Effects Of An 8-Week Resisted Sprint Training Program On Ice Skating Speed, Acceleration, And Measures Of Athletic Performance In Male Youth Ice Hockey Players

Martin Sterling Diettze-Hermosa

The University of Texas at El Paso

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EFFECTS OF AN 8-WEEK RESISTED SPRINT TRAINING PROGRAM ON ICE SKATING SPEED, ACCELERATION, AND MEASURES OF ATHLETIC PERFORMANCE IN MALE YOUTH ICE HOCKEY PLAYERS

MARTIN STERLING DIETZE-HERMOSA
Doctoral Program in Interdisciplinary Health Sciences

APPROVED:

_________________________________________________________________
Sandor Dorgo, Ph.D., Chair

_________________________________________________________________
Jeffrey Eggleston, Ph.D.

_________________________________________________________________
Cory Smith, Ph.D.

_________________________________________________________________
Roger Gonzalez, Ph.D.

_________________________________________________________________
Brian K. Schilling, Ph.D.

_________________________________________________________________
Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School
DEDICATION

I dedicate this dissertation to my wife Paige, who has been a source of support, strength, and inspiration throughout my academic journey. Certainly, all academic successes I accomplished are directly attributed to her, particularly the Ph.D. Thank you Paige, I love you. I also dedicate this dissertation to the most recent addition to our family; our son Luca. His smiles provided the energy to continue forward when I thought I could not. Secondly, is the support of my family. My mother Rocio and father Sterling provided encouragement during times of difficulty and their counsel provided needed fortitude to persevere during this journey. Brother David and sister Virginia provided laughter, fond memories, and words of reassurance that reinforced my resolve to achieve my goals. Lastly, I recognize that God was instrumental in every facet leading me to this point in my life. God provided the strength to overcome challenges, quickened intellect, and guidance to needed information that enabled me to arrive at this milestone.
EFFECTS OF AN 8-WEEK RESISTED SPRINT TRAINING PROGRAM ON ICE SKATING SPEED, ACCELERATION, AND MEASURES OF ATHLETIC PERFORMANCE IN MALE YOUTH ICE HOCKEY PLAYERS

by

MARTIN STERLING DIETZE-HERMOSA, PhDc.

DISSERTATION

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

Interdisciplinary Health Sciences

THE UNIVERSITY OF TEXAS AT EL PASO

May 2022
ACKNOWLEDGEMENTS

I express my gratitude to each committee member for their guidance leading me to the path of completion. Dr. Dorgo, who from our initial contact years ago took the time to converse with Paige and I and make us feel welcome at UTEP and optimistic about our journey in El Paso. Your insight, counsel, support, encouragement, and friendship played a vital role in allowing me to grow as an educator and has led to an enriching doctoral experience. Dr. Eggleston, your insight on research design and instrumentation are greatly appreciated. Our conversations regarding leadership and family have resonated with me and provided perspective for my desired future in academia. Dr. Smith, your wealth of knowledge and expertise are instrumental. Thank you for sharing your perspectives on higher education and becoming an effective educator. Moreover, I greatly appreciate your consistent reinforcement of the principle that “all are here to learn”. Dr. Gonzalez, our conversations on effective leadership in academia and your guidance on my dissertation are appreciated. Dr. Schilling, thank you for sharing valuable resources and engaging in conversations that improved the quality of my dissertation and aided in my professional growth. To all members, thank you for your patience with my shortcomings and helping me arrive at this milestone.

I acknowledge that I could not have completed this project without assistance from members of the Fitness Research Facility. Thank you for your feedback, support and encouragement. Additionally, the IHS faculty and staff played key roles in guiding my path towards dissertation completion. Notably, Darlene, for your guidance in administrative matters and for your words of reassurance and motivation. I acknowledge the great contributions of Brigham Young University - Idaho students. Thank you for your help with data collection, program implementation, and more. Thank you for your enthusiasm and passion towards the
project. A special thanks to all players, coaching staff and administration of the Cutthroats ice hockey organization. Lastly, I acknowledge and express gratitude to the National Strength and Conditioning Association Foundation for funding the project. It is thanks to their contributions that this project was completed.
ABSTRACT

Recently, resisted sprint training has become a widely utilized modality to increase the running speed and acceleration of athletes necessitating fast movements for successful sport performance. However, ice hockey is a sport that requires speed and acceleration despite not being running-based. Yet, the impact of a longitudinal resisted sprint training intervention with known resistance on ice skating remains uninvestigated. Ice hockey players engage in both on-ice and overground training. It is presently unknown whether an on-ice resisted sprint training program is superior to an overground resisted sprint training program to increase measures of ice hockey performance. Thus, purposes of this study were: 1) to compare the effects of an on-ice resisted sprint training intervention to an overground resisted sprint training intervention and a control condition (engaging in their usual training routine) for maximal ice skating completion time and other athletic measures associated with ice skating speed and acceleration (broad jump distance, vertical jump performance, isometric force, and overground sprint completion time); 2) to identify changes in ice skating kinematics during maximal ice skating after participation in the respective training intervention; and 3) to examine changes in the magnitude of muscle activation of the knee flexors and extensors during maximal ice skating after participation in the respective training intervention. To achieve these study purposes, 24 competitive youth ice hockey players were equally divided into three groups: 1) on-ice resisted sprint training intervention group (on-ice RST); 2) overground resisted sprint training intervention group (overground RST); and 3) bodyweight training control group (control group). The two RST intervention groups engaged in an 8-week resisted sprint training program, using sled towing methods twice a week on non-consecutive days. Sled towing loads were individualized for maximal power expression with the number of resisted sprints varying depending on the
intervention week. Dependent variables were tested before and after the 8-week intervention. A series of repeated ANOVAs with post-hoc comparisons were conducted. All training programs improved certain measures associated with ice skating completion time including broad jump distance \( [F(1,21) = 58.95; \ p < 0.001; \ \eta_p^2 = 0.75; \ \text{large}; \ 21\%] \), vertical jump height \( [F(1,21) = 7.192; \ p = 0.014; \ \eta_p^2 = 0.26; \ \text{large}; \ 7\%] \), 9.14-meter completion time \( [F(1,21) = 7.445; \ p = 0.013; \ \eta_p^2 = 0.271; \ \text{large}; \ 0.06 \text{ seconds}; \ 3\%] \), 36-meter completion time \( [F(1,21) = 10.406; \ p = 0.004; \ \eta_p^2 = 0.342; \ \text{large}; \ 0.222 \text{ seconds}; \ 4\%] \), and 30-meter top speed completion time \( [F(1,21) = 15.256; \ p < 0.001; \ \eta_p^2 = 0.433; \ \text{large}; \ 0.387 \text{ seconds}; \ 12\%] \). Only RST groups substantially altered components of their overground sprint profile components as well as skate profile components \([\text{Overground: (maximal horizontal force} = 15 - 22\%}; \ \text{(maximal horizontal power} = 13 - 24\%}; \ \text{(maximal ratio of force} = 3 - 9\%}; \ \text{On-ice: (horizontal force} = 23 - 29\%}; \ \text{(maximal ratio of force} = 5 - 7\%}] \), knee extensor muscle activity \([((\text{Overground} = 3 - 5\%}; \ ((\text{On-ice} = 10\%}] \), and kinematics \([\text{on-ice step length} = 5 - 6\%}] \). RST groups displayed superior improvements across ice skating completion time tests, with the on-ice RST displaying a greater magnitude of improvement compared to the overground RST group during 30-meter top speed \((6\% \text{ vs.} 1\%) \) and s-cornering agility drill ice skating completion times \((10\% \text{ vs.} 4\%) \). Ice hockey coaches should incorporate on-ice RST to improve ice skating completion time across maximal cornering and straight line ice skating tests. When on-ice RST is not feasible, overground RST appears to be an effective alternative to induce comparable changes across most measures.
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CHAPTER 1: INTRODUCTION

IMPORTANCE OF ICE SKATING SPEED AND ACCELERATION ON ICE HOCKEY PERFORMANCE

Ice hockey requires athletes to rapidly skate up and down the ice rink to contribute to an offensive or defensive play. Montgomery et al. (1988) noted that ice hockey players must skate maximally for 30-60 second shifts interspaced with a 2-3 minute passive (on bench) recovery. Ice skating speed and acceleration during straight-line ice skating and cornering are considered fundamental skills for proficient ice hockey players (Mascaro, Seaver, & Swanson, 1992). Consequently, maximal ice skating speed during straight-line ice skating is one of the main contributors to successful ice hockey performance, accounting for up to 55% of the variance in ice hockey performance (Farlinger, Kruisselbrink, & Fowles, 2007; Ransdell, Murray, & Gao, 2013). Moreover, ice skating acceleration is needed to rapidly change directions during gameplay (Blanár, Broďáni, Kováčová, Czaková, & Šiška, 2019; Mascaro et al., 1992; Price, 2003). Ice skating acceleration is purported to be equally, if not more vital, for ice hockey players than reaching maximal ice skating speed, with completion time over short distances exhibiting a stronger association of -0.93 with measures of ice hockey performance compared to a -0.84 association for completion time during the top speed phase of ice skating. (Janot, Beltz, & Dalleck, 2015; Peterson et al., 2016; Thompson, Safadie, Ford, & Burr, 2020). In ice hockey, the ice skating acceleration is usually measured over the first 15 meters with the player commencing from a stationary position (Gilenstam, Thorsen, & Henriksson-Larsén, 2011; Janot et al., 2015; Peterson et al., 2016; Thompson et al., 2020). In contrast, ice skating speed is measured with the player having a skating start and instructed to reach maximal speed at a given
point on the ice rink (Gilenstam et al., 2011; Janot et al., 2012; Janot et al., 2015; Runner, Lehnhard, Butterfield, Tu, & O’Neill, 2016).

Intuitively, ice skating speed and acceleration aids players during game-defining moments such as rapidly covering ice on a defensive play to prevent the opposition from scoring or accelerating and skating past an opponent to generate a scoring opportunity. Thus, the opportunities to either prevent or generate an important play are more numerous for faster ice hockey players compared to their slower counterparts. A study by Renaud et al. (2017) reported that high caliber ice hockey players completed the 4-meter ice skating acceleration phase distance 0.12 seconds faster compared to low caliber players (p = 0.03). Similarly, a significant difference in maximal ice skating speed was noted between elite (E) and sub-elite (SE) ice hockey players during a 1-min maximal ice skating trial performed on a synthetic skating treadmill (E = 17.6 km/h, SD = 0.30 km/h; SE = 13.6 km/h, SD = 0.70 km/h; p < 0.05) (Upjohn, Turcotte, Pearsall, & Loh, 2008). Moreover, ice skating speed differed by 11.7% between elite and recreational ice hockey players during the first 10-meter acceleration phase and by 11.2% during the total 30-meter distance (Buckeridge, Tscharner, & Nigg, 2015). Recently, Robbins et al. (2018) found that high-caliber players displayed an average speed of 6.00 m/s compared to 5.53 m/s for low-caliber players. It is apparent that maximal ice skating speed is a distinguishing characteristic between elite and sub-elite ice hockey players, and thus faster ice skaters will display superior ice hockey performance (Peterson et al., 2014). Therefore, increasing maximal ice skating speed and acceleration is often a main goal of ice hockey strength and conditioning training programs.
OFF-ICE ATHLETIC PERFORMANCE MEASURES ASSOCIATED WITH ICE SKATING SPEED AND ACCELERATION

There are certain commonly incorporated off-ice measures of athletic performance that prior research indicates are associated with ice skating top speed and acceleration phase completion time. Top speed ice skating phase completion time as measured over a certain distance (typically 30-meters) after skaters are provided with 40 meter or more of skating start to attain maximal skating speed (Runner et al., 2016). Acceleration ice skating phase completion time is measured by timed skating over a distance less than 40 meters with players starting from a standstill position (Janot et al., 2015; Runner et al., 2016). Those measures of athletic performance displaying the strongest associations include vertical jump height, broad jump distance, overground sprint speed and acceleration phase completion time (Table 1.1) (Behm, Wahl, Button, Power, & Anderson, 2005; Blanár et al., 2019; Bower et al., 2010; Bracko & George, 2001; Farlinger et al., 2007; Haukali & Tjelta, 2015; Janot et al., 2015; Patrick, Nathan, Ryan, & Ross, 2019; Runner et al., 2016).

Table 1.1. (#1) Association between Off-Ice Measures of Athletic Performance and Ice Skating Completion Time.

<table>
<thead>
<tr>
<th>Study</th>
<th>Overground Sprint Completion Time</th>
<th>Vertical Jump Height</th>
<th>Broad Jump Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haukali et al. (2015)</td>
<td>R = 0.81</td>
<td>R = -0.86</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Ice skating distance = 35m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farlinger et al. (2007)</td>
<td>R = 0.78</td>
<td>R = -0.71</td>
<td>R = -0.78</td>
</tr>
<tr>
<td>Ice skating distance = 35m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brower et al. (2010)</td>
<td>R = 0.43</td>
<td>R = -0.63</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Ice skating distance = 16.5m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Ice skating distance</td>
<td>( R )</td>
<td>( R )</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Janot et al. (2015)</td>
<td>44.80m</td>
<td>0.78</td>
<td>-0.72</td>
</tr>
<tr>
<td>Krause et al. (2012)</td>
<td>34.50m</td>
<td>0.81</td>
<td>-0.51</td>
</tr>
<tr>
<td>Bracko et al. (2001)</td>
<td>44.80m</td>
<td>0.72</td>
<td>-0.31</td>
</tr>
<tr>
<td>Runner et al. (2016)</td>
<td>36m</td>
<td>0.46</td>
<td>-0.55</td>
</tr>
<tr>
<td>Delisle-Houde et al. (2019)</td>
<td>30m</td>
<td>Not Reported</td>
<td>-0.60</td>
</tr>
</tbody>
</table>

It is suggested that the association displayed between these athletic measures and ice skating speed and acceleration completion time can be attributed to the muscular power necessary for rapid propulsion during maximal ice skating and the importance of muscular power during jumping and overground sprinting (Dawes, 2019; Farlinger et al., 2007).

**TRADITIONAL ICE HOCKEY TRAINING PROGRAMS**

Designing a comprehensive training program for ice hockey necessitates an assessment of the requirements and characteristics needed for successful ice hockey performance. Given the importance of ice skating speed and acceleration, coaches design programs tailored to enhance ice skating speed and acceleration during straight-line and cornering ice skating (Ebben, Carroll, & Simenz, 2004; Hedrick, 2002; Manners, 2004; Nightingale, 2014; Pollitt, 2003). These training programs have primarily included overground (land-based) training. For instance, explosive exercises such as Olympic lifts (clean, snatch) are widely incorporated into training...
programs by ice hockey strength and conditioning coaches with a desired translation to ice
skating acceleration (Ebben et al., 2004). In athletes, literature suggests that participation in
Olympic lifting interventions result in a 71% improvement in maximum integrated
electromyography: a neuromuscular parameter (p < 0.05) (Judge, Moreau, & Burke, 2003). This
improvement includes increased motor unit activation and rate coding, which enables the
generation of increased muscular contraction capacity (Cormie, McGuigan, & Newton, 2011).
The increased activated motor units and rate coding alteration results in an outward improvement
in measures of power and acceleration (Cormie et al., 2011).

Nightingale (2014) recommended focusing on maximum muscular strength and power
during the ice hockey season's preparatory phase, with the maintenance of strength, power, and
power endurance being the primary focus during the competitive phase of the season. It is
postulated that increased strength and power will translate to improved ice skating acceleration.

When prescribing strength and power exercises, lower body musculature is of utmost importance
(Manners, 2004). This is due to lower body musculature playing a vital role in the generation of
power and forward propulsion during maximal ice skating (Buckeridge, LeVangie, Stetter, Nigg,
& Nigg, 2015). For example, the literature indicates that a 30-60% increase in hip abductors and
adductors muscle activation corresponded to a 2.67 m/s increase in ice skating speed (Chang,
Turcotte, & Pearsall, 2009). The important role of lower body musculature in ice skating is
apparent in Figure 1.1, where lower body muscles are needed for effective and rapid ice skating
stride cycling. Therefore, sport-specific exercises such as lunges, squats, single leg hops, lateral
hops, and others performed either with a high rate of force development recommended for ice
hockey players.
Overground training studies adopting high rate of force development and strength-based exercises have resulted in improvements in ice skating acceleration and the maximum ice skating speed (Dæhlin et al., 2017; Janot et al., 2012; Naimo et al., 2015; Reyment, Lundquist, & Bonis, 2007; Rønnestad, Øfsteng, & Ellefsen, 2019). An 8-week combined plyometric and strength program was effective at substantially decreasing 10-meter ice skating acceleration phase completion time by 2.8% in high-caliber ice hockey players (p = 0.03) (Dæhlin et al., 2017). Moreover, Naimo et al. (2015) reported a 5.2% decrement in maximal 33-meter ice skating time in a high intensity training group compared to a 1.2% time decrement for the low intensity training group (p = 0.02).

**ON-ICE ICE HOCKEY TRAINING PROGRAMS**

Ice hockey training programs are primarily implemented overground compared to on-ice (Ebben et al., 2004). In fact, only two studies have incorporated an on-ice approach to training or a training session; with one study being acute in nature (Matthews, Comfort, & Crebin, 2010) and the other a very short (4-week) longitudinal study (Janot et al., 2012). Mathews et al. (2010) explored the impact of a single session resisted ice skating bout on subsequent unresisted ice skating completion time, concluding that single bout of resisted ice skating decreased 25-meter
ice skating completion time by 2.6% in collegiate male ice hockey players (p = 0.02) (Matthews et al., 2010). Janot et al. (2012) reported that in youth (11-14 years old) ice hockey players, a short (4-week; twice a week) resisted ice skating training program decreased 45-meter ice skating top speed phase completion time by 4.3% and 6-meter acceleration phase completion time by 3.4% (p < 0.05).

However, major limitations exist with the Matthews et al. (2010) and Janot et al. (2012) studies that incorporated on-ice training. In both studies, elastic cords were used to provide the resistance during the study. Figure 1.2 depicts the use of elastic cords to provide resistance during ice skating. As acknowledged in both studies, the variable resistance provided by the elastic cord does not enable accurate quantification of the resistance, as the resistance is dependent on the effort of the subject, the elastic cord tension, and the effort of the assistant holding the elastic cord (Janot et al., 2012; Matthews et al., 2010). Consequently, the resistance experienced by the subject is unknown and players can experience distinct resistances when elastic cords are used. Moreover, only Janot et al. (2012) explored the impact of multiple sessions of resisted ice skating, but a 4-week study is short, and the authors suggested that a longer intervention should be explored in future research with differing populations. It was purported that the lack of larger improvements in ice skating speed and acceleration may be attributed to the short intervention duration and the unknown resistance experienced by the subjects (Janot et al., 2012). Thus, there is little research exploring the impact of on-ice training on ice skating speed and acceleration in ice hockey players.
In contrast, recently, various studies have explored the impact of sport-specific resistance modalities to enhance running speed and acceleration in field-based sports (Alcaraz, Carlos-Vivas, Bruno, & Martínez-Rodríguez, 2018; Hicks, Schuster, Samozino, & Morin, 2019; Haugen, Seiler, Sandbakk, & Tønnessen, 2019; Petrakos, Morin, & Egan, 2016). One such modality is sled towing, a form of resisted sprint training, which has been incorporated in overground sports with 2.4-5.0% improvements in sprint acceleration phase and top speed phase completion time reported (Alcaraz et al. 2018; Bachero-Mena & Badillo, 2014; Harrison & Bourke, 2009; Petrakos et al., 2016; West et al., 2013). The studies incorporated an overground resisted sprint training program exceeding 4-weeks, with most lasting 6 weeks or more (Alcaraz et al., 2018; Petrakos et al., 2016). Despite improvements in speed and acceleration phase completion time after engaging in resisted sprint training, on-ice resisted sprint training lasting beyond 4-weeks, with a known resistance, has not been explored in ice hockey. As such, it is now stipulated that a similar duration on-ice resisted sprint intervention may elicit a comparable
response. This lack of exploration is a major gap in the ice hockey literature with far-reaching implications for ice hockey training.

