints of this aspect of knowledge translation. The knowledge creation funnel suggests that knowledge inquiry should be synthesized and used to guide knowledge products and tools such as educational modules or clinical practice guidelines to be more useful to end users (Straus et al., 2013). In a perfect scenario, all research knowledge would follow this path and eventually move into the action cycle, but this format ignores the realities of some sports science research. Regardless of who their research findings are relevant for, academic sports science researchers tend to primarily focus on publishing research in peer reviewed journals and presenting at conferences. On the other hand, industry or athletic-team sports science researchers primarily seek to apply findings to products or athletes, without necessarily sharing their findings with the broader audience of potential end-users. Although it is a limitation that the results of chapters 3 and 4 are not presently at a stage of knowledge creation that is easily actionable for coaches and athletes, it is also worth noting that the typical academic channels of dissemination are, in this case, the appropriate ones. In the KTA process, more emphasis should be placed on translating knowledge (at any stage of knowledge creation) to the appropriate audience/end users and not disregard the value of disseminating findings that may not yet be actionable within a population. Implementing this change to the KTA process could have direct implications for how knowledge translation is accounted for in grant applications or peer-reviewed journal publications that, with increasing frequency, require researchers to disclose KT plans.

Tailoring of Knowledge

The tailoring knowledge component of the knowledge creation funnel tends to be considered from the perspective of how established knowledge is tailored, while the process of tailoring knowledge creation itself (and therefore driving products and tools/technologies) is often overlooked. Academic-industry research partners are at the forefront of knowledge inquiry/knowledge creation and have a distinct need to find mutually beneficial research paths. These partnerships also offer a unique perspective when considered within the greater scope of the KTA process because knowledge inquiry often directly impacts stakeholders (e.g., first-generation biomechanics knowledge impacting mass-produced running shoes) rather than necessarily going through knowledge synthesis or being more specifically tailored.

The findings of chapter 5 demonstrated the intricacies of building productive cooperative strategies between the groups. Academic and industry research groups entered the partnerships with their own set of institutional logics but needed to create a mutually beneficial set of shared logics to collaborate successfully. Collaboration is at the heart of knowledge translation as those with knowledge and those who will use the knowledge must work together for translation at any stage of the process to be effective. Therefore, the concept of creating mutually beneficial shared institutional logics can be applied to other aspects of the KTA process, from knowledge creation to application, as groups of researchers and stakeholders may often operate from their own set of "institutional logics" that need to be reconciled to maximize project success. A common, mutually beneficial shared logic in the partnerships studied was best formed via dialogue and active participation, leadership and guidance, and structuring. Key takeaways that may be applicable to other partnered research groups or researchers and their partnered stakeholders emphasize a commitment to engaging in regular dialogue seen equal to "practical work," establishing mutual goals early, and defining leadership roles.

From a general sports biomechanics perspective, the task of tailoring knowledge often needs to take many dimensions into account, including sport, sex/gender, location, skill level, and end user (e.g., coach, athlete, etc.) to ensure relevance. At the knowledge creation level, this involves including many groups in research queries, especially those that are historically underrepresented (e.g., women, people of colour). For knowledge application, researchers should not only involve underrepresented groups, but should also ensure that resources created through the tailoring of knowledge are accessible to all potential end users.

7.2.2 Action Cycle

This dissertation examined the use of the KTA process for applying sports biomechanics knowledge to a unique population with special and necessary considerations. There is a demonstrated gap between the knowledge sports science researchers create and the application of this knowledge by practitioners (i.e., sports medicine staff, coaches, athletes, etc.), indicating a need for sports science researchers to move beyond typical academic dissemination and into intentional application. However, the adequacy of the KTA process to guide this translation with a remote Indigenous community had not been investigated within the context of sports biomechanics.

Because research involving Indigenous Peoples in Canada has historically been carried out without the consideration of the communities involved, the collaborative nature of the KTA process made it particularly useful for translating sports science knowledge in this setting. The findings of chapter 6 reflect not only the flexibility of KTA, but the vagueness. The openness of this KT process suggests that it can be moulded to fit any number of populations or settings, but it also does not provide all the necessary support for certain populations. The KTA process demonstrated merit for leveraging sports science knowledge and remote presence sporting technology to support Indigenous governance in sport, but it is recommended that researchers also use additional appropriate frameworks to address the context-specific gaps of the KTA process.