**RESISTED SPRINT TRAINING**

A popular modality utilized by strength and conditioning coaches to increase sprint acceleration and speed is resisted sprint training. This modality requires the athlete to sprint with added external resistance. The resistance can be provided by a loaded sled, parachute, incline, or weighted vest (Leyva, Wong, & Brown, 2017). The athlete sprints over a predetermined distance with one of the main goals of improving acceleration. Prior literature indicates that resisted sprint training in the form of sled towing was effective in increasing sprint acceleration in athletes of different running-based sports (Cahill, Cronin, et al., 2019; Gil et al., 2018; Harrison & Bourke, 2009; West et al., 2013). For example, Harrison and Bourke (2009) reported that professional rugby players substantially decreased their 10-meter sprint acceleration phase completion time by 0.30 seconds after six weeks of resisted sprint training twice a week using a weighted sled at 13% of bodyweight (p = 0.02). In professional soccer players, a longitudinal intervention with sled load resistance that caused a 10% decrease in maximal sprint speed lowered 5-, 10-, 15-, 20-, and 25-meter sprint completion times, thus corresponding to a 3-7% improvement in sprint acceleration phase completion time (p < 0.05) (Gil et al., 2018). Similarly, another study conducted in professional soccer players reported a 5-8% increase in 5, 10, 20, and 30-meter sprint speeds after five weeks of resisted sprint training with sled loads ranging from 5-20% of bodyweight (Loturco et al., 2017).

The improvement in sprint speed and acceleration are partially attributed to alterations in sprint mechanics. Given the importance of stride length and stride frequency in achieving maximal sprint speeds, alterations in these two components and their subcomponents (contact
time, flight time, contact distance, flight distance) can result in faster sprint speeds (Dorgo, Perales, Boyle, Hausselle, & Montalvo, 2019; Hunter, Marshall, & McNair, 2004). Studies support the positive alterations in sprinting mechanics following resisted sprint training resulting in faster sprint speeds and acceleration (Prieske, Krüger, Aehle, Bauer, & Granacher, 2018; Spinks, Murphy, Spinks, & Lockie, 2007). These alterations include a 9.98% increase in estimated horizontal force application and an 8.0-9.1% increase in stride frequency during the acceleration phase after resisted sprint training contributing to decreased sprint acceleration phase completion time (Alcaraz, Elvira, & Palao, 2014; Morin, Capelo-Ramirez, Rodriguez-Pérez, Cross, & Jimenez-Reyes, 2020).

Certain biomechanical benefits following resisted sprint training include an accompanying 6.3-11.8% decrease in contact time and 8.1-9.5% increase in stride frequency (Hrysomallis, 2011; Kawamori, Newton, Hori, & Nosaka, 2013; Prieske et al., 2018; Spinks et al., 2007). Hence, research indicates that athletes are able to increase the number of times they apply forces to the ground while simultaneously decreasing the time they spend in contact with the ground, all while maintaining or increasing their propulsive ground impulses (Petrakos et al., 2016). It appears that team sport athletes (soccer, rugby, basketball) exhibit superior benefits from participating in a sled towing program compared to sprint trained athletes (Cohen’s d = 0.42; small; p = 0.02) (Alcaraz et al., 2018; Hopkins, 2009). One explanation may be that sled towing “teaches” non-sprinters to apply forces in a more horizontal manner and results in an improved intermuscular synchronization during force application (Petrakos et al., 2016). Leading researchers in sprint performance state the importance of horizontal force application during sprinting (Hicks et al., 2019; Morin et al., 2012; Morin, Edouard, & Samozino, 2011; Rabita et al., 2015). Another apparent biomechanical benefit of sled towing is the adoption of an increased
trunk lean, proposed to assist athletes apply forces in a more horizontal direction (Lockie, Murphy, & Spinks, 2003; Spinks et al., 2007). Authors attribute increased force application to physiological adaptations such as increased rate coding and motor unit recruitment. This follows reason since sled towing, particularly when performed with high loads, necessitates the generation of large forces to overcome the inertia of the sled and accelerate to maximal capacity and therefore may recruit large amounts of muscle fibers (Cross et al., 2019). It appears that some of the benefits of sled towing include a reduction in contact time, increased stride frequency, neuromuscular adaptations, and horizontal force application.

Engaging in a longitudinal resisted sprint training intervention decreases top speed and acceleration phase completion time by up to 7.0% (Alcaraz et al., 2018; Petrakos et al., 2016; Rodríguez-Osorio, Gonzalo-Skok, & Pareja-Blanco, 2019). Therefore, this modality can be useful for athletes requiring high levels of acceleration and speed during sports participation.

STATEMENT OF THE PROBLEM

As mentioned, one method implemented by strength and conditioning coaches in field-based sports to increase speed, acceleration, and muscular power is resisted sprint training (Alcaraz et al., 2018; Morin et al., 2017; Petrakos et al., 2016). However, there are other sports that necessitate speed and acceleration and muscular power despite not being running-based, such as ice hockey. Speed, acceleration, and muscular power are key for hockey players since players must regularly skate the entire length of the ice rink, with an apparent emphasis on acceleration over attaining maximal speed (Bond, Bennett, & Noonan, 2018; Janot et al., 2015). Although it is anticipated that a longitudinal resisted sprint training program would improve ice skating acceleration and kinematics, this remains to be ascertained in the literature. In fact, no literature exists exploring the effects of a longitudinal resisted sprint training program with
known resistance in ice hockey players. Furthermore, given the combination of both on-ice and overground training ice hockey players are exposed to, whether an on-ice resisted sprint training program is superior to an overground resisted sprint training program to increase ice skating speed and acceleration is undetermined.

**CONCEPTUAL FRAMEWORK**

As stated earlier, despite the vital role of ice skating speed and acceleration on ice hockey performance, on-ice strength and conditioning modalities are rarely implemented in regular ice hockey strength and conditioning programming (Ebben et al., 2004; Nightingale, 2014). Consequently, most strength and conditioning training for ice hockey occurs overground with emphasis placed on increasing speed, acceleration, and muscular power. There exist considerable evidence suggesting that resisted sprint training can increase sprint speed, acceleration and improve explosive measures of sports performance in various running-based athletes (Alcaraz et al., 2018; Petrakos et al., 2016). However, the employment of resisted sprint training in ice hockey strength and conditioning programming is not commonplace.

A simple conceptual framework was created to guide the proposed study (Figure 1.3). The model depicts the anticipated connection between resisted sprint training and ice hockey performance. The overload stimulus provided by resisted sprint training causes positive biomechanical and physiological changes in the athlete (Luteberget, Raastad, Seynnes, & Spencer, 2015; Petrakos et al., 2016). Moreover, the resisted sprint modality enhances proper sprinting technique, allowing athletes to optimally apply ground forces during sprinting (Hicks et al., 2019; Spinks et al., 2007; West et al., 2013). Consequently, resisted sprint training can result in up to a 7% decrease in top speed and acceleration phase completion time (Alcaraz et al., 2018; Gil et al., 2018; Petrakos et al., 2016). Athletes who engaged in resisted sprint training display
substantial improvement in measures of muscular power (Harrison & Bourke, 2009; Kawamori et al., 2013). Importantly, these measures of muscular power such as vertical jump height, broad jump distance, and overground sprint speed are associated with ice skating speed and acceleration in ice hockey players (Janot et al., 2015; Runner et al., 2016). All pathways positively impacting ice skating speed and acceleration are of utmost significance since ice skating speed and acceleration are the main predictors of successful ice hockey performance (Bond et al., 2018; Farlinger et al., 2007).

Figure 1.0.3. Conceptual Framework

**PURPOSE OF THE STUDY**

Although prior literature has explored resisted sprint training in running-based athletes, none have examined the impact of a longitudinal resisted sprint training with known resistance in ice hockey players. Furthermore, longitudinal training interventions in ice hockey have rarely used any on-ice training component. Consequently, exploring the differences between on-ice and overground training interventions has not been explored. Moreover, given the recent advancements in sport performance technology, key assessments and variables have been
excluded from prior ice hockey research. Thus, it is unknown whether a resisted sprint training intervention with known resistance will enhance ice skating speed, acceleration, and performance on assessments used to determine ice hockey player performance. Hence, exploring the impact of a longitudinal training intervention for ice hockey players is highly desirable, thereby adding to the minimal research on ice hockey sports performance. Therefore, the purposes of the study are: 1) to investigate the effects of an on-ice resisted sprint training intervention, an overground resisted sprint training intervention and a traditional training control condition for maximal ice skating top speed and acceleration phase completion time and other measures associated with ice skating top speed and acceleration phase completion time; 2) to identify changes in ice skating kinematics during maximal ice skating after participation in the respective training intervention; and 3) to examine changes in the magnitude of muscle activation of the knee flexors and extensors during maximal ice skating after participation in the respective training intervention.

**RESEARCH QUESTIONS AND HYPOTHESES**

This study aims to ascertain the impact of resisted sprint training on ice skating speed, acceleration, and athletic measures associated with ice skating in ice hockey players investigates the following:

1) An on-ice resisted sprint training program, overground resisted sprint training program, and control on ice skating top speed and acceleration phase completion time.

2) An on-ice resisted sprint training program, overground resisted sprint training program, and control on measures of athletic performance associated with ice skating top speed and acceleration phase completion time.
3) Changes in the magnitude of muscle activation of knee flexors and extensors during maximal ice skating after participation in a resisted sprint training intervention.

4) Changes in ice skating kinematics during maximal ice skating after participation in a resisted sprint training intervention.

**Based on the literature, the following hypotheses were developed:**

1) The on-ice resisted sprint program would result in a 2.0-4.0% decrease in maximal ice skating top speed completion time and a similar magnitude decrease in acceleration phase completion time.

2) Both the on-ice and overground resisted sprint training programs would be effective at improving vertical jump height by at least 15.0%, broad jump distance by at least 8.0%, and overground sprint completion time by at least 5.0%. Both resisted sprint training programs would display superior performance alterations in vertical jump, broad jump, and overground sprint completion times compared to the control group by 1.0-3.0%.

3) Knee extensor and flexor muscle activation during maximal ice skating at the conclusion of the resisted sprint intervention will display changes compared to baseline measures.

4) There would be a 7.0-9.0% increase in step length or step frequency with an accompanying 6.0-11.0% decrease in contact time after participation in either resisted training program.

**LIMITATIONS**

The study may have the following possible limitations:

- Given the sample population, findings may only be generalizable to youth male competitive ice hockey players.
CHAPTER 2: LITERATURE REVIEW

OVERGROUND SPRINTING

Sprinting is categorized by the ability to accelerate and achieve then maintain maximal velocity (Hunter et al., 2004). Thus, sprinting can be decomposed into two phases; an acceleration and a maximal velocity phase (Yu et al., 2016). The acceleration phase comprises the first 40 meters of the sprint performance with the maximal velocity phase consisting of distances beyond 40 meters (Maćkała, Fostiak, & Kowalski, 2015). To improve sprint performance across both phases, appropriate alterations in primary sprint performance determinants are required (Morin et al., 2012). In particular, the product of stride length and stride frequency is the determinant of sprinting velocity, which can be further broken down into the following subcomponents: contact time, flight time, contact distance, and flight distance (Figure 2.1) (Hunter et al., 2004; Young & Choice, 2007). Initial acceleration is characterized by increased stride length during the first 0-12 meters (Maćkała et al., 2015). Prior literature suggests a linear increase in both stride length and frequency during the acceleration phase up until 7 m/s (Mero, Komi, & Gregor, 1992). The same authors further reported that during the maximal velocity phase, there is greater incremental increase in stride frequency compared to stride length. Thus, athletes increase sprinting velocity by optimally altering their stride frequency as opposed to stride length. In elite sprinters, a step frequency of 5 steps per second with flight times ranging from 0.120 to 0.140 seconds and contact times of 0.080 to 0.100 seconds have been reported (Mann, 2005; Mero & Komi, 1990; Mero et al., 1992).
Consequently, alterations in stride frequency and length modify sprint performance. Research indicates the importance of horizontal force application in achieving improved sprint speed and acceleration (Hicks et al., 2019; Morin et al., 2012; Rabita et al., 2015). To optimally apply forces in the horizontal direction, athletes adopt a forward lean to optimally orient the striking angle of the foot during the contact phase (Hicks et al., 2019; Spinks et al., 2007). For example, despite similar contact times, elite sprinters able to generate higher horizontal force during ground contact achieved superior maximal velocity (Cohen’s $d = 3.64$; very large; $p < 0.05$) and longer minimum step lengths (Cohen’s $d = 1.00$; moderate; $p < 0.05$) compared to sub-elite sprinters (Rabita et al., 2015). Additionally, the importance of horizontal force application in sprint performance is further supported by significant correlations between horizontal force and maximal speed ($r = 0.775$; $p < 0.01$), mean 100-m speed ($r = 0.736$; $p < 0.01$), and early acceleration ($r = 0.621$; $p < 0.05$) (Morin et al., 2011).

**SPRINTING KINEMATICS**

Overground sprinting necessitates proper ankle ranges of motion. Dorsiflexion during the swing phase of overground sprinting enables the foot to be repositioned in preparation for subsequent ground contact (Bezodis, Willwacher, & Salo, 2019; Howard, Conway, & Harrison,
For instance, Struzik et al. (2016) reported a significant correlation between ankle dorsiflexion angle and completion time over a 10-meter acceleration phase in competitive female athletes ($r = 0.64; p < 0.05$). A significant correlation between ankle range of angular velocity and ruining time over the 10-meter acceleration phase distance was also reported ($r = 0.75; p < 0.05$). At ground contact, sprinters adopt an extended knee position (Higashihara, Nagano, Ono, & Fukubayashi, 2015, 2018). An extended knee position may increase leg stiffness and utilization of the stretch-shortening cycle, particularly during the maximal velocity phase (Higashihara et al., 2015). During sprinting, peak knee flexion angle (~120°) occurs at around 60-65% of the gait cycle (Chumanov, Heiderscheit, & Thelen, 2007; Higashihara et al., 2015). Hip extension range of motion and hip extension velocity appears to be an important predictor of higher speeds and acceleration during sprinting. Peak hip extension angles (~20°) during sprinting occur between 30-40% of the gait cycle (Higashihara et al., 2015; Higashihara, Ono, Kubota, Okuwaki, & Fukubayashi, 2010). Sprinters adopt a forward trunk position during the initiation of the sprint; gradually, the trunk becomes more erect as the sprinters enter the maximal velocity phase (Hicks et al., 2019; Rabita et al., 2015).

The literature indicates increases in both step length and step frequency with rising speeds (Kyröläinen, Avela, & Komi, 2005; Mann, Moran, & Dougherty, 1986; Miyashiro, Nagahara, Yamamoto, & Nishijima, 2019). Miyashiro et al. (2019) reported a 9% increase in step frequency when competitive male sprinter increased their sprint speed from 8.99 m/s to 10.82 m/s. In addition to alterations in step length and frequency with rising speeds, the phase of the sprint (acceleration or maximal velocity) may also impact step length and frequency (Girard, Brocherie, Morin, Degache, & Millet, 2015). For instance, in both elite and sub-elite sprinters, step frequency reached its maximum (4.80-4.95 steps/second) during the later stages of the 40-
meter sprint trial (Rabita et al., 2015). Likewise, during steps 2-5, step frequency was lower compared to steps 12-15 (Cohen’s d = 0.66; moderate; p < 0.05) during a sprint trial (Girard et al., 2015). Across both males and females, there was an increase in step length from initial acceleration to maximal velocity (Males = Cohen’s d = 8.36; nearly perfect; p < 0.01; Females = Cohen’s d = 5.48; nearly perfect; p < 0.01) (Debaere, Jonkers, & Delecluse, 2013). This finding is also supported by additional literature by Nagahara et al. (2014) who indicated increased step length at the 24th step (2.14 m) compared to the 5th step (1.5 m). Furthermore, the authors reported a rapid decrease in contact time from initial acceleration (0.17 seconds at 2nd step) to maximal velocity phase (0.090 seconds at 20th step). Similarly, additional research indicates longer contact times during initial acceleration steps with progressive decrease in step contact time as the individual transitions to the maximal velocity phase (Bezodis et al., 2019). In male competitive athletes, average contact times during steps 2-5 was significantly longer than average contact times during steps 12-15 (Cohen’s d = 1.1; moderate; p < 0.05) (Girard et al., 2015). This finding agrees with literature in elite male sprinters demonstrating longer contact time during the first step compared to later steps (Cohen’s d = 1.35; large; p < 0.05) (Ciacci, Merni, Bartolomei, & Di Michele, 2017).

**MUSCLE ACTIVITY DURING SPRINTING**

Literature indicates increased sEMG activity in certain muscle groups in response to rising sprint speeds (Chumanov et al., 2007; Howard et al., 2017; Kyröläinen et al., 2005; Mero & Komi, 1987). Chumanov et al. (2007) reported increased sEMG activity of the hamstrings in response to increasing sprint speeds with maximal sprinting eliciting the highest peak EMG activity of the hamstrings (p < 0.05). Increased sEMG was associated with higher hamstring muscular force with the authors reporting that average peak hamstring force increased from 36
N/kg at 80% speed to 52N/kg at maximal speed (p < 0.05). Similarly, in elite male runners, sEMG activity (%MVIC) of the vastus lateralis, rectus femoris, and gluteus maximus, increased in response to higher sprinting speeds (p < 0.001) (Kyröläinen et al., 2005). For instance, sEMG activity of the gluteus maximus at the start of running was lower at 4m/s compared to at maximal speed (Cohen’s d = 1.23; large; p < 0.05). Mann et al. (1986) reported prolonged sEMG activation of the hamstrings with rising speeds during the support phase. The authors suggest that the hamstrings are important hip extensors during the propulsive phase as speeds rise and during acceleration. Furthermore, a more powerful force production in the optimal direction for rising running speeds requires increased sEMG activity of the biarticulate muscles (biceps femoris, rectus femoris, and gastrocnemius) during the entire running cycle (Kyröläinen et al., 2005).

When sEMG during the sprint cycle is explored, the hamstrings, quadriceps, gastrocnemius and tibialis anterior achieve peak activity during late swing phase just prior to ground contact (Higashihara et al., 2015; Howard et al., 2017; Mero & Komi, 1987). During early stance, agonist and antagonist muscles co-contract to stabilize joints and facilitate optimal force transfer in preparation for propulsion (Howard et al., 2017). For instance, the rectus femoris is active during the stance phase to assist with forceful knee extension and during the swing phase to quickly reposition the limb for subsequent ground contact (Howard et al., 2017; Jönhagen, Ericson, Németh, & Eriksson, 1996). The biceps femoris displayed high activation before and after foot contact facilitating controlled deceleration of knee extension and ensuing forceful hip extension during the propulsion phase (Higashihara et al., 2015, Higashihara et al., 2018). The tibialis anterior is active during swing phase keeping the ankle dorsiflexed (preventing tripping) and in preparation for the breaking phase to stabilize the ankle (Howard et al., 2017).
Figure 2.0.2. Lower Limb Muscle Activity during Sprinting. Muscle activity duration can be seen for each distinctive sub-phase of the sprint cycle. (reproduced from Howard et al., 2017).