7.2.3 Sports Biomechanics and the Knowledge-to-Action Process

The knowledge-to-action process is useful as a general guide for translating sports biomechanics research but is challenging to engage as a whole. The KTA cycle is most frequently employed by researchers in individual pieces, but the KTA cycle alone does not expand on the full scope of the knowledge creation component (i.e., utilising knowledge translation even when results are not being directly applied to a group) or provide considerations for special populations. Although the openness of the KTA process does allow for flexibility in its application, creating key notes or prompts that can be used alongside the knowledge creation funnel and action cycle for researchers to consider could improve its overall relevance and usefulness within sports biomechanics.

7.3 Limitations

Specific limitations for chapters 3-5 were described previously in the corresponding chapters. Limitations of this dissertation or specific chapters within the context of the KTA process will be discussed in the following section. First, the knowledge inquiry studies (chapters 3 and 4) did not include end-of-project translation outside of the traditional academic channels of conference presentations and peer-reviewed publications. Although these were deemed the most suitable modes of translation for these projects as the findings were not necessarily directly applicable to coaches and athletes, the audience is still limited to attendees of the conferences and researchers with access to the journals, restricting the accessibility of this knowledge. The findings of chapters 3 and 4 would be most useful in informing future hockey skating coordination studies which may result in findings that can be better applied within athlete training programs by coaches.

A key limitation of this dissertation is that it does not follow one specific topic from knowledge creation to application. Although insights into knowledge translation in sports biomechanics were still gained from engaging in various aspects of the KTA, taking one topic all the way through the process would likely provide a more thorough understanding of knowledge translation as it pertains to that topic. Conversely, engaging the KTA process with a variety of related topics within sports science may have provided a broader scope of understanding within the field. Chapter 5 investigated tailoring knowledge inquiry but did not regard the tailoring of existing knowledge, which is a central element of tailoring knowledge as it pertains to the knowledge funnel. Finally, although the findings of chapter 6 focus on knowledge application in First Nations communities, the extent to which applying sports science knowledge with the use of KTA is appropriate or relevant may vary by community.

7.4 Recommendations for Future Research

Future research on knowledge translation in sports biomechanics should similarly involve all aspects of knowledge translation but should follow one single topic from knowledge creation to application. Due to time constraints, this task may be challenging to complete in the duration of one academic program but could be undertaken by career faculty or industrial researchers who may be in a research role for several years. While this dissertation shed light on the general knowledge translation process within sports biomechanics, engaging in the entire knowledge translation process from start to finish with the same topic could be particularly fruitful for understanding the advantages, pitfalls, and areas for improvement.

Research on each specific aspect of the knowledge translation process investigated in this dissertation should also be investigated further. For skating coordination, the process of skating coordination development should be studied further by examining male and female athletes just beginning skating, intermediate skaters, and high-calibre skaters. The differentiation of each stage of experience should provide deeper insight into how coordination develops and provide a general direction for training protocols that may lead to more effective coordination patterns. These results would also likely have implications for a broader range of end users than simply other researchers. Tailoring knowledge inquiry should be investigated outside of academic-industry research partnerships to gain a better understanding of the relationship between researchers and other stakeholders. Sports teams/coaching staff and performance science researchers are one example of a partnership that should be investigated more thoroughly and could have implications for other stakeholder partnerships. Further, if a single topic is taken from knowledge creation to knowledge application, the process of tailoring existing knowledge to a community can be described more comprehensively. The action cycle of the KTA process should also be applied for translating sports biomechanics knowledge within other community contexts as investigation into other settings may reveal additional opportunities to make the KTA process more relevant to sports science.

7.5 Conclusions

This dissertation aimed to explore the process of creating and translating sports biomechanics knowledge within the knowledge-to-action framework. Addressing the knowledge creation funnel, knowledge inquiry was undertaken, and tailoring knowledge was investigated. Specifically, lower-extremity intersegment coordination was compared between high- and low-calibre male hockey players during forward full stride skating and between high-calibre male and female hockey players during forward skating starts, and the relationship between sports science researchers and their industry partners were examined. The KTA action cycle was used to implement a remote biomechanical analysis program with a remote First Nation hockey team.

Results from this dissertation reveal that 1) coordination demands during skating differ along the kinetic chain, with an increased need for stability at the foot-shank segments and increased adaptability at the shank-thigh segments, 2) more in-phase skating coordination may offer increased stability while more out-of-phase coordination may offer increased adaptability, 3) academic and industry research partners must create a mutually beneficial and shared institutional logic to overcome the challenges of their respective competing institutional logics, and 4) the KTA process can be used to leverage sports science knowledge to support Indigenous governance in sport, particularly in conjunction with context-specific frameworks such as Indigenous STS.

In addition to the specific findings listed above, the greater process of knowledge translation in sports biomechanics was considered. Ultimately, the KTA process can be an effective tool for translating sports biomechanics knowledge, but some adjustments to the process could be beneficial to KT outcomes in this field: 1) researchers may be encouraged to engage more intentionally with the knowledge translation process if the KTA placed more emphasis on translating knowledge to the appropriate end users at any stage of the knowledge creation funnel, 2) researchers and stakeholders should work to create a mutually beneficial shared "institutional logic" to productively collaborate to tailor knowledge and put knowledge into action, 3) additional frameworks can be used in conjunction with the KTA process and creating prompts to be used alongside the knowledge creation funnel and action cycle steps to help researchers collaborate and translate knowledge more effectively can improve the overall relevance of the KTA process in this field and for certain populations.

Although the contexts in which the respective parts of the KTA process were investigated in this dissertation did not directly involve the same knowledge transitioning from creation to application, engaging in the different aspects of the KTA process provided insight into its utility for sports biomechanics. Knowledge translation is a complex process which tends to be viewed by many simply as dissemination. This work can serve to remind sports science researchers that all aspects of research, from formulating research questions to applying research findings, should bear the process of taking knowledge to action in mind to maximise research relevance and applicability.

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Appendix A: Academic Staff Interview Guide

Pre-interview Routine

Thank you for taking the time to participate in this focus group. The goal of this study is to examine the relationship between sport science researchers and industry partners from a knowledge translation standpoint. All questions are designed to be open-ended so please elaborate as much or as little as you want. I would like to remind you that participation in this study is strictly voluntary and that you are free to ask questions or to withdraw your consent to participate in this study at any time with no penalty. You are also free to refuse to answer any line of questioning during the interview process. The focus group should take anywhere from 60-90 minutes to complete and will be recorded using Zoom. Due to the nature of focus group discussions where everyone can hear and see other participants, confidentiality cannot be fully guaranteed. We ask that everyone please refrain from discussing or sharing information with anyone outside of the group.

Does anyone have any questions?

Is it alright with everyone if I start the recording?

Opening Questions

1. Please tell us your name, how long you've been a member of the academic research team, and how long you've been working with your industry partner?

2. How would you describe your relationship with your industry partner?
   Probe: How would you describe the role you play within your research partnership?
   Probe: Can you comment a bit on how the partnership started?

3. Are your research team and your industry partner located in the same state/province or country? How do you think this may impact the relationship or interactions between the teams?

Introductory Questions

4. Can you briefly describe your experience with formulating research questions or project ideas as a member of this team?
   Probe: What processes are in place for developing questions?
   Probe: How much/what type of involvement does your industry partner have?
   Probe: How satisfied are you with the direction of your research?

5. Can you think of a time you had an interaction with your industry partner that you walked away from feeling especially positive (e.g., hopeful, excited, motivated)? What about particularly negative (e.g., frustrated, disappointed, stressed)?

Main Questions

6. Do you think your research has any impact on product design or development? How?
   Probe: How does this align with any expectations you may have had upon entering this type of research partnership?

7. What are your feelings about the current processes in place for communication between the academic and industry research teams?
   Probe: How often do your teams interact?
   Probe: Can you tell me more about what those interactions are like?