Moreover, sEMG differs within a muscle group, depending on the sprint phase. During the middle swing phase, the activity of the semitendinosus muscle was significantly greater than that of the biceps femoris muscle at 75% (p < 0.001), 85% (p < 0.01), and 95% (p < 0.05) of running speed with semitendinosus exhibiting higher activity across all speeds. Furthermore, peak activation time (seconds) differed between the biceps femoris and semitendinosus during 95% of running during both the stance phase (Cohen’s d = 1.22; large; p < 0.01) and the swing phase (Cohen’s d = 0.60; moderate; p < 0.01) (Higashihara et al., 2010). When comparing the maximal velocity and acceleration phases, relative sEMG activation of the biceps femoris muscle was at times 15% higher than the semitendinosus (p < 0.01) (Higashihara et al., 2018). During the late stance through terminal mid-swing of maximal velocity, the semitendinosus showed a 4-15% higher activation compared to the biceps femoris (p < 0.01). At the early-swing and the first half of the mid-swing, activation of the semitendinosus was 2-15% greater than biceps femoris activation in both the acceleration and maximal velocity phases (p < 0.01). During acceleration,
relative biceps femoris activation at the early-stance was 3% greater than semitendinosus (p < 0.05). The authors proposed that the biceps femoris is highly activated primarily as a strong hip extensor at early stance during the acceleration phase, which requires a higher hip extension moment to push the ground backward as compared to the maximal velocity phase (Higashihara et al., 2018). Moreover, they concluded that the hamstring muscles contribute as strong eccentric knee flexors at late stance during the maximal velocity phase compared to the acceleration phase.

**ICE SKATING**

Similar to overground sprinting, acceleration and achieving maximal ice skating speed relies on an initial forward trunk lean, high stride frequency, and shorter support phases (contact time) (Marino, 1977). Maximal ice skating can be separated into two distinct phases; the acceleration and glide phases (Budarick et al., 2018; R. Thomas & Berger, 1995). The acceleration phase requires substantial movement in the frontal plane, rotation of the lower limb joints, and high landing forces (de Koning, Thomas, Berger, de Groot, & van Ingen Schenau, 1995; Shell et al., 2017). The first to 7-8 steps is when the greatest acceleration occurs during maximal ice skating (Shell et al., 2017). Literature by USA Hockey indicates that in high-caliber ice hockey players, 60-65 feet (around 20 meters) is required to attain maximal ice skating speed. Budarick et al. (2018) and Shell et al. (2017) stated that around 14 steps were taken in high-caliber ice hockey players to achieve maximal speed during the maximal speed phase (19-34 meters) of ice skating. Consequently, ice hockey literature aiming to determine ice skating acceleration has typically used distances of 36 meters or less, whereas distances of above 36 meters are used for maximal speed determination (Gilenstam et al., 2011; Janot et al., 2012; Janot et al., 2015; Peterson et al., 2016; Runner et al., 2016; Thompson et al., 2020). The distinction between ice skating acceleration and top speed testing is depicted in Figure 2.3. De
Koning et al. (1995) reported that during initial push off steps (acceleration) the ice skaters exhibited a “running like” movement to generate necessary propulsive forces and then transitioned to a glide technique during steady state ice skating. During the glide phase, the rapid movements of the lower limbs in the frontal and sagittal planes allow the ice skater to achieve high speeds.

![Figure 2.0.3. Acceleration and Top Speed Ice Skating Testing. (Left = Acceleration; Top Speed = Right). (reproduced from Runner et al., 2016).](image)

The skating stride is biphasic and consists of both a stance and a swing phase (Figure 2.4) (Renaud et al., 2017; Upjohn et al., 2008). The stance phase is further divided into a single and double leg support. Single leg support occurs at 18% of the stride cycle and double support occurring at 82% (Marino, 1983; Pearsall, Turcotte, & Murphy, 2000). Propulsion happens during both single and double leg support during the outward rotation of thigh, which coincides with hip and knee extension (Pearsall et al., 2000). Renaud at al. (2017) indicated short double
leg support times during acceleration, further supporting the “running like” technique adopted during acceleration.

Figure 2.0.4. Phases and Events of Ice Skating Stride (Glide Phase). a) Side view. b) Inferior view. Both stance and swing phases are illustrated. Double- and single-leg support is also shown. (reproduced from Upjohn et al., 2008).

ICE SKATING KINEMATICS

Ice skating requires sufficient ankle ranges of motion. During ice skating acceleration, higher caliber players demonstrate increased dorsiflexion and inversion during ice contact (Renaud et al., 2017). An increased stretch of the plantar flexors during early stance phase may contribute to greater forces during concentric plantar flexion and eversion, helping “flick” the ice in the propulsion phase (Budarick et al., 2018; Robbins et al., 2018). Ice skaters display an increased range of motion at the knee as speeds rise. At ice contact through the propulsive phase, ice skaters adopt a flexed position (Budarick et al., 2018; Upjohn et al., 2008). For ice skaters, the inability to apply propulsive forces to the ice if the knee is completely extended may explain adopting a more flexed position. Adopting an extended knee would cause the blade of the skate to be flush with the ice, thereby limiting the “grip” with which to push against the ice.
Additionally, a more flexed knee contributes to a greater stability on the ice as speeds increase and ice skaters push against the ice with forceful knee extension (Robbins et al., 2018). During maximal ice skating, peak knee flexion occurs around 50% of the skating cycle and reaches a maximum of 100° (Budarick et al., 2018; Shell et al., 2017) or lower (Upjohn et al., 2008). At the hip joint, ice skating requires increased movement in both the frontal and transverse planes (Buckeridge, LeVangie, et al., 2015; Budarick et al., 2018; Chang et al., 2009). Movements in these planes are necessary to orient the blade to make appropriate contact with the ice. At ice skating initiation, ice skaters adopt an externally rotated hip, which increases the “grip” of the blade against the ice. As they transition to the glide phase, the hips gradually internally rotate, and the ice skater commences to utilize hip abduction/adduction movements to propel themselves forward (Chang et al., 2009; Shell et al., 2017). However, hip extension range of motion and hip extension velocity appears to be important indicators of achieving higher ice skating speeds. Peak hip extension during ice skating occurs at 60-65% of the skating cycle and reaches 5° beyond the anatomical 0° position (Chang et al., 2009; Upjohn et al., 2008). Lastly, ice skaters adopt a forward trunk position during initiation of the sprint and continue to have an increased trunk lean as they transition to the glide phase of skating (Budarick et al., 2018).

When spatiotemporal kinematics are explored, increased ice skating speeds were achieved by both higher stride length and frequency (Chang et al., 2009; Renaud et al., 2017; Upjohn et al., 2008). For instance, Chang et al. (2009) reported increased strides rates during rising speeds of 3.33 m/s to 5.00 m/s (Cohen’s d = 1.35; large; p < 0.01) and from 3.33 m/s to 6.66 m/s (Cohen’s d = 2.86; very large; p < 0.01). Moreover, stride length increased during higher speeds of 3.33 m/s to 5.00 m/s (Cohen’s d = 1.96; large; p < 0.01) and from 3.33 m/s to 6.66 m/s (Cohen’s d = 2.10; very large; p < 0.01). Across a sample of competitive male
university ice hockey players completing a 30-meter maximal ice skate, the mean estimated ice contact time for all strides was 0.324 seconds, with the mean stride duration being 0.554 seconds (Stetter, Buckeridge, von Tscharner, Nigg, & Nigg, 2016). During the glide phase, the contact time was significantly longer than the acceleration phase (Upjohn et al., 2008). Additionally, literature suggested that players adopt a wider stance with increasing speed in order to aid with stability and balance (Shell et al., 2017).

Alterations in spatiotemporal variables have been reported depended on experience level (Shell et al., 2017). They reported the importance of high stride frequency to achieve greater acceleration and high skating speed for both male and female ice hockey players. High-caliber players displayed a mean stride frequency of 59.9 strides per minute compared to 55.1 for low-caliber players. As suggested by authors, this difference contributed to the higher maximal ice skating speed achieved by the high-caliber players compared to low-caliber players (Cohen’s d = 7.43; nearly perfect; p < 0.001) (Upjohn et al., 2008). Moreover, high-caliber ice hockey players displayed longer stride lengths compared to low-caliber ice hockey players (Buckeridge, LeVangie, et al., 2015; Upjohn et al., 2008). This is supported by prior research indicating that on average, high caliber players displayed a stride length of 520.5 cm compared to 442.1 cm for low-caliber players (Cohen’s d = 7.16; nearly perfect; p = 0.001) (Upjohn et al., 2008). However, one study indicated comparable stride lengths between high and low-caliber ice hockey players (Cohen’s d = 0.33; small; p = 0.19) (Robbins et al., 2018). Differences between studies may be attributed to the ice skating environment (synthetic ice treadmill versus on-ice) used or the study sample. Since in some studies, both male and female ice hockey players were used, with recent literature indicating differences in step kinematics between males and females (Budarick et al., 2018).
MUSCLE ACTIVITY DURING ICE SKATING

Previous research reported that increasing ice skating speeds resulted in 15-60% increase in muscle activity of the hip flexors, knee extensors, and plantar flexors, resembling the muscle activity response observed during increasing overground sprint speeds (Chang et al., 2009; Goudreault, 2003; Howard et al., 2017). As previously mentioned, ice skating requires hip abduction and adduction to propel the payer forward during ice skating. Interestingly, Chang et al. (2009) reported disproportional levels of peak activation and activation duration of the adductor magnus compared to other lower body musculature (vastus medialis, biceps femoris, gluteus maximus) during maximal skating in ice hockey players. During the glide phase of ice skating, the literature suggests higher activation of the knee extensors (vastus medialis and lateralis) and flexors (biceps femoris) as compared to the acceleration phase (Behm et al., 2005; Buckeridge, LeVangie, et al., 2015; Buckeridge, Tscharner, et al., 2015). For instance, Behm et al. (2005) reported that during the glide phase, knee extensors achieved 85% of MVC and knee flexors achieving 90% of MVC. In contrast, during acceleration, knee extensors displayed an activation equivalent to 70% of MVC and knee flexors achieving 50% of MVC. Another study found a 10% increase in vastus medialis activity and 13% increase in vastus lateralis muscle activity during the glide phase compared to the acceleration phase of ice skating (Buckeridge, LeVangie, et al., 2015). Increased muscle activity exhibited by the VM and VL muscles are likely an important mechanism contributing to greater knee extension during the propulsive portion of the glide phase. Consequently, some authors suggest that high ice skating speeds during the glide phase can be achieved through appropriate training of the knee extensor muscles, which then allows for greater joint range of motion. As reported by Buckeridge et al. (2015), there appears to be greater reliance on the plantar flexors during the acceleration phase of
ice skating. There was a 6% (p < 0.05) decrease in gastrocnemius muscle activity during the glide phase steady strides compared to the acceleration phase. This finding coincides with research indicating the importance of plantarflexion during the acceleration phase of ice skating (Buckeridge, LeVangie, et al., 2015; Renaud et al., 2017).

OFF-ICE PREDICTORS OF ICE HOCKEY SKATING SPEED AND ACCELERATION

Ice hockey requires athletes to rapidly skate up-and-down the rink to contribute to an offensive or defensive play. Maximal ice skating acceleration and speed are two of the main contributors to successful ice hockey performance (Farlinger et al., 2007). Previous literature explored the relationship between maximal skating speed and commonly used off-ice measures of sports performance. For example, Runner et al. (2016) found that an increase in vertical jump height, a commonly used measure of lower body muscular power, contributed to decreased ice skating completion time ($b = -0.029$, $t_{(35)} = -2.680$, $p < 0.011$) in collegiate male ice hockey players. In a seminal study by Mascaro et al. (1992) it was reported that vertical jump height had the highest correlation ($r = 0.85$) with maximal ice skating speed in professional male hockey players (Mascaro et al., 1992). In another study on male competitive ice hockey payers, the authors reported that ice skating completion time was associated with overground 30-meter sprint completion time ($r = 0.78$), broad jump distance ($r = -0.74$), and vertical jump height ($r = -0.71$) (C. Farlinger et al., 2007). Recently, Blanàr et al. (2019) reported associations between the Weave test completion time (ice skating in a crossover manner) with power during squat jump at 70% of body weight ($r = -0.383; p = 0.001$), vertical jump height ($r = -0.363; p = 0.002$), left single-leg lateral jump distance ($r = -0.581; p = 0.009$), and right single-leg lateral jump distance ($r = -0.563; p = 0.01$) in youth male ice hockey players. This led to the following predictive equation for Weave test completion time, which explained 0.814% of the variance: Weave test =
8.357 + 1.450(squat jump at 70% of body weight) – 1.529(vertical countermovement jump) – 0.855(left single-leg lateral jump) + 1.409(right single-leg lateral jump). Consequently, it seems that lower body power as measured by jumping is associated with improved ice skating acceleration and speed.

Multiple studies have reported strong associations between overground speed/acceleration with on-ice skating speed/acceleration (Behm et al., 2005; Bracko & George, 2001; Haukali & Tjelta, 2015; Janot et al., 2012; Krause et al., 2012). For instance, Krause et al. (2012) reported that overground 36-meter sprint completion time was strongly associated with ice skating completion time ($r = 0.81$) in high school male ice hockey players. Authors suggested that for every one-second improvement in overground 36-meter sprint time, this would equate to a 0.6-second improvement in on-ice 36-meter sprint time. Although seemingly small, this potential increase in ice skating speed can result in ice hockey players getting to the hockey puck faster and thus having more opportunities to score or to prevent a goal. Additional literature in young male ice hockey players reported significant associations between overground 36-meter sprint completion time ($r = 0.81$) and vertical jump height ($r = -0.86$) with maximal ice skating completion time (Haukali & Tjelta, 2015). Authors suggested that an off-ice training program that includes sprint training and jumping exercises may have a positive impact on young hockey players’ ice skating speed and acceleration. Behm et al. (2005) reported that among young ice hockey players, 40-yard sprint speed ($r = 0.51$) and balance ratio ($r = -0.51$) were the only off-ice measures associated with maximal ice skating speed. Balance ratio was obtained by calculating contact time with floor to no contact time via the 30-second wobble board test. Moreover, the authors suggested the following predictive equations for maximal ice skating speed which explained 38% of the variance: 1) speed = 1.1647 + 0.1451(40-yard speed); 2) speed = 2.0765 –
Interestingly, in this study, Behm and colleagues did not report significant associations between maximal ice skating speed and squat jump height \( (r = -0.30) \) or drop jump height \( (r = -0.16) \). However, differences in association strength compared to other studies may be attributed to the jumping protocol, instrumentation utilized, or the experience of the players.

In studies incorporating anaerobic measures, fastest ice skating completion time \( (r = -0.48; p = 0.027) \) and average ice skating completion time \( (r = -0.43; p = 0.05) \) were correlated with Wingate relative peak power in a male ice hockey players (Potteiger, Smith, Maier, & Foster, 2010). Indicating that players able to generate more relative peak power completed the ice skating distance in the shortest amount of time. Similarly, in university male ice hockey players, 30-meter ice skating completion time was significantly correlated with Wingate relative peak power \( (r = -0.61; p < 0.01) \), standing long jump distance \( (r = -0.41; p < 0.05) \), and vertical jump impulse \( (r = -0.60; p < 0.01) \) (Patrick et al., 2019).

Associations between off-ice athletic performance measures and on-ice skating speed have also been reported for female ice hockey players. Bracko and George (2001) found a significant relationship between overground 36-meter sprint speed and on-ice skating speed \( (r = 0.71) \) in young female ice hockey players, with authors stating that the following regression equation best predicted ice skating speed explaining 58% of the variance: speed = 4.913 - (0.0107 x kilograms) + (0.4356 x overground 36-meter time). Another study on Division III female ice hockey players reported that overground 36-meter sprint completion time \( (r = 0.810) \) and vertical jump height \( (r = -0.822) \) were significantly associated with on-ice maximal ice skating completion time (Janot et al., 2015). Henriksson et al. (2016) reported that in competitive-level female players, single-leg standing long jump distance explained 57.1% of the variance during transition acceleration ice skating, 38.1% during agility cornering s-turns, and
29.1% of the variance during modified repeated ice skate sprinting. It appears that unilateral lower body power may be vital during ice skating requiring a rapid change of direction and acceleration. Incorporating physiological measures, Gilenstam et al. (2011) reported that maximal ice skating completion time was negatively correlated with percent lean body mass ($r = -0.773$), onset of blood lactate ($r = -0.817$), respiratory exchange ratio ($r = -0.890$), and maximal aerobic capacity (VO$_{2}$peak; $r = -0.792$) in competitive level female ice hockey players. In a recent study on Division I female ice hockey players, repeated ice skate sprint completion time was significantly associated with relative hex bar deadlift ($r = -0.48; p = 0.04$), maximal bench press ($r = -0.50; p = 0.02$), Keiser squat ($r = -0.52; p = 0.02$), and Wingate average power ($r = -0.47; p = 0.04$) (Boland, Miele, & Delude, 2017). A study by Skowronek et al. (2013) also reported a significant association between Wingate peak power per kilogram and 5x54 meter shuttle ice skating test time in senior ice hockey players ($r = -0.44; p < 0.05$), although authors did not state the sex of the participants.

It appears that measures of muscular power, including maximal overground sprint speed and acceleration, present strong associations and predictive ability for maximal ice skating speed and acceleration in ice hockey players across sex and competitive levels. This is further supported by literature indicating that across 853 competitive ice hockey players, muscular power measured by jump tests (standing long jump and vertical jump) were the tests that displayed the strongest associations with ice hockey skating completion time (Burr et al., 2008). Therefore, it seems that improved maximal overground sprint speed/acceleration may translate to better maximal ice skating speed/acceleration.
Figure 2.0.5. Associations between Off-Ice Measures of Athletic Performance and On-Ice Maximal Ice Skating Speed/Acceleration. Overground sprint speed and lower muscular power appear to be very likely to be associated with on-ice skating speed and acceleration. (reproduced from Virgile, 2019).

**RESISTED SPRINTING**

In recent years, resisted sprint training has become a widely utilized method to increase the speed, acceleration, and muscular power of athletes in sports such as soccer, football, and rugby, and noticeable improvements may occur after only six weeks (Petrakos et al., 2016). The intent of resisted sprint training is to provide the athlete with an overload stimulus to cause positive adaptations in sprint performance, ultimately translating to better sports performance.