8. What features of the processes currently in place work well in your opinion?
   Probe: Can you elaborate on that a bit more?
   Probe: Why do you think that is?

9. What does not work well?
   Probe: Can you elaborate on that a bit more?
   Probe: Why do you think that is?

10. Do you have experience with/what are your thoughts on legal restrictions (e.g., copyright law, NDAs, etc.) in working with your partner?
    Probe: Do you think that this affects your partnership/the research you do? In what ways?

11. What changes do you think would be beneficial to the relationship between the academic and industry research teams?
    Probe: What potential setbacks might there be to altering the relationship between research teams?

12. Do you have situations where students come to you with concerns about the industry partner or vice versa? How do you manage that?

Closing Questions

13. Is there anything else you'd like to like to add that we didn't get to in this interview?
Do you have any closing thoughts, questions, or comments you'd like to share?

Appendix B: Student Interview Guide

Pre-interview Routine

Thank you for taking the time to participate in this focus group. The goal of this study is to examine the relationship between sport science researchers and industry partners from a knowledge translation standpoint. All questions are designed to be open-ended so please elaborate as much or as little as you want. I would like to remind you that participation in this study is strictly voluntary and that you are free to ask questions or to withdraw your consent to participate in this study at any time with no penalty. You are also free to refuse to answer any line of questioning during the interview process. The focus group should take anywhere from 60-90 minutes to complete and will be recorded using Zoom. Due to the nature of focus group discussions where everyone can hear and see other participants, confidentiality cannot be fully guaranteed. We ask that everyone please refrain from discussing or sharing information with anyone outside of the group.

Does anyone have any questions?

Is it alright with everyone if I start the recording?

Opening Questions

1. Please tell us your name, how long you've been a member of the academic research team, and how long you've been working with your industry partner?

2. How would you describe your relationship with your industry partner?
   Probe: How would you describe the role you play within your research partnership?

3. Are your research team and your industry partner located in the same state/province or country? How do you think this may impact the relationship or interactions between the teams?

Introductory Questions

4. Can you briefly describe your experience with formulating research questions or project ideas as a member of this team?
   Probe: What processes are in place for developing questions?
   Probe: How much/what type of involvement does your industry partner have?
   Probe: How satisfied are you with the direction of your research?

5. Can you think of a time you had an interaction with your industry partner that you walked away from feeling especially positive (e.g., hopeful, excited, motivated)? What about particularly negative (e.g., frustrated, disappointed, stressed)?

Main Questions

6. Did you know that you would be working with your industry partner before beginning your academic program? What expectations did you have for the relationship?

7. Do you think your research has any impact on product design or development? How?
   Probe: How does this align with any expectations you may have had upon entering this type of research partnership?

8. What are your feelings about the current processes in place for communication between the academic and industry research teams?
   Probe: How often do your teams interact?
   Probe: Can you tell me more about what those interactions are like?
   Probe: Do these communications tend to be more in-person or virtual?

9. Have you ever had a concern or change about the partnership that you wanted to bring forth? Are processes in place for you to do so?
   Probe: Were you comfortable bringing these concerns up?

10. What features of the processes currently in place work well in your opinion?
    Probe: Can you elaborate on that a bit more?
    Probe: Why do you think that is?

11. What does not work well?
    Probe: Can you elaborate on that a bit more?
    Probe: Why do you think that is?

12. What changes do you think would be beneficial to the relationship between the academic and industry research teams (focusing specifically on the academic-industry relationship itself)?
    Probe: What potential setbacks might there be to altering the relationship between research teams?

Closing Questions

13. Is there anything else you'd like to like to add that we didn't get to in this interview?
14. Do you have any closing thoughts, questions, or comments you'd like to share?