Literature supports the importance of generating horizontal ground reaction forces during sprinting (Rabita et al., 2015). In fact, studies suggest that the application of force in a more horizontal direction is a leading indicator for improved sprint performance (Morin et al., 2012; Morin et al., 2015; Petrakos et al., 2016). There exist multiple modalities to provide resistance, including sleds, weight vests, parachutes, and inclines. Each modality presents some advantages.
and drawbacks, yet the most widely used modality is the sled (either sled tow or sled push) (Leyva et al., 2017). Given the nature of the device, sled towing requires athletes to generate forces in a more horizontal direction. The increase in force generation is modulated by the load placed on the sled, with higher loads corresponding to increases in athlete-generated horizontal and vertical forces (Kawamori et al., 2013). The sled is loaded with a predetermined weight, and the athlete either pushes or pulls the sled over a specific distance. Intuitively, improved sprint speeds and acceleration would enable an athlete to outperform his/her competitor, for example, arriving at the ball faster than an opposing player during a soccer chase.
RESISTED SPRINT TRAINING (SLED) TO INCREASE SPEED, ACCELERATION, AND POWER

Prior literature demonstrated that resisted sprint training is effective in increasing sprinting speed and acceleration in athletes of different running-based sports (Alcaraz et al., 2018). For example, Harrison and Bourke (2009) reported that professional rugby players increased their sprint acceleration completion time (Cohen’s d = 1.21; large; p < 0.01) after only six weeks of resisted sprint training twice a week using a weighted sled at 13% of bodyweight. Another study on male rugby players reported an increase in vertical jump height (2.00 ± 0.20 cm) and drop jump height (20.10 ± 0.50 cm) after eight weeks of resisted sprint training (p < 0.001) (Spinks et al., 2007). In male rugby players, a 6-week resisted sprint training program performed twice a week was superior at decreasing 10-meter (Cohen’s d = 2.0; very large; p < 0.001) and 30-meter (Cohen’s d = 1.66; large; p < 0.001) sprint completion times compared to a traditional non-resisted sprint training program (West et al., 2013). In male high school athletes (rugby and lacrosse), an 8-week resisted sprint program (2 days/week) was successful at
increasing 5-20 meter split times (Cohen’s d = 0.34-1.16; small-moderate; p < 0.05) across all prescribed training loads corresponding to 20, 50, and 75% velocity decrement (Cahill et al., 2020). Authors reported that the greatest improvements across all loads were during the first 5 meters (distance within the acceleration phase) (Cohen’s d = 0.67-0.84; moderate; p < 0.05), with diminished improvements after 5 meters (Cohen’s d = 0.08-0.57; trivial-small) and the heaviest load group exhibiting the greatest enhancements compared to baseline. Moreover, the unresisted sprint training group did not perform better than any of the resisted training groups. This finding is supported by additional literature indicating that resisted sprinting is superior to traditional sprint training at increasing muscular power, sprint speed and acceleration (Luteberget et al., 2015).

Table 2.1. (#2) Improvements in Athletic Measures after Participation in a Resisted Sprint Training Program in Soccer Players.

<table>
<thead>
<tr>
<th>Study</th>
<th>Improvement in 10m completion time</th>
<th>Improvement in 20m completion time</th>
<th>Improvement in 30m completion time</th>
<th>Vertical Jump Height</th>
<th>Broad Jump Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Gil et al., 2018)</td>
<td>5.4% (Cohen’s d = 1.3; large)</td>
<td>2.7% (Cohen’s d = 0.60; moderate)</td>
<td>2.7% (Cohen’s d = 0.60; moderate)</td>
<td>15.5% increase (Cohen’s d = 1.8; large)</td>
<td>12.7% increase (Cohen’s d = 1.3; large)</td>
</tr>
<tr>
<td>(Loturco et al., 2017)</td>
<td>0.10 second decrease (Cohen’s d = 1.64; large)</td>
<td>0.80 second decrease (Cohen’s d = 0.81; moderate)</td>
<td>0.10 second decrease (Cohen’s d = 0.46; small)</td>
<td>0.80 cm increase (Cohen’s d = 0.39; small)</td>
<td>0.90 cm increase (Cohen’s d = 40; small)</td>
</tr>
<tr>
<td>Myer et al. (2007)</td>
<td>0.70 second decrease (Cohen’s d = 0.68; moderate)</td>
<td>Not Reported</td>
<td>Not Reported</td>
<td>0.9.93 cm increase (Cohen’s d = 0.44; small)</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Cross et al. (2018)</td>
<td>2.1% (Cohen’s d = 0.24; small)</td>
<td>1.96% (Cohen’s d = 0.22; small)</td>
<td>2.99% (Cohen’s d = 0.25; small)</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>
In a non-competitive population, a 6-week resisted sprint training program consisting of three sessions per week of around 45-60 minutes, young, active adults displayed a significant increase in speed (4.5%; Cohen’s $d = 1.23$; large; $p = 0.009$) (Prieske et al., 2018). In male sports science students, a 7-week program using 5-20% bodyweight resistance, significantly improved 0-40-meter completion time by 0.1-0.3 seconds ($p < 0.05$). Moreover, authors reported that the group prescribed the resistance of 20% bodyweight displayed better improvements in 0-20 and 0-30 meter completion times compared to the 5 and 12.5% bodyweight resistance groups (Bachero-Mena & Badillo, 2014). Both the 20 and 12.5% bodyweight resistance groups improved their countermovement jump and squat jump compared to baseline values. Kawamori et al. (2013) reported that 8-weeks of resisted sprint training significantly improved 5 and 10-meter sprint times in physically active males. Specifically, a group prescribed a sled load corresponding to a 30% reduction in sprint speed displayed improvements in 5-meter (5.7%; $p < 0.05$) and 10-meter (5.0%; $p < 0.05$) acceleration phase sprint times compared to baseline.

**DETERMINING RESISTANCE LOAD**

Debate exists concerning the determination of optimal loading for sled towing (Alcaraz et al., 2018; Petrakos et al., 2016). Improper loading can lead to a lack of enhancement of key biomechanical characteristics of sprint performance. Early resisted sprint literature primarily utilized a prescribed percentage of bodyweight to equate load (Harrison & Bourke, 2009; Lockie et al., 2003; Spinks et al., 2007). Typically these loads have ranged between 5-30% of body weight (Petrakos et al., 2016). However, loads of up to 80% of bodyweight have been utilized (Morin et al., 2017). A limitation with prescribing a load based on bodyweight is that the load may not represent the same stimulus to athletes with differing muscular strength and power capacities. Other authors have suggested and adopted a prescribed percentage of velocity
decrease from an unresisted maximal sprint in order to individualize the load (Alcaraz et al., 2018; Alcaraz, Palao, & Elvira, 2009; Cahill, Oliver, et al., 2019; Cahill et al., 2020; Gil et al., 2018; Hrysomallis, 2011). However, despite these efforts, disagreement exists between the appropriate % BW or %Vdec to prescribe. It may depend on the sprint phase targeted by the intervention.

Heavy sled towing (>20% BW or 30%Vdec) appears most effective at increasing the acceleration phase of sprinting (Alcaraz et al., 2018; Morin et al., 2017; Petrakos et al., 2016). Lower loads are purported to increase capacity during the maximum velocity phase of sprinting (Alcaraz et al., 2018). Consequently, athletes desiring to target the acceleration phase, which is of greater importance compared to maximal velocity in the majority of team-based sports, may benefit more from a heavier load.

Recent literature proposes a manner to determine optimal loading for sled towing to enhance power (Cross, Brughelli, Samozino, Brown, & Morin, 2017). In brief, participants complete a maximal sprint trial under specific loads and predetermined distances: unresisted = 30 meters; 25% BW = 30 meters; 50% BW = 20 meters; 75% BW = 20 meters; 100% BW = 15 meters. The force-velocity and power-velocity relationships are obtained according to prior literature (Romero-Franco et al., 2017; Samozino et al., 2016) and outlined in detail in Chapter 3 (Methods; Sprint Profile subsection). Maximum power can then be determined by the optimal combination of force and velocity. The average velocity attained and maintained for 2 seconds is then taken for each resistance sprinted against (0, 25, 50, 75, 100% BW). The data are then fit with a least-square regression to generate an individualized load-velocity profile. Subsequently, the velocity that maximum power occurred is substituted into the regression equation to generate the needed load (Figure 2.8). Moreover, this method has been used to prescribe loads during
resisted sled sprint in recent literature (Cross et al., 2018; Lahti et al., 2019; Pantoja, Carvalho, Ribas, & Peyré-Tartaruga, 2018).

2.0.7. Force-Velocity and Power-Velocity Relationships During Sprinting ($P_{\text{max}}$ = maximum power; $F_0$ = theoretical maximum force; $V_0$ = theoretical maximum velocity; $S_{FV}$ = force-velocity relationship). (reproduced from Cross et al., 2018).

Figure 2.0.8. Load-Velocity Relationship. Optimal load ($L_{\text{opt}}$) is determined by inserting the velocity at maximum power ($V_{\text{opt}}$) into the regression equation. Values displayed in Figure 2.8. are for a 1.73 meter, 95 kilogram rugby player. (reproduced from Cross et al., 2018).
EFFECTS OF RESISTED SPRINTING ON SPRINTING MECHANICS

Proper sprinting mechanics are key to achieving the highest possible sprint acceleration and speeds (Gonzales, 2018). Literature has explored both the acute and longitudinal impact of resisted sled sprinting on sprint mechanics. Acutely, resisted sled towing negatively altered sprint time, stride length, contact time, flight time, and stride frequency with no apparent benefit in subsequent unresisted sprinting (Alcaraz et al., 2009; Cottle, Carlson, & Lawrence, 2014; Lockie et al., 2003; Murray et al., 2005; Pantoja et al., 2018). For instance, with increased load, there was a 10-24% decrease in stride length, 10-22% increase in contact time, and a 16-21% decrease in flight time (Cottle et al., 2014; Lockie et al., 2003; Murray et al., 2005). Given these alterations in important spatiotemporal parameters of successful sprint performance, certain researchers and practitioners contend that resisted sled sprinting may be deleterious to sprint performance (Petrakos et al., 2016).

However, long-term detriments to important characteristics of sprinting biomechanics after participation in a sled towing program are not supported. In fact, quite the opposite is true. Positive adaptations occur in stride length and stride frequency, the product of which would sprint performance (Petrakos et al., 2016). For example, Prieske et al. (2018) reported a 0.07 meter increase in step length, one of the main contributors of sprint performance, after participation in a 6-week resisted sprint training program in young, active adults. Adult subjects performed three training sessions per week, with a total of 18 training sessions of 45-60 minutes. Subjects performed three to four repetitions of resisted sprinting lasting around 10 seconds with two minutes rest between sprints. An 8-week resisted sprint study in physically active men also reported 0.08-meter increase in step length (5.1%; p < 0.05), resulting in improved 5- and 10-meter sprint times and an accompanying 8.1% (p < 0.05) increase in step frequency (Kawamori
et al., 2013). After participation in a 4-week (3 days/week) resisted sprint program, female college students significantly increased their stride length (5.9%; p < 0.05) and increased their mean running velocity (2.5%; p < 0.05) (Makaruk, Sozański, Makaruk, & Sacewicz, 2013). Another biomechanical adaption is the reduction in contact time, leading to faster sprint times and greater distances covered during a given sprint duration (Alcaraz et al., 2018). The literature suggests positive adaptations in contact time from resisted sled sprinting by teaching athletes to apply forces in a more horizontal direction and consequently improving the ratio of horizontal to resultant force over the entire duration of the sprint (Hicks et al., 2019). Spinks et al. (2007) reported a 0.02-second reduction in contact time during maximal sprinting after an 8-week resisted sprint training program, resulting in 0.60 m/s velocity increase during maximal sprinting in Australian football players. The study required the football players to tow a sled loaded with a given percentage of their body weight twice a week. Similarly, Preiske et al. (2018) reported a 6.3% reduction in contact time (Cohen’s d = 1.45; large; p < 0.05) after participation in a resisted sprint training program. Certainly, multiple studies employing resisted sled sprinting noted increases in trunk angle compared to baseline, with literature suggesting an increased trunk angle may also aid in horizontal force application (Spinks et al., 2007; West et al., 2013). Another possible mechanism proposed is the increase in force application despite a reduction in contact time.

**CURRENT ICE HOCKEY TRAINING PROGRAMS**

The ability to generate power from the lower body musculature enables ice hockey players to achieve rapid acceleration and high maximal skating speeds (Behm et al., 2005; Farlinger et al., 2007). Additionally, the movement patterns undertaken by players during ice skating can greatly hinder or enhance their ability to achieve rapid acceleration and high speeds.
(Budarick et al., 2018). Therefore, ice hockey strength and conditioning coaches structure training programs that are tailored to improve ice skating mechanics, acceleration, and speed.

In ice hockey, strength and conditioning programs are most commonly executed overground (off-ice); rarely are implements used on-ice for strength and conditioning. These programs, therefore, may limit the direct sports-specific adaptations that occur. A study that surveyed strength and conditioning practices across the National Hockey League (NHL) reported that 100% of coaches used Olympic-style lifts (clean, jerk, snatch) and plyometric exercises with their ice hockey players. Additionally, strength and conditioning coaches reported that Olympic-style lifts and squats were the most implemented exercises in program design for their ice hockey players (Ebben et al., 2004). Coaches may adopt these compound movements in an effort to develop the muscular power needed for rapid ice skating acceleration during game situations.

Prior literature suggests that increased muscular power resulting from participation in Olympic-style lifts will translate to increased ice skating speed and acceleration (Nightingale, 2014). This has led to research exploring off-ice training interventions. For example, after participation in an 8-week plyometric and strength training intervention, ice hockey players decreased 10-meter ice skating completion time (-2.6 ± 3.1%; p = 0.02) (Dæhlin et al., 2017). Another study that explored the impact of a 4-week high-intensity interval training program reported decreased repeated ice skate test completion compared to baseline (-1.1 ± 2.8%; p = 0.08) (Naimo et al., 2015). Recently, Rønnestad et al. (2019) compared block and traditional periodization models for the development of muscular capacity in ice hockey players. After the 6-week intervention focusing on muscular strength-endurance, the authors observed that peak torque in knee extension at 60°/second increased more in block periodized group compared to the traditional group (2.1% vs −0.1%; Cohen’s d = 0.83; moderate; p = 0.08). Similarly, block periodization
had a larger increase in knee extension peak torque at 180°/second than the traditional group (6.6% vs −4.2%; Cohen’s d = 1.18; moderate; p = 0.01). Moreover, mean power output during the 30-seconds sprint displayed a larger improvement in the block periodized compared to the traditional group (4.1% vs −0.3%; Cohen’s d = 0.89; moderate; p = 0.06).

In youth ice hockey players, an 8-week (2-3 session/week) isokinetic resistance training combined with eccentric overload training was superior at increasing lower body muscle hypertrophy (14.8%; p = 0.03) and drop jump performance (9.8%; p = 0.01) compared to a traditional resistance training program (Horwath, Paulsen, Esping, Seynnes, & Olsson, 2019). Lastly, Schuhbeck et al. (2019) reported that a 12-week whole-body electrostimulation was successful at increasing vertical jumping height (5.15%; p < 0.05), decreasing 10-meter ice skating completion time (5.00%; p < 0.05), and increasing maximal isokinetic force at 300°/s (7%; p < 0.05) in male amateur ice hockey players.

Interestingly, in an NHL strength and conditioning coach survey, none reported implementing any on-ice speed/acceleration/sprint training with their athletes despite its recommendation by practitioner research (Manners, 2004). Prior literature indicates the importance of ice hockey players to be able to achieve high acceleration and sustain high levels of ice skating speed. Players may need to maximally ice skate in repeated, short bursts of effort (10 seconds) to contribute offensively or defensively (Twist, 2007). Therefore, Manners (2004) and Twist (2007) suggest that power and speed/acceleration training be incorporated as regular ice hockey strength and conditioning components to increase maximal on-ice skating speed and acceleration. Surprisingly, the literature only provides one study mentioning the implementation of any on-ice specific strength and conditioning training for speed and power development in ice hockey (Pollitt, 2003).
Moreover, the impact of on-ice training on ice skating speed and acceleration has seldom been studied in the ice hockey training literature. For instance, Matthews et al. (2010) explored the acute effect of on-ice resisted sprints on subsequent maximal ice skating speed. Authors reported a 2.6% decrease in 25-meter maximal skating completion time compared to baseline completion time. The control condition, consisting of an unrested maximal sprint, did not display any significant difference compared to baseline completion time. Hence, authors suggested that an acute bout of on-ice resisted sprinting may increase ice skating speed. Youth ice hockey players who participated in a 4-week on-ice training intervention displayed decreases in 44.8-meter ice skating completion time (4.3%; \( p = 0.038 \)) and top speed phase completion time (4.2%; \( p = 0.022 \)) (Janot et al., 2012). Resistance was provided by the Bungee training system with the program consisting of 2 sessions/week. The Bungee system consisted of an anchor strap secured to the sideboard to which 10-foot bungee cords were attached with strap attached to the waist of the player. Players performed five repetitions of five 30-meter ice skating drills with a 3:1 rest-to-work ratio. However, in Matthews et al. (2010) and Janot et al. (2012), the use of elastic bands/cords were implemented to provide the resistance, making it challenging to determine the specific load experienced by players. Consequently, the resistance experienced by subjects was not constant and was dependent on the effort of the subject, the elastic cord tension, and the effort of the assistant holding the elastic cord (Cronin & Hansen, 2006; Janot et al., 2012; Myer, Ford, Brent, Divine, & Hewett, 2007). Therefore, implementation of a known resistance that can be individualized to each subject remains to be investigated. Moreover, recent systematic reviews and meta-analyses of resisted sprint interventions argue that a minimum intervention of six weeks should be implemented to observe meaningful changes in sprint speed and acceleration (Alcaraz et al., 2018; Petrakos et al., 2016). This is an apparent limitation of the
sole on-ice intervention study by Janot et al. (2012) which incorporated a four week intervention and unquantifiable resistance. Evidently, given the lack of quantifiable resistance and short duration of prior ice hockey resisted sprint interventions, additional literature exploring the longitudinal effects of on-ice strength and conditioning on ice skating speed and acceleration is needed.
CHAPTER 3: METHODS

EXPERIMENTAL DESIGN

Subjects recruited from a local high school ice hockey team (Cutthroats) were randomly assigned (using a random online generating tool Link) to eight weeks of either on-ice or overground resisted sprint training or a control group. All subjects underwent a familiarization session where they practiced and performed all testing and training procedures. Moreover, the individualized sled load for the intervention was determined as outlined in a subsection below (see Training Program). During the subsequent session, subjects completed pre-testing (baseline) measures. Subjects completed the testing spread across three non-consecutive days. During the on-ice and overground acceleration sprints, split times, kinematics, and muscle activation data were collected. On the first day of pre-testing, anthropometrics and isometric mid-thigh pull scores were obtained. On day two, vertical and broad jump tests as well as overground sprints were performed. Lastly, on-ice sprint tests and on-ice cornering S-turns tests were conducted on day three (Figure 3.1). On testing days one and two, subjects were given a 5-minute warm-up of jogging at a self-selected pace before completing the overground testing in a randomized order. On testing day three, players were provided a 5-minute warm-up consisting of skating at a self-determined intensity. Following pre-testing, the randomized subject groups participated in two resisted sprint training sessions per week on non-consecutive days for 20-30 minutes following recommendations from prior literature (Alcaraz et al., 2018; Petrakos et al., 2016). After the 8-week intervention, post-testing took place following the same 3-day design as outlined for pre-testing.
SUBJECTS

Subjects were recruited from a local high school ice hockey club, the Cutthroats. The team consists of players ages 14-18 years old and therefore this study focused on this population. The teams’ roster consists of 30 players, and it was anticipated that all of the players would participate in the study. The study was approved by the Brigham Young University - Idaho Institutional Review Board prior to the commencement of data collection, parents gave consent, subjects gave assent, and appropriate forms were collected by the research team.

Using the G*Power software (version 3.1, Universität Kiel, Germany) a mixed factorial repeated measures ANOVA *a priori* power analysis was conducted using 35-meter ice skating completion time data from Farlinger and colleague (Farlinger & Fowles, 2008) (Cohen’s $f = 0.34$) and an alpha of 0.05, indicating with a sample of 30 players (10 per group) a statistical power of 0.893 was reached. With a total of 24 players (8 per group) this was reduced to 0.798.

MEASUREMENTS OF INTEREST

ANTHROPOMETRICS

The subjects’ body mass and height were measured with subjects removing their shoes and standing with back straight and head in a neutral position. Height was measured to the nearest centimeter and mass to the nearest hundredth of a kilogram. Leg length was assessed with a metric tape measure (Gulick, M-22 CII, Michigan, USA) and recorded in centimeters. For leg length, participants were asked to stand erect with their feet flat on the floor. Length was
measured as the distance from the anterior superior iliac spine and the medial malleolus of the tibia to the nearest cm (Beattie, Isaacson, Riddle, & Rothstein, 1990; Gurney, 2002). The tape measure was placed on both landmarks ensuring the tape measure ran along the body smoothly.

**ISOMETRIC MID-THIGH PULL**

The mid-thigh position during the isometric mid-thigh pull (IMTP) for each subject was determined at a 130° knee angle and 145° hip angle, and was checked using a goniometer prior to the execution of the test (Beckham et al., 2018; Brady, Harrison, & Comyns, 2018; Dos'Santos, Jones, Comfort, & Thomas, 2017). Once subjects adopted the proper lower body joint positions, the bar height was adjusted to correspond to the height necessary for the players to grasp the bar with a closed pronated grip with arms fully extended. All trials were performed with an immovable bar set at the determined mid-thigh height (Thomas, Comfort, Jones, & Dos'Santos, 2017). Then subjects maximally pulled upwards for three seconds while on the force platforms (1,000 Hz; PASPORT force platform, PS-2142, PASCO Scientific, Roseville, CA, USA), and data was summed between the two force platforms for analysis similar to previous research (Townsend et al., 2017). Recent literature validated the use of the proposed force platforms for data collection during isometric mid-thigh pulls (Keogh, Collins, Warrington, & Comyns, 2020). Specifically, the instruction was given to “pull as hard and fast as possible” (Brady et al., 2018). To determine the start time of the test, a one second quiet time (motionless) was used prior to the initiation of the movement as a baseline, from which a mean and standard deviation were calculated. Then, a threshold of mean plus five standard deviations denoted the commencement of the test (Dos'Santos et al., 2017). The data were filtered using a fourth-order low-pass Butterworth filter with cutoff frequency set at 10 Hz in an effort to remove noise from the acquired signal (Beckham et al., 2018; Suchomel, Nimphius, & Stone, 2020). The variables
of interest were peak force and rate of force development (RFD). Peak force was the maximal vertical force achieved during the three-second trial. During isometric mid-thigh pull, RFD was obtained using the time-interval and maximal RFD methods (Comfort, Allen, & Graham-Smith, 2011; Haff, Ruben, Lider, Twine, & Cormie, 2015). For example, the time-interval method calculated the [change in force/change in time] for a predetermined set of time intervals. Time intervals calculated were: 0-50, 0-100, 0-200, and 0-300 milliseconds (Townsend et al., 2017). Peak RFD was determined as the highest RFD over a 20-millisecond sampling window, which displayed the highest reliability as suggested by Haff et al. (2015). The data were imported into MATLAB and a custom script was used to obtain the variables of interest. Previous research indicated the association between RFD during isometric mid-thigh pull and power during CMJs and sprint speed/acceleration (Brady, Harrison, Flanagan, Haff, & Comyns, 2019; Khamoui et al., 2009; Slawinski et al., 2010; Wang et al., 2016). Subjects performed three trials with two minutes separating each trial with average used for data analysis.

**VERTICAL AND BROAD JUMPS**

Vertical jumps were performed with subjects standing on the force platforms with one foot on each force platform (1,000 Hz; PASPORT force platform, PS-2142, PASCO Scientific, Roseville, CA, USA) and left and right force platform data were summed for analysis. Recent literature reported the reliability and validity of the proposed force platforms for vertical jump analysis (Lake et al., 2018; Peterson Silveira et al., 2017; Raymond et al., 2018; Sands et al., 2020). The subjects began each trial with a one-second quiet stance (motionless) after which the researcher provided a “go” command to signal the execution of the vertical jump. Subjects completed three trials of the vertical jump with hands placed on iliac crests, similar to prior literature (Cormack, Newton, McGuigan, & Doyle, 2008; Dietze-Hermosa, Montalvo, Cubillos,
The average of the three trials was used for analysis for all measures of interest. Data were imported into MATLAB (MATLAB, MathWorks, Natick, MA, USA) for data processing. Data were filtered using a fourth-order low-pass Butterworth filter and smoothed at a cutoff frequency determined by a Fast Fourier Transform frequency analysis (Harry, Blinch, Barker, Krzyszkowski, & Chowning, 2020). Certain variables of interest were calculated using previously validated custom Microsoft Excel spreadsheet (Link to Spreadsheet) (Chavda et al., 2017). The start of the vertical jump was determined as the moment in time when the vertical force was reduced by more than five standard deviations of the calculated body weight (Chavda et al., 2017; Owen, Watkins, Kilduff, Bevan, & Bennett, 2014). Takeoff was identified as the moment in time when vertical force decreases below 10 N (Chavda et al., 2017; Mundy, Lake, Carden, Smith, & Lauder, 2016). The variables of interest for the vertical jump were estimated jump height, relative peak force, and relative peak power. In order for proper comparison across subjects, normalization techniques for some variables of interest were used. Normalization to body weight was utilized for peak force and peak power similar to recent literature (Gajeskii et al. 2018; Zabaloy et al. 2020; Chavda et al. 2018). Although the force platforms do not directly provide a measure of power, peak power during vertical jumps was obtained through mathematical calculations. Specifically, for power during the vertical countermovement jump was calculated by: 1) obtaining acceleration by dividing vertical ground reaction force by body mass; 2) calculating velocity by trapezoid integration of area under the acceleration curve with the integration beginning at the start of the jump and ending at take-off; 3) calculating power by multiplying the vertical ground reaction force by velocity during the upward phase (when velocity becomes positive until take-off) to obtain power at each time point creating a power curve for the vertical jump trial. Peak power
was the highest point represented by the curve. This method was proposed by previous authors to calculate power during vertical jumps utilizing force platform data (Gheller et al., 2015; Owen et al., 2014). In total, subjects performed three vertical jump trials separated by a two-minute rest. Trials were discarded and repeated if the subject landed outside the force platform area or if submaximal effort was not given. No more than six trials were given to successfully complete the three trials (Harry, Barker, Eggleston, & Dufek, 2018).

For the broad jumps, the distance was the primary variable of interest. Subjects commenced standing with both feet behind a baseline, then subjects executed a forward countermovement jump incorporating an arm swing (Runner et al., 2016). Jumps with hands placed on iliac crests were executed after the researcher provided an audible ‘go’ command. Jump distance was measured to the nearest centimeter using a measuring tape. Jump distance was measured as the distance from the takeoff to the back of the athlete’s heel (Lockie et al., 2014; Peterson et al., 2006). Trials were rejected if the subject took additional steps after landing. Subjects were given three attempts separated by a two-minute rest.

OVERGROUND 36M ACCELERATION SPRINTS

Subjects completed three maximal 36-meter (40-yard) sprints separated by a two-minute rest. Subjects started in an upright standing position at the 0-meter mark, with the remote starter placed at the heel of the subject. Completion time was calculated as the time when the subject moved their heel away from the remote starter until they crossed the timing gates at 36 meters. Timing gates (TC-timer, Brower timing system, Draper, UT, USA) were used to accurately capture completion time during overground sprints, and time to the nearest hundredth of a second was recorded. This test has previously been implemented in various sports, including ice hockey, to assess acceleration phase completion time (Dietze-Hermosa et al., 2021). The
protocol outlined in prior research was followed (Janot et al., 2015). Moreover, to capture split time, timing gates were also placed at the 9.14-meter (10 yards) mark.

**ON-ICE 36M ACCELERATION SPRINTS**

Subjects completed three maximal 36-meter (40-yard) sprints separated by a two-minute rest. Timing gates (TC-timer, Brower timing system, Draper, UT, USA) were used to accurately capture completion time during skating sprints. The trial commenced with subjects standing still at the 0-meter mark, with the remote starter placed at the heel of the subject. Time commenced once subjects moved their heel from the remote starter and continued until they crossed the timing gates placed at 36 meters (Figure 3.2). Time was recorded to the nearest hundredth of a second. A similar protocol has previously been implemented to assess ice skating acceleration phase completion time in ice hockey players (Dæhlin et al., 2017; Peterson et al., 2016; Runner et al., 2016). Once again, an additional set of timing gates was placed at 9.14-meter (10 yards) mark to capture split times. The 36-meter sprint distance was selected since it mimics the distance covered during a bout of offensive or defensive on-ice rush and previously has been implemented in ice hockey research (Behm et al., 2005; Farlinger et al., 2007).

![Figure 3.0.2. Ice Skating Acceleration Phase Test.](image-url)
OVERGROUND 30M TOP SPEED SPRINTS

Subjects completed three maximal top speed sprints separated by a two-minute rest. Subjects started in an upright standing position 40 meters away from the first marker (timing gate). After slowly gathering speed, athletes were at top speed once reaching the first marker and attempted to maintain top speed until the end marker set at a 30-meter distance from the first marker. Time commenced once subjects crossed the first marker (timing gate) and continued until they crossed the opposite timing gate placed 30 meters away. Time was calculated to the nearest hundredth of a second. A similar protocol incorporating a running start has been previously implemented in sports to determine top speed phase completion time (Abdelkader & Elmorsi, 2016; Baron, Bieniec, Swinarew, Gabrys, & Stanula, 2019; Dietze-Hermosa et al., 2021).

ON-ICE 30M TOP SPEED SPRINTS

Subjects completed three maximal top speed sprints separated by a two-minute rest. Timing gates (TC-timer, Brower timing system, Draper, UT, USA) were used to accurately capture completion time during skating sprints. The trial commenced with subjects standing still and the opposite of the ice rink at the red line. Subjects slowly gathered speed and continued around the net area, whereupon they progressed to top speed. Subjects were at top speed once reaching the first marker and attempted to maintain top speed until the end marker set at a 30-meter distance from the first marker. Time commenced once subjects crossed the first marker (timing gate) and continued until they crossed the opposite timing gates placed 30 meters away. Time was recorded to the nearest hundredth of a second. A similar protocol was implemented to assess ice skating top speed phase completion time in ice hockey players (Gilenstam et al., 2011; Janot et al., 2012; Janot et al., 2015; Runner et al., 2016).
ON-ICE AGILITY CORNERING S TRURN TEST

Subjects completed three maximal agility cornering S-Turns separated by a two-minute rest. Timing gates (TC-timer, Brower timing system, Draper, UT, USA) were used to accurately capture completion time. The trial commenced with subjects standing still behind the goal line and net. Subjects maximally ice skated around the two near face-off circles in an S-type fashion (Figure 3.4). Time commenced once subjects moved their heel from the remote starter and continued until they crossed the timing gates placed at the blue line. Time was recorded to the nearest hundredth of a second. If a player cut inside the face off circles or fell, the trial was restarted. Cones were placed around the face-off circles to enforce proper ice skating movement during testing. This protocol has been implemented to assess ice skating agility completion time in ice hockey players (Gilenstam et al., 2011; Henriksson et al., 2016; Janot et al., 2015).
SPRINT/SKATE PROFILE

During both the on-ice and overground acceleration sprints, the subject’s sprint (or skate) profile was obtained. This enabled the creation of the force-velocity and power-velocity curves of athletes during sprinting (Cross, Brughelli, Samozino, Brown, et al., 2017; Cross et al., 2018; Hicks et al., 2019; Pantoja et al., 2018; Samozino et al., 2016). The simple method allowed for the calculation of theoretical maximal force (N·kg⁻¹), velocity (m·s⁻¹), and peak power (W·kg⁻¹). The method makes the following assumptions: 1) the entire body is represented by center of mass displacement; 2) no vertical acceleration occurs during the sprint trial when averaged over the entire acceleration phase; 3) the air drag remains constant (Cross, Brughelli, Samozino, & Morin, 2017; Morin, Samozino, Murata, Cross, & Nagahara, 2019; Samozino et al., 2016). A mono-exponential function is applied to the velocity-time data (Cross et al., 2015; Cross, Brughelli, Samozino, Brown, et al., 2017; Samozino et al., 2016). The laws of dynamics in the horizontal direction are applied so that the net horizontal anterior-posterior ground reaction force
applied to the center of mass of the athlete are modeled over time (Cross, Brughelli, Samozino, & Morin, 2017; Morin et al., 2019; Samozino et al., 2016). Important model input variables are the mass of the athlete, athlete height, and the aerodynamic drag to overcome during sprinting, all of which can be obtained from additional equations (Cross, Brughelli, Samozino, & Morin, 2017; Samozino et al., 2016). The force-velocity relationship and power were then determined for the sprint trial. The values calculated with the methodology represent theoretical values where the estimates of instantaneous force, velocity, and power across the entire sprint or skate can be obtained (Morin et al. 2018; Perez et al. 2019; Samozino et al. 2016). However, the maximal horizontal force, velocity, and power averaged across trials are frequently utilized and reported in the literature (Cahill et al. 2020; Cross et al. 2019; Perez et al. 2020).

Recent research suggested a practical method to obtain the force-velocity and power-velocity curves using a single high-speed camera system (240 fps) and markers placed at specific distances (5, 10, 15, 20, 25, and 30 meters) (Romero-Franco et al., 2017). It was available in an IOS-based application (MySprint) and has been validated against the original methodology proposed by Samozino et al. (2016). Figure 3.5 illustrates a portion of the sprint profile provided by the MySprint application.

Figure 3.0.5. MySprint Application Sprint Profile Output.
Moreover, authors provided a Microsoft Excel spreadsheet used in the present study to calculate measures of interest based on information obtained using the MySprint application (Link to Spreadsheet). The MySprint application has been utilized in recently published literature (Dietze-Hermosa et al.; 2021; Fort-Vanmeerhaeghe et al., 2020; Lasse et al., 2019; Passos-Monteiro et al., 2020) and the methodology proposed by Samozino et al. (2016) was used to reliably obtain sprinting profiles during maximal ice skating in hockey players (Perez, Guilhem, & Brocherie, 2019; Perez, Guilhem, Hager, & Brocherie, 2020). Therefore, the MySprint application and corresponding Microsoft Excel spreadsheet were used to obtain the force-velocity and power profiles of subjects during on-ice and overground sprinting. An iPad Air (Apple Inc., Cupertino, CA, USA, 240 fps) was used for data collection. The iPad was placed on a fixed tripod at a height of 1.5 meters and a perpendicular distance of 10 meters from the 15-meter mark as outlined in the application and corresponding literature (Romero-Franco et al., 2017)(Figure 3.6).

Figure 3.0.6. Motion Capture/Video Camera Set Up (Kinovea & MySprint).
SPRINTING KINEMATICS

The study by Damsted et al. (2015) and Wild et al. (2018) adopted a similar approach to obtain kinematics during both on-ice and overground acceleration sprints. A single high-speed camera with a capturing frequency of 240 Hz was placed on a stationary stand with the optical axis perpendicular to the movement plane (sagittal) of the lower limbs during sprinting. A video camera placed perpendicular to the movement axis capturing a portion of the sprint enabled accurate identification of joint angular kinematic parameters as well as spatiotemporal parameters of interest such as step length, step frequency, flight time, and contact time. According to prior literature, a high-speed camera placed at a height of 1-1.5 meter and at a perpendicular distance of 10-20 meters allowed for the capture of up to a 10-meter field of view (Miyashiro et al., 2019; Wild et al., 2018). An illustration of the setup for motion capture that also coincided with the setup for the MySprint application is provided in Figure 3.6. The camera (iPad Air) for motion capture was the same utilized to capture the sprint profile as described in an earlier section. The captured video file was imported into the Kinovea software (v.0.9.5) for kinematic analysis. The Kinovea software is an open-access software that allows for video analysis of sports performance. The Kinovea software has a few limitations that can impact the estimated results obtained such as the angle and distance between the camera and the object. Researchers suggest a perpendicular camera angle (90°) and a distance below 10 meters for best results (Puig-Diví et al., 2019). Moreover, the camera capturing rate and screen resolution of the processing computer can impact the results (Puig-Diví et al., 2019). Despite these limitations, the Kinovea software offered a cost effective and practical manner to determine kinematics given the constraints of the present study. Moreover, literature supported the software’s validity and reliability in sports performance settings (Adnan et al., 2018; Balsalobre-Fernández, Tejero-
Recently, sprint and resisted sprint literature has utilized the Kinovea software to obtain relevant kinematic parameters (Lahti et al., 2019; Miyashiro et al., 2019; Pantoja et al., 2018; Wild et al., 2018; Zabaloy et al., 2020). To calculate kinematic parameters such as joint angles during a given movement phase, markers were placed on the greater trochanter, lateral femoral condyle and the lateral malleolus on the tibia by the “line” and “cross marker” functions. Then, utilizing the “angle” function, a goniometer was placed on the knee centered on the marker denoting the lateral femoral condyle and the spikes (arrows) were fitted through the greater trochanter and lateral malleolus, denoting knee flexion angle. A vertical line running from the ground through the greater trochanter denoted a plumb line. A second goniometer centered on the greater trochanter was placed from the ear to the plumb line, denoting the trunk flexion angle. Another goniometer was placed centered on the greater trochanter, with one spike fitted through the lateral femoral condyle and one aligned with the torso of the subject; denoting hip flexion angle. Lastly, to denote hip extension, a line was fitted from the ear through the greater trochanter to the ground (indicating 0). Another line was then fitted from the lateral femoral condyle and centered on the greater trochanter to indicate extension angle (Figure 3.7). Markers placed on the individual aided in the calculation of corresponding joint angles. It is acknowledged that the joint marker placement constituted an approximation of the joint center given the bony landmarks and may have resulted in slight inaccuracies of joint angles calculated. Yet, recent research indicated that the digitized coordinates and angles were comparable with those obtained using a gold standard motion capture system (Puig-Diví et al., 2019). Joint angles were calculated during toe-off and touchdown of the right limb corresponding to a step within the 10–20-meter range during on-ice and overground acceleration sprints.
To ascertain the spatiotemporal variables of interest (flight time, contact time, step length, step frequency), the touchdown (first frame the foot is visibly in contact with the ground) and toe-off (first frame the foot has visibly left the ground) were identified. The first two steps in the 10-20 meter distance using the 6x zoom in Kinovea were selected similar to recent sprint literature (Lahti et al., 2019; Wild et al., 2018). Each video was analyzed twice by the same observer and the same leg sequence was analyzed for pre and post testing. The video footage was calibrated using a pike (1.2 m) located vertically at the 15-meter mark in the center of the camera field of view. Data were synchronized with surface electromyography data during the 10–20-meter distance and exported to a Microsoft Excel spreadsheet for additional processing. The digitized coordinates were used to obtain contact time (s), flight time (s), step length (m; the
horizontal displacement between subsequent touchdowns), step frequency (Hz; the reciprocal of step duration, determined as the sum of step contact time and subsequent flight time) (Lahti et al., 2019; Wild et al., 2018; Zabaloy et al., 2020).

Kinematics during ice skating were obtained using the same methodology as during overground sprinting. However, calculation of flight time was modified as there exists no “true” flight phase during ice skating given that, after the first few steps, one skate blade remains in contact with the ice at all times (Budarick et al., 2018). Therefore, flight time was calculated as the time from toe-off to the subsequent touchdown of the same limb, representing a stride rather than a step (Robbins et al., 2018; Shell et al., 2017).