Appendix C: Industry Interview Guide

Pre-interview Routine

Thank you for taking the time to participate in this focus group. The goal of this study is to examine the relationship between sport science researchers and industry partners from a knowledge translation standpoint. All questions are designed to be open-ended so please elaborate as much or as little as you want. I would like to remind you that participation in this study is strictly voluntary and that you are free to ask questions or to withdraw your consent to participate in this study at any time with no penalty. You are also free to refuse to answer any line of questioning during the interview process. The focus group should take anywhere from about 60-90 minutes to complete and will be recorded using Zoom. Due to the nature of focus group discussions where everyone can hear and see other participants, confidentiality cannot be fully guaranteed. We ask that everyone please refrain from discussing or sharing information with anyone outside of the group.

Does anyone have any questions?

Is it alright with everyone if I start the recording?

Opening Questions

1. Please tell us your name, title, how long you've been a member of the industry research team, and how long you've been working with your academic partner(s)?

2. Can you provide some information about how this partnership operates (e.g., is it ongoing or a single project?)
   Probe: How was the partnership established?
   Probe: Do you have experience with other partnership styles?

3. How would you describe your relationship with your academic partner?
   Probe: How would you describe the role you play within your research partnership?

4. Are your research team and your academic partner located in the same state/province or country? How do you think this may impact the relationship or interactions between the teams?

Introductory Questions

5. Can you think of a time you had an interaction with your academic partner that you walked away from feeling especially positive (e.g., hopeful, excited, motivated)? What about particularly negative (e.g., frustrated, disappointed, stressed)?

6. Can you briefly describe your experience with formulating research questions or project ideas in conjunction with or created for your academic partner?
   Probe: What processes are in place for developing questions?
   Probe: How much/what type of involvement does your academic partner have?
   Probe: How satisfied are you with the direction of your academic partner's research?

Main Questions

7. In terms of the impact of research from this collaboration on product design or development, can you describe the level of involvement your academic partner has in this part of the process, if any?
   Probe: How does this align with any expectations you may have had upon entering this type of research partnership?

8. What are your feelings about the current processes in place for communication between the academic and industry research teams?
   Probe: How often do your teams interact? Weekly, data check ins after 10 subjects
   Probe: Can you tell me more about what those interactions are like?

9. What features of the processes currently in place work well in your opinion?
   Probe: Can you elaborate on that a bit more?
   Probe: Why do you think that is?

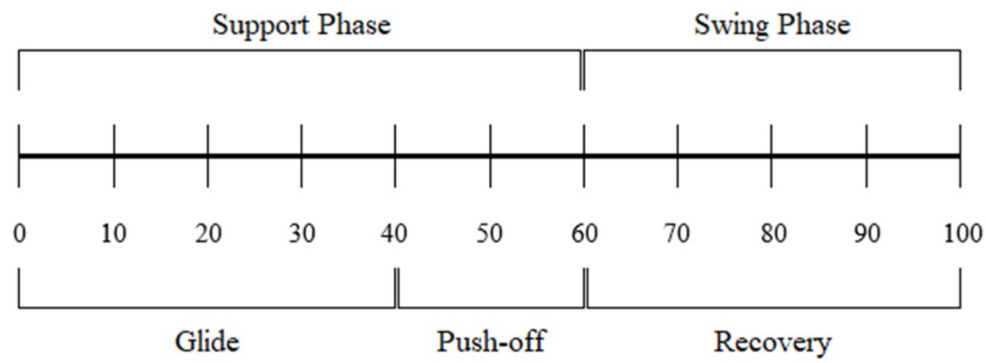
10. What does not work well?
    Probe: Can you elaborate on that a bit more?
    Probe: Why do you think that is?

11. What changes do you think would be beneficial to the relationship between the academic and industry research teams?
    Probe: What potential setbacks might there be to altering the relationship between research teams?