**ELECTROMYOGRAPHY**

Muscle activation, as measured by surface electromyography (sEMG) was measured during both the on-ice and overground acceleration sprints at baseline and post intervention. The sEMG and motion capture data obtained during the sprint trial were synchronized and represented as sprint cycles (touchdown of one foot to the subsequent touchdown of the same foot), similar to prior sprint literature (Buckeridge, Tscharner, et al., 2015; Chumanov et al., 2007; Higashihara et al., 2015, 2018; Howard et al., 2017). An Ag/AgCl dual electrode with a fixed 20 mm inter-electrode distance were placed on the right vastus lateralis and right biceps femoris muscles as outlined by prior literature (Hermens et al., 1999; Rainoldi, 2013). In brief, the electrode for the vastus lateralis was placed at 66% of the distance between the anterior superior iliac spine and the lateral border of the patella, oriented at 20° to approximate the pennation angle of the muscle fibers. The electrode placement for the biceps femoris was 20% of the distance between the ischial tuberosity and the lateral side of the popliteal cavity. All electrode placements were marked with a permanent marker to ensure exact placement during post-intervention data.
collection. Skin was prepared by shaving the area, then abraded and cleaned according to SENIAM guidelines (Hermens et al., 1999). Electrodes, already containing adhesive, and sensors were secured using elastic fixation bandages. The data were captured and sampled at 2000 Hz, pre-amplified at the source at a gain of 500 Hz, converted by 24-bit analog-to-digital converter, and transmitted telemetrically to a PC interface receiver (Ultium, Noraxon, Scottsdale, AZ, USA) and were recorded by a data acquisition system (MyoResearch, version 3.18, Noraxon, Scottsdale, AZ, USA). Raw sEMG data were then full wave rectified and filtered using a bandpass at 10-500 Hz. Data were expressed as Root Mean Square for both the vastus lateralis and biceps femoris for maximal on-ice and overground acceleration sprinting trials. The sEMG amplitude (RMS; 100 ms) were expressed as a percentage of maximal voluntary contraction (MVC) to facilitate comparisons following prior sprint literature recommendations (Howard et al., 2017; Schuermans, Danneels, Van Tiggelen, Palmans, & Witvrouw, 2017). To obtain MVC, three trials per muscle were conducted. For the biceps femoris, the subject was in a prone, neutral position on the examination table, then maximally resisted torque toward knee flexion from a 30-degree knee flexion position (lower leg and foot supported by the upper leg of tester). For the vastus lateralis, subjects were seated and maximally performed knee extension from a 90-degree knee flexed position. For both MVC procedures, subjects were asked to gradually raise the amount of muscle force, reaching maximum in approximately three seconds. Maximum force output was maintained for five seconds, after which the subject gradually lowered the muscle force while returning to the neutral starting position until full relaxation was reached. The MVC procedures were implemented in prior literature (Konrad, 2005; Schuermans et al., 2017). The analyzed sEMG data corresponded to the 10-meter distance coinciding to the 10–20-meter range of on-ice and overground sprint trials. Each muscle’s peak EMG activity (% of MVC)
during the whole ground contact phase from touchdown to take-off of the first complete cycle corresponding to the 10–20-meter range was utilized for analysis.

SYNCHRONIZATION OF MOTION CAPTURE AND SURFACE ELECTROMYOGRAPHY

To synchronize both sEMG and kinematic data obtained via motion capture, the video file was imported into the MyoResearch software. Then, using the “synchronize time” function in the software, both the motion capture and sEMG data were synchronized. This approach is suggested and advertised by the manufacturer (video link). The motion capture and sEMG data during sprinting were double checked through slow-motion video, to ensure that second contact from touchdown to toe-off coincides with the peak sEMG amplitude of biceps femoris during the early stance phase (Zabaloy et al., 2020). As stated in earlier subsections, the first steps within the 10–20-meter range during on-ice and overground acceleration sprints were analyzed; this distance was selected given it is that over which maximal acceleration is achieved (Budarick et al., 2018; Favero, Drust, & Dawson, 2015; Schuermans et al., 2017; Shell et al., 2017). The distances for analysis (10-20 meters) were easily identifiable given the makers placed along the floor/ice rink (Figure 3.6).

TRAINING PROGRAM

Subjects were randomly assigned to an on-ice intervention, and overground training intervention or to a control group. The on-ice intervention was completed in a standard dimension ice hockey rink on freshly Zambonied ice. Both overground groups completed the training interventions in a local school gym with finished hardwood flooring. The overground resisted sprint training group participated in two weekly sessions of 6-9 maximal sprints pulling a sled over a 20-meter distance, with subjects given three minutes of rest between each resisted
sprint. The on-ice resisted sprint training group also participated in two weekly sessions of 6-9 maximal skating sprints over the same distance (20 meters). Both resisted sprint groups completed the 20-meter distance in approximately 4 seconds. The sled was used for the resisted sprint interventions as suggested by ice hockey strength and conditioning practitioners and prior literature (Cronin & Hansen, 2006; Petrakos et al., 2016; Pollitt, 2003) (Figure 3.8). The overground sprint intervention incorporated both straight-line and lateral direction resisted sprint training in an effort to increase comparability between interventions. During each session, two out of the total prescribed resisted sprints were lateral-direction resisted sprints. The subject grabbed or was harnessed to the sled via a non-elastic nylon tether attached to the sled by high-tensile karabiners. The sled was loaded, accounting for the unloaded sled weight, with calibrated weight plates to achieve the corresponding load needed for the athlete. The control group engaged in the prescribed training program of the Cutthroats coaching staff, since the omission of any training would likely result in decreased sports performance (Table 3.1). The training program will resembled those suggested by prior ice hockey strength conditioning practitioners (Neeld, 2018; Nightingale, 2014). The training program duration of the control group was equal to the experimental groups. In order to estimate engagement in additional physical activity during the study, all subjects completed the “Exercise is Medicine” questionnaire (Appendix A) at the conclusion of the 8-week study similar to prior research (Sallis, 2015; Valasek, Bieganski, Desrochers, & Young, 2018).
The load for the resisted sprint was determined through the load-velocity testing as outlined in prior literature (Cross, Brughelli, Samozino, Brown, et al., 2017; Cross et al., 2018; Lahti et al., 2019). The subject completed one unloaded and three loaded tests (50% bodyweight, 75% bodyweight, and 100% bodyweight) with one sprint per loading condition. The load-velocity data, captured via the MySprint application, were exported to a custom Microsoft Excel spreadsheet and fitted with a least-square linear regression to generate an individualized load-velocity profile for each athlete. Using the MySprint application data, the velocity at which maximal power occurred was identified. Then, a load corresponding to that velocity (identified using the load-velocity profile) and thus the maximal power output for each athlete was prescribed for the intervention (Cross, Brughelli, Samozino, Brown, et al., 2017) (Link to...
Power was computed as the product of force and velocity (P = F*V), and derived from MySprint application collected force and velocity data, then the relationship between power and velocity was fitted with quadratic equations (Morin & Samozino, 2016). The maximum value (peak) of the power-velocity relationship represents maximal power, which was determined by the equation: (F*V)/4 (Cross, Brughelli, Samozino, Brown, et al., 2017; Vandewalle, Peres, Heller, Panel, & Monod, 1987).

The session duration for both intervention groups was around 20-30 minutes depending on the week. Prior to each training session, subjects engaged in a 10-minute standardized warm up, including submaximal unresisted sprints and body weight movements targeting major muscle groups of the upper and lower extremities. Following the warm up, the subjects engaged in their assigned training program (Cahill et al., 2020). Thus, the athletes did not engage in any additional strength and conditioning program outside of their assigned study intervention (on-ice = only resisted ice skating; overground resisted sprinting = only resisted sprinting; control = only bodyweight exercise program) for the duration of the study intervention. All players participated in two to three weekly ice hockey practices and/or games as well as one to two 60-minute weekly physical education class their high school. After the 8-week intervention, subjects were reassessed on measures of athletic performance. The 6–8-week mesocycle training model was suggested and implemented in power training such as a plyometric program in ice hockey players (Nightingale, 2014; Reyment et al., 2007). Moreover, the specific total program distance (>2300 m), volume (2x/week), and duration (8-weeks) of the program was based on recent systematic reviews and meta-analyses indicating the sprint improvements observed in team-based athletes (Alcaraz et al., 2018; Petrakos et al., 2016). The allotted number of resisted sprint
repetitions depended on the intervention week. Participants performed resisted sprints over a 20-meter distance with 3 minutes of rest between each sprint repetition (Table 3.2). A similar protocol to recent resisted sprint literature was followed (Cahill et al., 2020; Lahti et al., 2019).

Table 3.1. (#3) Training Program for Control Group

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Time/Reps</th>
<th>Rest Time</th>
<th>Rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squats</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Push Ups</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Planks</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Glute Bridge</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Broad Jumps</td>
<td>5 reps</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Dead Bugs</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Squat Jump</td>
<td>5 reps</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Time/Reps</th>
<th>Rest Time</th>
<th>Rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skaters</td>
<td>5 reps each leg</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>SL RDL</td>
<td>5 reps each leg</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Bird/Dog</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Superman</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Burpees</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Plank</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>Alternating</td>
<td>1 min</td>
<td>30 seconds</td>
<td>2-3</td>
</tr>
<tr>
<td>lunges with arm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reach</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2. (#4) Training Program for both On-ice and Overground Resisted Sprint Interventions

<table>
<thead>
<tr>
<th>Week</th>
<th>Reps /session</th>
<th>Distance /rep</th>
<th>Total Distance /session</th>
<th>Total Distance /week</th>
<th>Rest /rep</th>
<th>Sled Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>20 meters</td>
<td>120</td>
<td>240</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>20 meters</td>
<td>140</td>
<td>280</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>20 meters</td>
<td>160</td>
<td>320</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>20 meters</td>
<td>120</td>
<td>240</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>20 meters</td>
<td>140</td>
<td>280</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>20 meters</td>
<td>160</td>
<td>320</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>20 meters</td>
<td>180</td>
<td>360</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>20 meters</td>
<td>140</td>
<td>280</td>
<td>3 minutes</td>
<td>Individualized Load</td>
</tr>
</tbody>
</table>

STATISTICAL ANALYSIS

All data collected for variables of interest were restructured in a comprehensive Microsoft Excel sheet and imported into Statistical Package for the Social Sciences (SPSS) version 26 (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.) for statistical processing. Assumptions of normality were verified using the Shapiro-Wilk tests and visual assessment of distribution through histogram. The test-retest reliability of each variable of interest was determined using intraclass correlation coefficient (ICC, two-way mixed effects, absolute agreement) with 95% confidence intervals. ICCs were interpreted as: <0.40 = poor; 0.40-0.60 = fair; 0.60-0.75 = good; 0.75-1.00 = excellent, similar to prior sprint literature (Lahti et al., 2019; Koo & Li 2016). Variables of interest displayed acceptable test-retest reliability, thus, the average value was used for statistical analysis. Levene's test was used to ensure the data met the criteria for homogeneity of variance. To establish the effects of the intervention on outcome variables, a series of two-way mixed factorial ANOVAs (3 groups x 2 time-points) were performed. Significant interactions were decomposed using Holm-Bonferroni adjusted pairwise comparisons (Field, 2013). When assumptions of sphericity were violated, the Huynh-Feldt correction was reported. Moreover, partial eta squared ($\eta^2_p$) calculated from the
ANOVA were provided and interpreted as: small ($\eta^2_p = 0.01$); medium ($\eta^2_p = 0.09$); and large ($\eta^2_p = 0.25$) effects (Cohen, 2013; Lakens, 2013).

Additionally, Cohen’s d was calculated to represent effect sizes using pooled standard deviation in a custom Excel spreadsheet. The effect sizes were interpreted as: trivial $\leq 0.20$; small $= 0.20$ to 0.60; moderate $= 0.60$ to 1.2; large $= 1.2$ to 2.0; very large $= 2.0$ to 4.0; nearly perfect $> 4.0$ (Hopkins, 2009). All data were analyzed at a significance level of 0.05. Spaghetti plots were created using the JASP software (Version 0.16).
CHAPTER 4: RESULTS

DESCRIPTIVES

Subjects had a mean age of 16 years and were 1.79 meters tall and weighed 68.17 kg on average (Table 4.1). In total, all 30 were recruited with 24 players completing the study (4 unable to complete due to COVID-19 protocols; 2 due to injury). Additional descriptives for measures of interest (mean and standard deviation) at pre- and post-testing are found in Table 4.2.

Table 4.1. (#5) Descriptives of Subjects (n = 24)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>16.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.79</td>
<td>0.09</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.17</td>
<td>12.73</td>
</tr>
<tr>
<td>BMI</td>
<td>22.37</td>
<td>2.89</td>
</tr>
<tr>
<td>Exercise (minutes)</td>
<td>163.00</td>
<td>23.00</td>
</tr>
</tbody>
</table>

Table 4.2. (#6) Descriptives of Measures of Interest (n = 24)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-Testing</th>
<th>Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Broad Jump Distance (cm)</td>
<td>168.00</td>
<td>19.00</td>
</tr>
<tr>
<td>CMJ Jump Height (relative to body height (cm) * mass (kg))</td>
<td>0.33</td>
<td>0.10</td>
</tr>
<tr>
<td>CMJ Peak Force (N/kg)</td>
<td>11.78</td>
<td>1.58</td>
</tr>
<tr>
<td>CMJ Peak Power (W/Kg)</td>
<td>49.28</td>
<td>7.49</td>
</tr>
<tr>
<td>IMTP Max Force (N)</td>
<td>1386.62</td>
<td>359.39</td>
</tr>
<tr>
<td>IMTP RFD 0-30ms (N/s)</td>
<td>4970.91</td>
<td>3080.70</td>
</tr>
<tr>
<td>IMTP RFD 0-50ms (N/s)</td>
<td>4793.38</td>
<td>2970.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>IMTP RFD 0-90ms (N/s)</td>
<td>3905.72</td>
<td>2420.55</td>
</tr>
<tr>
<td>IMTP RFD 0-100ms (N/s)</td>
<td>3550.65</td>
<td>2200.50</td>
</tr>
<tr>
<td>IMTP RFD 0-200ms (N/s)</td>
<td>3213.47</td>
<td>1335.07</td>
</tr>
<tr>
<td>IMTP RFD 0-300ms (N/s)</td>
<td>2690.71</td>
<td>824.07</td>
</tr>
<tr>
<td>Overground Completion Time (9.14-Meter) (seconds)</td>
<td>1.89</td>
<td>0.13</td>
</tr>
<tr>
<td>Overground Completion Time (36-Meter) (seconds)</td>
<td>6.02</td>
<td>0.41</td>
</tr>
<tr>
<td>Overground Completion Time (30-Meter Top Speed) (seconds)</td>
<td>4.45</td>
<td>0.51</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Theoretical Horizontal Force (N/kg)</td>
<td>9.11</td>
<td>1.65</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Theoretical Horizontal Velocity (m/s)</td>
<td>7.21</td>
<td>0.53</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Theoretical Horizontal Power (W/kg)</td>
<td>16.49</td>
<td>3.14</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Force-Velocity Slope</td>
<td>-1.26</td>
<td>0.23</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Maximal Ratio of Force (Horizontal/Resultant)</td>
<td>0.43</td>
<td>0.03</td>
</tr>
<tr>
<td>Overground 30-meter Sprint Decrease in Maximal Ratio of Force</td>
<td>-0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>Overground Contact Time (seconds)</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>Overground Flight Time (seconds)</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>Overground Step Length (cm)</td>
<td>136.20</td>
<td>11.55</td>
</tr>
<tr>
<td>Overground Step Rate (steps/second)</td>
<td>4.15</td>
<td>0.29</td>
</tr>
<tr>
<td>Overground Sprint Trunk Angle at Take-Off (degrees)</td>
<td>17.67</td>
<td>5.49</td>
</tr>
<tr>
<td>Overground Sprint Hip Swing Angle at Take-Off (degrees)</td>
<td>82.11</td>
<td>9.73</td>
</tr>
<tr>
<td>Overground Sprint Knee Swing Angle at Take-Off (degrees)</td>
<td>74.33</td>
<td>13.07</td>
</tr>
<tr>
<td>Overground Sprint Hip Stance Angle at Take-Off (degrees)</td>
<td>16.12</td>
<td>7.21</td>
</tr>
<tr>
<td>Overground Sprint Knee Stance Angle at Take-Off (degrees)</td>
<td>161.68</td>
<td>6.50</td>
</tr>
<tr>
<td>Overground Sprint Trunk Angle at Touchdown (degrees)</td>
<td>17.98</td>
<td>5.22</td>
</tr>
<tr>
<td>Category</td>
<td>Value 1</td>
<td>Value 2</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Overground Sprint Hip Swing Angle at Touchdown (degrees)</td>
<td>57.80</td>
<td>7.82</td>
</tr>
<tr>
<td>Overground Sprint Knee Swing Angle at Touchdown (degrees)</td>
<td>141.84</td>
<td>5.37</td>
</tr>
<tr>
<td>Overground Sprint Hip Stance Angle at Touchdown (degrees)</td>
<td>3.16</td>
<td>7.76</td>
</tr>
<tr>
<td>Overground Sprint Knee Stance Angle at Touchdown (degrees)</td>
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<td>Ice Skating Completion Time (9.14-Meter) (seconds)</td>
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<td>Ice Skating Completion Time (36-Meter) (seconds)</td>
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<td>45.79</td>
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<td>Ice Skating Sprint Hip Swing Angle at Take-Off (degrees)</td>
<td>99.92</td>
<td>7.56</td>
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<td>Ice Skating Sprint Knee Swing Angle at Take-Off (degrees)</td>
<td>109.70</td>
<td>7.49</td>
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</table>
Ice Skating Sprint Hip Stance Angle at Take-Off (degrees)  
-14.72  9.85  -17.19  9.33

Ice Skating Sprint Knee Stance Angle at Take-Off (degrees)  
165.14  6.16  164.53  7.09

Ice Skating Sprint Trunk Angle at Touchdown (degrees)  
49.96  6.62  50.79  6.19

Ice Skating Sprint Hip Swing Angle at Touchdown (degrees)  
101.27  7.25  102.59  6.96

Ice Skating Sprint Knee Swing Angle at Touchdown (degrees)  
102.26  9.34  101.01  8.54

Ice Skating Sprint Hip Stance Angle at Touchdown (degrees)  

Ice Skating Sprint Knee Stance Angle at Touchdown (degrees)  
154.45  10.95  153.51  8.90

Ice Skating Vastus Lateralis Muscle Activity (%MVIC)  
98.85  23.00  101.81  27.47

Ice Skating Biceps Femoris Muscle Activity (%MVIC)  
56.24  15.69  52.82  16.76

DATA NORMALITY

Data normality were assessed through visual distribution and the Shapiro Wilk’s test (Table 4.3). Additionally, intraclass correlation coefficients indicated good to excellent test-retest reliability at both pre- and post-testing (ICC > 0.60; Table 4.4) (Koo et al. 2016).

Table 4.3. (#7) Shapiro Wilks’s Test

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Table 4.4. (#8) Intraclass correlation coefficient and coefficient of variation

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<td>0.887</td>
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<td>Angle at Take-Off</td>
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<td>0.939</td>
<td>0.076</td>
<td>0.733</td>
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<tr>
<td>Angle at Take-Off</td>
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<td>0.958</td>
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<td>Angle at Take-Off</td>
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<td>Angle at Touchdown</td>
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<td>Ice Skating Biceps Femoris</td>
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<td>0.782</td>
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**VERTICAL JUMP**

The series of 3x2 factorial ANOVAs revealed no significant group*time interaction or group main effect for CMJ jump height, peak force, or peak power (p > 0.05). However, there was a significant main effect for time on CMJ jump height \([F(1,21) = 7.192; p = 0.014; \eta^2_p = 0.264; \text{large}]\). This corresponds to a 7% increase in jump height across all groups (Cohen’s d = 0.56; p = 0.014; small). There was also a main effect of time on peak force \([F(1,21) = 12.098; p = 0.002; \eta^2_p = 0.377; \text{large}]\), and peak power \([F(1,21) = 40.802; p < 0.001; \eta^2_p = 0.671; \text{large}]\). Consequently, there was a 9% increase in peak force (Cohen’s d = 0.73; p = 0.002; moderate) and a 10% increase in peak power (Cohen’s d = 1.33; p < 0.001; large) across all groups (Figures 4.0-4.2).
Figure 4.0. Group means and 95% confidence intervals for vertical jump height at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.1. Group means and 95% confidence intervals for vertical jump peak force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.2. Group means and 95% confidence intervals for vertical jump peak power at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.

**BROAD JUMP**

There was no significant group*time interaction effect or main effect for group (p > 0.05). There was a significant main effect for time on jump distance [F(1,21) = 58.95; p < 0.001; \( \eta^2_p = 0.747 \); large]. This corresponds to a 21% (35 cm) increase in broad jump distance across all groups (Cohen’s d = 1.60; p < 0.001; large) (Figure 4.3). There was no significant main effect for group or a significant group*time interaction effect (p > 0.05).
Figure 4.0.3. Group means and 95% confidence intervals for broad jump distance at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.

ISOMETRIC MID-THIGH PULL

There was a significant group*time interaction effect \[F(2,21) = 5.651; p < 0.011; \eta_p^2 = 0.361; \text{large}\]. Follow-up analyses indicated pre- to post-testing changes for the off-ice RST group (mean diff = 183.81 N; p = 0.007; Cohen’s d = 0.50; small) and for the on-ice RST group (mean diff = 150.69 N; p = 0.065; Cohen’s d = 0.40; small) (Figure 4.4). There were no main effects or a group*time interaction effect for RFD 0-30 ms, 0-50 ms, 0-90 ms, 0-100 ms, 0-200 ms, or RFD 0-300 ms (p > 0.05) (Figures 4.5-4.10). However, it should be noted that the RFD 0-100 ms group*time interaction effect approached significance \[F(2,21) = 2.877; p = 0.079; \eta_p^2 = 0.223; \text{moderate}\].
Figure 4.0.4. **Graph 1:** Group means and 95% confidence intervals for Isometric Mid-Thigh Pull peak force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant interaction effect. **Graphs 2-4:** Isometric Mid-Thigh Pull peak force at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.5. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-30 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.6. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-50 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.7. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-90 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.8. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-100 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.9. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-200 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.10. Group means and 95% confidence intervals for Isometric Mid-Thigh Pull RFD 0-300 ms at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.

OVERGROUND SPRINTING

COMPLETION TIME

The series of 3x2 factorial ANOVAs revealed no significant group*time interaction effect or main effect for group for 9.14-meter acceleration or 30-meter top speed completion times (p > 0.05). However, there was a significant main effect of time on 9.14-meter completion time [F(1,21) = 7.445; p = 0.013; ℓ2 = 0.271; large; 0.06 seconds], 36-meter completion time [F(1,21) = 10.406; p = 0.004; ℓ2 = 0.342; large; 0.222 seconds], and 30-meter top speed completion time [F(1,21) = 15.256; p < 0.001; ℓ2 = 0.433; large; 0.387 seconds] (Figures 4.11-4.13). For 9.14-meter completion time this equates to small effect size (Cohen’s d = 0.57; p = 0.013); a moderate
effect size (Cohen’s $d = 0.67; p < 0.004$) for 36-meter completion time; and a large effect size for 30-meter top speed completion time (Cohen’s $d = 1.30; p < 0.001$).

Figure 4.0.11. Group means and 95% confidence intervals for overground 9.14-meter completion time (seconds) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.12. Group means and 95% confidence intervals for overground 36-meter completion time (seconds) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.13. Group means and 95% confidence intervals for overground 30-meter top speed completion time (seconds) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.

**KINEMATICS**

There was no significant group*time interaction effect, main effect for group, main effect for time for flight time or step length (p > 0.05) (Figures 4.15 & 4.16). There was a significant main effect for time on contact time [F(1,21) = 8.310; p = 0.009; \( \eta_p^2 = 0.310 \); large; 0.005 seconds] (Figure 4.14). This corresponds to a moderate effect size (Cohen’s d = 0.62; p < 0.007). There was a significant group*time interaction effect on step rate [F(2,21) = 5.014; p = 0.017; \( \eta_p^2 = 0.334 \); large]. Follow up analysis revealed a moderate decrease for the off-ice RST group (Cohen’s d = 0.64; moderate) (Figure 4.17).
There was significant group*time interaction effect on trunk angle at touchdown \([F(2,21) = 4.387; p = 0.026; \eta^2_p = 0.305; \text{large}]\). Follow up analyses revealed increased trunk angle for the off-ice RST group (mean diff = 8.706; \(p = 0.014\); Cohen’s \(d = 1.07\); moderate) (Figure 4.23). There was no significant group*time interaction effect, main effect for group or time for trunk angle at take-off, hip swing flexion angle at take-off, hip stance extension angle at take-off, knee stance flexion angle at take-off, hip swing flexion angle at touchdown (\(p > 0.05\)). There was a significant main effect for time on knee swing flexion angle at take-off \([F(1,21) = 8.167; p = 0.010; \eta^2_p = 0.290; \text{large}; 5 \text{ degrees}]\); knee swing flexion angle at touchdown \([F(1,21) = 10.818; p = 0.004; \eta^2_p = 0.351; \text{large}; 5 \text{ degrees}]\); hip stance extension angle at touchdown \([F(1,21) = 15.383; p < 0.001; \eta^2_p = 0.435; \text{large}; 10 \text{ degrees}]\); knee stance flexion angle at touchdown \([F(1,21) = 9.230; p = 0.006; \eta^2_p = 0.316; \text{large}; 5 \text{ degrees}]\) (Figures 4.20 & 4.25-4.27). This corresponds to a moderate effect size for knee swing flexion angle at take-off (Cohen’s \(d = 0.60; p < 0.01\)); knee swing flexion angle at touchdown (Cohen’s \(d = 0.69; p = 0.004\)); hip stance extension angle at touchdown (Cohen’s \(d = 0.82; p < 0.001\)); and knee stance flexion angle at touchdown (Cohen’s \(d = 0.63; p = 0.006\)).
Figure 4.0.14. Group means and 95% confidence intervals for overground sprint contact time (seconds) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.15. Group means and 95% confidence intervals for overground sprint flight time (seconds) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.16. Group means and 95% confidence intervals for overground sprint step length (cm) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.17. **Graph 1:** Group means and 95% confidence intervals for overground sprint step rate at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. $\S$ denotes a group*time interaction effect. **Graphs 2-4:** Overground sprint step rate at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.18. Group means and 95% confidence intervals for overground sprint trunk angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.19. Group means and 95% confidence intervals for overground sprint hip swing flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.20. Group means and 95% confidence intervals for overground sprint knee swing flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.21. Group means and 95% confidence intervals for overground sprint hip stance extension angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.22. Group means and 95% confidence intervals for overground sprint knee stance flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.23. **Graph 1**: Group means and 95% confidence intervals for overground sprint trunk angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes significant group*time interaction effect. **Graphs 2-4**: Overground sprint trunk angle at touchdown at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.24. Group means and 95% confidence intervals for overground sprint hip swing flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.25. Group means and 95% confidence intervals for overground sprint knee swing flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.26. Group means and 95% confidence intervals for overground sprint hip stance extension angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.27. Group means and 95% confidence intervals for overground sprint knee stance flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.

**SPRINT (KINETIC) PROFILE**

There were significant group*time interaction effects on theoretical maximal horizontal force \[F(2,21) = 5.857; p = 0.010; \eta_p^2 = 0.369; \text{large}\]; theoretical maximal horizontal power \[F(2,21) = 5.211; p = 0.015; \eta_p^2 = 0.343; \text{large}\]; the force-velocity slope \[F(2,21) = 4.948; p = 0.018; \eta_p^2 = 0.331; \text{large}\]; and maximal ratio of force \[F(2,21) = 5.938; p = 0.013; \eta_p^2 = 0.351; \text{large}\]. Follow-up analyses indicated significant pre- to post-testing changes for the on-ice RST group on theoretical maximal horizontal force (mean diff = 1.886 N/kg; \(p = 0.046; \text{Cohen’s d = 1.13; moderate}\)), theoretical maximal horizontal power (mean diff = 3.679 W/kg; \(p = 0.016; \text{Cohen’s d = 1.21; large}\)), and maximal ratio of force (mean diff = 0.038; \(p = 0.004; \text{Cohen’s d = 0.16; small}\)).
Although not significant at the p < 0.05 level, small-to-moderate changes were noted for theoretical maximal horizontal force (Cohen’s d = 0.72; moderate), theoretical maximal horizontal power (Cohen’s d = 0.71; moderate), and ratio of maximal force (Cohen’s d = 0.57; small) in the off-ice RST group (p = 0.05-0.10). There was significant main effect for time on theoretical maximal velocity [F(1,21)= 4.668; p = 0.043; ηp² = 0.189; moderate; 0.178 m/s] (Figure 4.29).
Figure 4.0.28. **Graph 1:** Group means and 95% confidence intervals for overground sprint horizontal force (N/kg) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Overground sprint horizontal force (N/kg) at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.29. Group means and 95% confidence intervals for overground sprint horizontal velocity (m/s) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.30. **Graph 1:** Group means and 95% confidence intervals for overground sprint horizontal power (W/kg) at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Overground sprint horizontal power (W/kg) at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.31. **Graph 1:** Group means and 95% confidence intervals for overground sprint force-velocity slope at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Overground sprint force-velocity slope at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.32. **Graph 1:** Group means and 95% confidence intervals for overground sprint maximal ratio of force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Overground sprint maximal ratio of force at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.33. Group means and 95% confidence intervals for overground sprint decrease in maximal ratio of force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.

MUSCLE ACTIVITY

There was a significant group*time interaction effect on Vastus Lateralis muscle activity [F(2,21) = 4.918; p = 0.018; \( \eta_p^2 = 0.330 \); large]. Follow up analysis indicated small increases in VL muscle activity for both the off-ice RST (Cohen’s d = 0.28; small) and on-ice RST (Cohen’s d = 0.13; small) groups (p 0.05-0.11) (Figure 4.34). There was no significant group*interaction effect, main effect for group or time for Biceps Femoris muscle activity (p> 0.05).
Figure 4.0.34. **Graph 1:** Group means and 95% confidence intervals for overground sprint vastus lateralis muscle activity at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes significant group*time interaction effect. **Graphs 2-4:** Overground sprint vastus lateralis muscle activity at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.35. Group means and 95% confidence intervals for overground sprint biceps femoris muscle activity at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.

ICE SKATING

COMPLETION TIME

There were significant group*time interaction effects on ice skating S-cornering agility drill completion time \([F(2,21) = 5.634; p = 0.011; \eta^2_p = 0.360; \text{large}]\) and ice skating 30-meter top speed completion time \([F(2,21) = 3.781; p = 0.040; \eta^2_p = 0.274; \text{large}]\) (Figures 4.36 & 4.37). Follow-up analyses indicated significant pre- to post-testing changes for the on-ice RST group on ice skating s-cornering completion time (mean diff = 0.412 seconds; \(p < 0.001; \text{Cohen’s } d = 1.75; \text{large}\)) and ice skating 30-meter top speed completion time (mean diff = 0.228 seconds; \(p = 0.163\)). The pre- to post changes for both the off-ice RST and control group did not reach
statistical significance for the s-cornering agility drill or ice skating 30-meter top speed
completion times (p > 0.05). Although not significant at the .05 level, there was a moderate
group*time interaction for 36-meter completion time [F(2,21) = 2.854; p = 0.081; \eta_p^2 = 0.174;
moderate]. Follow up analyses revealed significant pre- to post-testing changes for the on-ice
RST group (mean diff = 0.847 seconds; p < 0.001; Cohen’s d = 2.43; very large) and the off-ice
RST group (mean diff = 0.699 seconds; p < 0.001; Cohen’s d = 1.69; large) for 36-meter
completion time (Figure 4.39). Lastly, there was a main effect for time on 9.14-meter completion
time [F(1,21) = 9.601; p = 0.006; \eta_p^2 = 0.325; large]. This corresponds to a 0.074 second
difference across all groups (Cohen’s d = 0.65; moderate; p = 0.006) (Figure 4.38). It is noted
that the on-ice RST group displayed the greatest improvement (0.119 seconds compared to 0.058
seconds for off-ice RST and 0.040 seconds for control group) despite not reaching a statistical
group*time interaction effect for the 9.14-meter completion time.
Figure 4.0.36. **Graph 1:** Group means and 95% confidence intervals for ice skating s-cornering agility drill completion time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. ¥ denotes significant group*time interaction effect. **Graphs 2-4:** Ice skating s-cornering agility drill completion time at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.37. **Graph 1:** Group means and 95% confidence intervals for ice skating 30-meter top speed completion time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Ice skating 30-meter top speed completion time at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.38. Group means and 95% confidence intervals for ice skating 9.14-meter completion time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.39. Group means and 95% confidence intervals for ice skating 36-meter completion time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.

KINEMATICS

There was no significant group*time interaction effect, main effect for group or time on contact time, flight time, or step rate (p > 0.05)(Figures 4.40 - 4.41 & 4.43). There was a significant group*time interaction effect on step length \(F(2,21) = 3.530; \ p = 0.049; \ \eta_p^2 = 0.261; \text{large}\]. Follow up analysis revealed small effects both the off-ice RST (Cohen’s d = 0.33; small) and on-ice RST (Cohen’s d = 0.31; small) groups (Figure 4.42).

There was significant group*time interaction effect on knee swing flexion angle at touchdown \(F(2,21) = 4.320; \ p = 0.028; \ \eta_p^2 = 0.302; \text{large}\] with the on-ice RST group displaying a decrease in the angle (Cohen’s d = 0.55; small)(Figure 4.51). There was no significant group*time interaction effect, main effect of group or time on trunk angle at take-off, hip swing
flexion angle at take-off, knee swing flexion angle at take-off, hip stance extension angle at take-off, knee stance flexion angle at take-off, hip stance extension angle at touchdown, and knee stance flexion angle at touchdown (p > 0.05).

Figure 4.0.40. Group means and 95% confidence intervals for ice skating sprint step contact time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.41. Group means and 95% confidence intervals for ice skating sprint flight time at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.42. **Graph 1:** Group means and 95% confidence intervals for ice skating sprint step length at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Ice skating sprint step length at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.43. Group means and 95% confidence intervals for ice skating sprint step rate at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.44. Group means and 95% confidence intervals for ice skating trunk angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.45. Group means and 95% confidence intervals for ice skating hip swing flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.46. Group means and 95% confidence intervals for ice skating knee swing flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.47. Group means and 95% confidence intervals for ice skating hip stance extension angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.48. Group means and 95% confidence intervals for ice skating knee stance flexion angle at take-off at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.49. Group means and 95% confidence intervals for ice skating trunk angle at
touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground
Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.50. Group means and 95% confidence intervals for ice skating hip swing flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.51. **Graph 1:** Group means and 95% confidence intervals for ice skating knee swing flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Ice skating knee swing flexion angle at touchdown at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.52. Group means and 95% confidence intervals for ice skating hip stance extension angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.53. Group means and 95% confidence intervals for ice skating knee stance flexion angle at touchdown at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.

SKATE (KINETIC) PROFILE

There was a group*time interaction effect for maximal ratio of force \([F(2,21) = 3.657; p < 0.044; \eta^2_p = 0.159; \text{moderate}]\). Further analyses revealed a large increase for the on-ice RST group (mean diff = 0.05; \(p < 0.001; \text{Cohen’s} \ d = 1.20; \text{large}\)) and a moderate increase for the off-ice RST group (Cohen’s \(d = 0.76; \text{moderate}\)) (Figure 4.58). There was a main effect for time on theoretical maximal horizontal force \([F(1,21) = 28.911; p < 0.001; \eta^2_p = 0.599; \text{large}]\); theoretical maximal horizontal power \([F(1,21) = 35.765; p < 0.001; \eta^2_p = 0.622; \text{large}]\); the force-velocity slope \([F(1,21) = 20.690; p < 0.001; \eta^2_p = 0.508; \text{large}]\); and decrease in maximal ratio of force \([F(1,21) = 17.237; p < 0.001; \eta^2_p = 0.463; \text{large}]\). This corresponds to a 1.972 N difference in force (Cohen’s \(d = 1.12; \text{moderate}; p < 0.001\), a 3.038 W difference in power (Cohen’s \(d = 1.25\);
large; \( p < 0.001 \), a 0.328 difference in the force-velocity slope (Cohen’s \( d = 0.95 \); moderate; \( p < 0.001 \)), and a 0.031 difference in the decrease in maximal ratio of force (Cohen’s \( d = 0.87 \); moderate; \( p < 0.001 \)) across all groups (Figure 4.54, 4.56, 4.59). There were no interaction effect or main effect of group or time on theoretical maximal velocity (\( p > 0.05 \)) (Figure 4.55).

![Graph showing Ice Skating Sprint Horizontal Force](image)

**Figure 4.0.54.** Group means and 95% confidence intervals for ice skating sprint theoretical maximal horizontal force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.55. Group means and 95% confidence intervals for ice skating sprint theoretical maximal horizontal velocity at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
Figure 4.0.56. Group means and 95% confidence intervals for ice skating sprint theoretical maximal horizontal power at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.57. Group means and 95% confidence intervals for ice skating sprint force-velocity slope at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.
Figure 4.0.58. **Graph 1:** Group means and 95% confidence intervals for ice skating sprint maximal ratio of force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes a significant group*time interaction effect. **Graphs 2-4:** Ice skating sprint maximal ratio of force at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.59. Group means and 95% confidence intervals for ice skating sprint decrease in maximal ratio of force at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. * denotes a significant main effect for time.

MUSCLE ACTIVITY

There was a significant group*time interaction effect on Vastus Lateralis muscle activity [$F(2,21) = 10.548; p < 0.001; \eta^2 = 0.513; \text{large}$]. Follow up analysis indicated increases in VL muscle activity for the on-ice RST group (mean diff = 10.34%; $p = 0.001; \text{Cohen’s d} = 0.58; \text{small}$) (Figure 4.60). There was no group*time interaction, main effect of group or time on Biceps Femoris muscle activity ($p > 0.05$) (Figure 4.61).
Figure 4.60. **Graph 1:** Group means and 95% confidence intervals for ice skating sprint vastus lateralis muscle activity expressed as a percentage of maximal voluntary isometric contraction at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group. § denotes significant group*time interaction effect. **Graphs 2-4:** Ice skating sprint vastus lateralis muscle activity expressed as a percentage of maximal voluntary isometric contraction at pre- and post-testing by group (Off-ice BW = graph 2; Off-ice RST = graph 3; On-ice RST = graph 4).
Figure 4.0.61. Group means and 95% confidence intervals for ice skating sprint biceps femoris muscle activity expressed as a percentage of maximal voluntary isometric contraction at pre- and post-testing. Off-ice BW = Control Group; Off-ice RST = Overground Resisted Sprint Training Group; On-ice RST = Ice Skating Resisted Training Group.
CHAPTER 5: DISCUSSION

This study aimed to compare the effects of an 8-week on-ice resisted sprint training program, overground resisted sprint training program, and control on ice skating speed, acceleration, and athletic measures associated with ice skating in ice hockey players. The first hypothesis that an on-ice RST would result in a 2-4% decrease in ice skating tests completion time is supported with the on-ice RST group reducing their competition time across all ice skating tests (9.14-meter acceleration sprint, 6%; 36-meter acceleration sprint, 13%; 30-meter top speed, 6%; and s-cornering agility drill, 10%). Vertical jump height (7%), vertical jump peak force (9%), vertical jump peak power (10%), and broad jump distance (21%) increased across all three training groups. Moreover, 9.14-meter (3%) and 36-meter (4%) overground acceleration sprint completion times as well as 30-meter top speed (9%) completion time decreased across all groups. Thus, the second hypothesis is partially supported given the increase in jump measures with simultaneous reduction in overground sprint completion times across all groups; yet superior findings for the resisted sprint training groups were not observed. The third hypothesis was partially supported given the increase in %MVIC for the vastus lateralis observed for both overground (5%) and on-ice (3%) RST groups during overground acceleration sprints.