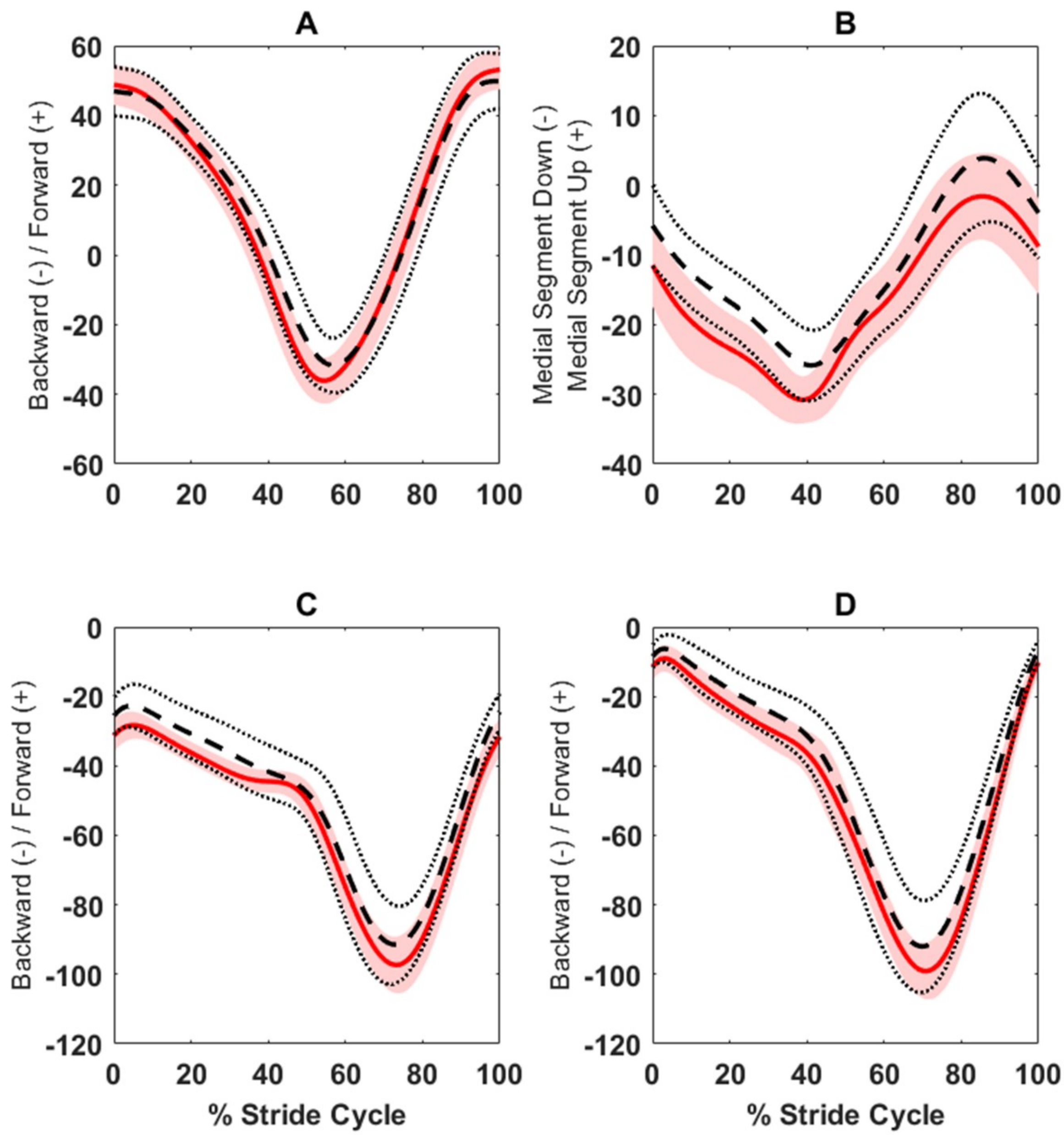
Closing Questions

12. Is there anything else you'd like to like to add that we didn't get to in this interview?
13. Do you have any closing thoughts, questions, or comments you'd like to share?

Appendix D: Chapter 3 Supplemental Figures



Appendix Figure 1. Phases of skating stride throughout stride cycle.



Appendix Figure 2. Group means for (A) thigh-sagittal, (B) thigh-frontal, (C) shank-sagittal, and (D) foot-sagittal segment angles during a full stride for high-calibre (red, solid lines) and low-calibre (black, dashed lines) groups. The pink shaded area represents one standard deviation for the high-calibre group and the dotted lines represent one standard deviation for the low-calibre group. Positive values represent forward movement (sagittal) and medial segment up (frontal).

Appendix E: Copyright License, Figure 2.1

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Portions
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