Additionally, the on-ice RST group displayed a 10% increase vastus lateralis muscle activity during 36-meter maximal ice skating acceleration test. However, biceps femoris muscle activity across time or between groups did not change, which failed to support the hypothesis. Contact time decreased across all groups (5%) with an accompanying increase in step rate for the on-ice RST group during overground sprints. Furthermore, step length increased for both on-ice (5%) and overground (6%) RST during on-ice sprints. Thus, the final hypothesis is partially supported.
JUMPING

Study findings agree with prior literature demonstrating increases in vertical jump measures after participating in overground RST (Gil et al., 2018; Spinks et al., 2007). After 6 weeks of overground RST, soccer players demonstrated increased vertical jump height (15%) (Gil et al., 2018). Interestingly, Gil and colleagues reported that the control group who participated in unresisted sprint training exhibited similar improvements (15%) to the overground RST intervention group (Gil et al., 2018). Present study findings also indicate no significant differences in vertical jump height improvement between overground RST and the control group (Gil et al., 2018). Similar to Gil and colleagues (2018), after a 6-week overground RST program, vertical jump height increased by 13% in physically active adults (Prieske et al., 2018). Recently, Uthoff and colleagues reported increased vertical jump height (11%) following an 8-week overground RST in male high-school athletes (Uthoff et al., 2019). In youth tennis players, after engaging in 6 weeks of overground RST, players reported an increase in vertical jump height (5%) and broad jump distance (5%) yet this was not different from the body weight training group (vertical jump height = 6%; broad jump distance = 3%) (Moya-Ramon et al., 2020). The lack of difference between overground RST and control groups in the current study is not unexpected as research indicates improved jumping following plyometric, strength, body weight, and unresisted sprint training (Lloyd et al., 2016; Petrakos et al., 2016). In the current study, there was a 7% increase in vertical jump height across all groups with no between group differences (Figure 4.0). We observed a 21% increase in broad jump distance across all groups (Figure 4.3). Prior literature supports improvements in broad jump performance after overground RST (Cahill et al., 2020; Moya-Ramon et al., 2020). The greater improvement in broad jump distance compared to vertical jump height, as a relative amount, may be a consequence of the
horizontal direction of force application during RST compared to vertical jumping (Cahill et al., 2020; Hicks et al., 2019). To our knowledge, this is the first study to demonstrate that jumping measures (both vertical and broad jump) can be improved by engaging in on-ice RST. Prior researchers suggest that RST can target the mechanisms that underpin the stretch-shortening cycle, thus resulting in improvements during plyometric exercise, such as vertical and broad jumping (Harrison & Bourke, 2009; Seiberl et al., 2021). Specifically, authors propose that longer ground contact times of RST may rely on the contractile and elastic element of the musculotendinous unit and promote improvements in jumping (Uthoff et al., 2019). This may explain the improvements observed in the present study across all groups.

**ISOMETRIC MID-THIGH PULL**

Small peak force increases were observed for the off-ice RST group (mean diff = 183.81 N; p = 0.007; Cohen’s d = 0.50; small; 12.20%) and the on-ice RST group (mean diff = 150.69 N; p = 0.065; Cohen’s d = 0.40; small; 12.75%) (Figure 4.4). Townsend and colleagues reported a strong association between peak force during IMTP and sprint completion times over various distances (5-20m; r = -0.62 to -0.69) in collegiate basketball players (Mangine et al., 2015; Townsend et al., 2017). Similar research indicates a correlation between IMTP peak force and sprint completion times (r = -0.53 to -0.69) (Brady et al., 2019; Thomas et al., 2017). Given their relationship, it is logical that increases in IMTP peak force would be accompanied by improvements in overground sprint completion times. High levels of peak isometric strength may be an important quality for ice hockey players to possess. In the current study, meaningful changes in RFD across all time intervals were not observed (Figures 4.5-4.10). Prior research indicates a lack of association between RFD across multiple time-intervals and overground sprint distances over 10-meters (Brady et al., 2019; Healy et al., 2019; Wang et al., 2016). Moreover,
studies report that plyometric training did not significantly alter IMTP RFD measures while an isometric strength program did (Burgess et al., 2007; Kubo et al., 2017; Lum et al., 2022).

Comfort and colleagues indicated that a 4-week moderate load strength program produced changes in IMTP peak force (7.7%; Cohen’s d = 2.02; p = 0.003); however, not in IMTP RFD (0.7%; p > 0.05). Instead, RFD changes were only observed after a high-load strength program (13%; Cohen’s d = 4.15; p = 0.001) (Comfort et al., 2022). Thus, the specificity of training, the adaptations to that training, the training load, and population may explain the lack of RFD improvement observed in the present study.

**COMPLETION TIMES**

Various studies report meaningful improvements in overground sprint completion times by a tenth of second or more following RST (Alcaraz et al., 2018; Grazioli et al., 2020; Petrakos et al., 2016). In the present study, there were no significant group*time interactions with all groups improving in overground 9.14-meter completion time (0.06 seconds; Cohen’s d = 0.57; p = 0.013; small; 3%), 36-meter completion time (0.222 seconds; Cohen’s d = 0.67; p = 0.004; moderate; 4%), and 30-meter top speed completion time (0.387 seconds; Cohen’s d = 1.30; p < 0.001; large; 9%) (Figures 4.11-4.13). Cahill and colleagues reported decreases in overground 10-meter (Cohen’s d = 1.05; moderate) and 20-meter (Cohen’s d = 1.03; moderate) completion times after an 8-week overground RST program in high school athletes (Cahill et al., 2020). Additionally, a 7-week overground RST program was sufficient to reduce 5-meter (Cohen’s d = 1.39; large) and 20-meter (Cohen’s d = 0.97; moderate) overground sprint competition times among soccer players (Ben Brahim et al., 2021). Study findings are further supported by authors who reported a 3% reduction in overground 10-meter completion time and a 2% reduction in 30-meter completion time after engaging in an 8-week overground RST program with 40% body
weight (Rodríguez-Rosell et al., 2020). Grazioli and colleagues indicated improvement in overground 10-meter (6%) completion time after a 11-week overground RST program (Grazioli et al., 2020). However, there exist conflicting results regarding magnitude of sprint completion time improvement when RST is compared to control or unresisted sprint training (Alcaraz et al., 2018). In the present study, there were no differences in overground completion times across groups. Present study results agree with prior literature demonstrating no differences in completion time between RST and unresisted sprint training or bodyweight training control groups (Gil et al., 2018; Prieske et al., 2018). Authors noting lack of differences between groups suggest that the magnitude of load may have been insufficient to induce changes above those observed by the unresisted sprinting or control training groups (Gil et al., 2018). Certainly, literature indicates that adaptations are impacted by sled load (Alcaraz et al., 2018; Petrakos et al., 2016). Another potential explanation for lack of differences between groups may be that training one component of muscle capacity (power with high velocity body weight exercises; i.e., vertical jump, push-ups, lunges) may translate over to increased overground sprint completion times (Prieske et al., 2018). When considering RST specifically, in addition to increasing ground forces applied horizontally as described in the subsequent section, RST is proposed to increase leg muscle strength during the stance phase potentially leading to decreased contact time and increased step rate. These changes are proposed to drive the reduced completion time noted after RST and may partially explain the RST findings of the present study (Alcaraz et al., 2018; Petrakos et al., 2016).

There exists sparse literature examining the impact of on-ice training programs. Acutely, decreases in 25-meter ice skating completion time (-3%; p = 0.02) were reported after a single bout of on-ice RST in male ice hockey players (Matthews et al., 2010). Janot and colleagues
reported an 4% increase in ice skating speed and a 4% increase in top speed among youth ice hockey players following a 4-week on-ice bungee-cord RST program (Janot et al., 2012). Literature reports improvements in on-ice agility after both a 4-week off-ice agility (2%) and on-ice agility (3%) training programs, with the on-ice group exhibiting greater improvements (Novák et al., 2019). Therefore, the on-ice RST group study findings support those of previous studies (10% improvement in on-ice agility and 13% improvement in 36-meter ice skating completion time). The present study was 8-weeks in duration, thus consisting of the longest on-ice training study with the on-ice RST group improving on ice skating s-cornering completion time (mean diff = 0.412 seconds; p < 0.001; Cohen’s d = 1.75; large; 10%) and 36-meter completion time (mean diff = 0.847 seconds; p < 0.001; Cohen’s d = 2.43; very large; 13%) (Figures 4.36 & 4.38). The off-ice RST group also displayed improvement in 36-meter completion time (mean diff = 0.699 seconds; p < 0.001; Cohen’s d = 1.69; large; 11%) (Figure 4.38). This study presents the first insights into positive alterations in s-cornering agility drill completion time following an on-ice training program. The improvements in linear ice skating completion time of the present study (13%) represent a substantial increase when considered to those reported by Janot and colleagues (4%) (Janot et al., 2012). The intervention duration (4 vs. 8 weeks) and the individualized resisted sled load (compared to elastic cords) may have yielded the differences observed in the current study compared to those of Janot. During overground resisted sprint training, interventions lasting longer than 6-weeks displayed the most reduction in sprint completion times (ES = 0.39; p = 0.01)(Alcaraz et al., 2018). Reasonably, a similar outcome may be expected during resisted ice skating. Moreover, the improvements in 36-meter ice skating completion time exhibited by the overground RST group (11%) exceed those
reported in prior literature following an overground training intervention (2 - 7%) (Dæhlin et al., 2017; Farlinger & Fowles, 2008; Naimo et al., 2015; Novák et al., 2019; Rønnestad et al., 2019).

Improvements in completion time may be driven by alterations in sprint (kinetic) profile components and kinematics as described below. For instance, Perez and colleagues indicated the importance of maximal horizontal power and force to attain high ice skating speeds (Perez et al., 2019; Perez et al., 2020). We found that maximal horizontal power during ice skating exhibited changes due to participating in RST (Figure 4.56). Moreover, increased trunk angle is reported as a result of RST which may lead to increased maximal horizontal force, maximal horizontal power, and maximal ratio of force (Hicks et al., 2019; Lahti et al., 2019; Spinks et al., 2007). These collective changes may explain the alterations observed in ice skating completion times.

**SPRINT/SKATE (KINETIC) PROFILE**

In the present study, both RST groups improved in overground sprint theoretical maximal horizontal force (Overground RST: Cohen’s d = 0.72; moderate; 15%; On-ice RST: Cohen’s d = 1.13; moderate; 22%), theoretical maximal horizontal power (Overground RST: Cohen’s d = 0.71; moderate; 13%; On-ice RST: Cohen’s d = 1.21; large; 24%), and maximal ratio of force (Overground RST: Cohen’s d = 0.57; small; 3%; On-ice RST: Cohen’s d = 1.32; large; 9%) (Figures 4.28, 4.30, 4.32). After 8-weeks of overground RST, male youth athletes exhibited improvements in maximal horizontal force (Cohen’s d = 0.51; small) and maximal horizontal power (Cohen’s d = 0.51; small), corroborating the present study findings (Cahill et al., 2020).

Recently, Edwards and colleagues reported improvements sprint completion times across various distances (Hedge’s g = 0.80-1.41; moderate-large), maximal horizontal force (Hedge’s g = 0.63; moderate), horizontal power (Hedge’s g = 1.04; moderate), and maximal ratio of force (Hedge’s g = 0.99; moderate) following a 10-week heavy RST in junior rugby players (Edwards et al.,
Moreover, improvements in overground maximal horizontal force (Cohen’s d = 1.03; moderate) and maximal horizontal power (Cohen’s d = 1.00; moderate) without observed improvements in maximal horizontal velocity and other Sprint Profile components are reported (Lahti et al., 2019). Additionally, Morin and colleagues reported improved overground maximal horizontal force (Cohen’s d = 0.80; moderate), horizontal power (Cohen’s d = 0.59; small) and maximal ratio of force (Cohen’s d = 0.95; moderate) yet no substantial alterations in horizontal velocity after an 8-week RST program (Morin et al., 2017). RST is known to target horizontal force application, thus improved overground horizontal force and power was anticipated (Hicks et al., 2019; Haugen et al., 2019). The increased maximal ratio of force suggests that athletes apply force in a more horizontal oriented direction compared to pre-testing; considered more efficient during the initial acceleration steps of sprinting (Haugen et al., 2019). The first few steps of overground sprinting are high-force dependent. Therefore, the load provided by RST may have aided in greater horizontal force and power development with accompanying improvement in maximal ratio of force (Cahill et al., 2020). Alterations in maximal horizontal force, maximal horizontal power and maximal ratio of force could underpin improvements seen in overground completion times (Morin et al., 2011; Rabita et al., 2015). Development of these components are vital since maximal horizontal force, maximal horizontal power, and maximal ratio of force are considered the premier components determining overground sprint and ice skating speeds (Morin et al., 2011; Perez et al., 2020; Rabita et al., 2015). Interestingly, the on-ice RST improvements appeared to translate to kinetic changes observed during overground sprinting. Prior literature suggests the carry-over of overground training to improved ice skating completion times (Dæhlin et al., 2017; Farlinger & Fowles, 2008; Novák et al., 2019). Yet, this
is the first study to quantify longitudinal changes in ice skating sprint kinetics and the carry-over of on-ice training to overground sprint kinetics.

The impact of on-ice or overground RST on ice skating kinetics is novel. Thus, present study findings constitute the first glimpse into this new area of research. We found significant pre to post changes for on-ice horizontal force in the overground RST (Cohen’s d = 1.00; moderate; 29%) and on-ice RST (Cohen’s d = 1.04; moderate; 23%) groups (Figure 4.56). Maximal ratio of force during ice skating also increased for the on-ice RST group (Cohen’s d = 1.20; large; 7%) and the overground RST group (Cohen’s d = 0.76; moderate; 5%) (Figure 4.58). Therefore, participating in either an overground or on-ice RST appear to alter important components of ice skating kinetics. The improvement of the on-ice RST group agrees with the principle of training specificity. As stated, literature indicates the importance of high horizontal force, horizontal power, and maximal ratio of force to attain high ice skating speeds with research indicating RST as an effective method to alter these components (Hicks et al., 2019; Perez et al., 2020). Unfortunately, given the novelty of the present work, there does not exist direct literature for comparison. In a somewhat relevant and recent study, Haug and colleagues explored the impact of overground sprint start training on ice skating completion time in short track speed skaters (Haug et al., 2017). Authors reported that a 4-week intervention performed twice a week resulted in small improvement in ice skating start time (0.07 seconds; Cohen’s d = 0.33). Although kinetics were not measured, provided findings stated in the “Completion Times” subsection of this Discussion, it may be that overground RST positively impacted ice skating performance. It is true that both locomotion types (sprinting and maximal ice skating) require a horizontal application of force, particularly during the first few steps of the acceleration phase.
(Lafontaine, 2007). Indeed, a positive transfer of overground RST kinetics to ice skating is certainly plausible.

**KINEMATICS**

Overground step contact time decreased across all groups (0.005 seconds; Cohen’s d = 0.62; p < 0.007; 5%) albeit with the on-ice RST group appearing to have the greatest reduction (0.009 seconds) (Figure 4.14). Prior research indicates reductions in contact time of up to 0.020 seconds following RST (Kawamori et al., 2013; Petrakos et al., 2016; Spinks et al., 2007). Others indicate non-significant differences in contact time following overground RST (Lahti et al., 2019; Rumpf et al., 2014). The contrasting findings in these studies may be attributed to the loading scheme utilized across studies (Alcaraz et al., 2018). In the present study, there was no significant changes in overground step rate across groups. Lack of step rate change following overground RST is not uncommon (Alcaraz et al., 2014; Lahti et al., 2019; Prieske et al., 2018). Given the resemblance of the loading scheme between the present study and that of Lahti and colleges, the load prescribed was not optimal to induce changes in step rate. Unfortunately, there exists no consensus on what sled loading best targets changes in steps rate, although some advocate for loads categorized as “lighter” (<20% bodyweight) in the literature (Alcaraz et al. 2018; Petrakos et al., 2016). When a sled of 7.5-10% bodyweight was implemented during a 9-week RST program, step rate decreased by 3%, yet step rate changes are not typically observed with heavier loads (Alcaraz et al., 2018; Makaruk et al., 2013). In our study, there was an increase in trunk angle at touchdown for the overground RST group (mean diff = 8.706; p = 0.014; Cohen’s d = 1.07; moderate; 48%) (Figure 4.23). Other studies also report increased trunk angles (16 - 58%) after engaging in overground RST (Alcaraz et al., 2018; Petrakos et al., 2016; Spinks et al., 2007). For instance, after 4-weeks of RST, trunk angle increased by 16% at
touchdown in national level track and field athletes (Alcaraz et al., 2014). Increased trunk angle is purported to aid athletes apply forces in a more horizontal direction thereby improving sprint completion times. Observed trunk angle changes agree with the Sprint (kinetic) Profile component modifications for RST groups in the present study (i.e., increased maximal horizontal force, maximal horizontal power, and maximal ratio of force) (Hicks et al., 2019). There were not any changes in trunk lean angle for the on-ice RST or control groups. The lack of alteration in trunk lean angle for the control group supports prior research (Alcaraz et al., 2014; Lahti et al., 2019). The absence of trunk lean adaptation for the on-ice RST may be due to players already adopting a substantially forward trunk lean during ice skating (50 degrees) compared to overground sprinting (18 degrees) (Shell et al., 2017).

During ice skating sprints, there was an increase in step length for both the overground RST (Cohen’s d = 0.33; small; 3 cm; 6%) and on-ice RST (Cohen’s d = 0.31; small; 3 cm; 6%) groups (Figure 4.42). Prior literature reports increased step or stride length as a consequence of RST, albeit during overground sprinting (Kawamori et al., 2013; Petrakos et al., 2016). The increase in step length may relate to the sprint (kinetic) profile component adaptations observed with the off-ice and on-ice RST groups during ice skating (i.e., increased maximal ratio of force and maximal horizontal power). For instance, authors propose that an increased step length may be attributed to higher impulse despite equivalent step contact time (Morin et al., 2015; Nagahara et al., 2021). Thus, the athlete is able to apply more forces, particularly horizontal oriented forces, within the same time window. Lastly, the on-ice RST group displayed a decrease in the knee swing flexion angle at touchdown (Cohen’s d = 0.55; small; 5 degrees; 5%) (Figure 4.51). This knee angle alteration may aid in preparing the limb for optimal contact between the ice skate blade and the ice surface allowing the athlete to apply forces more efficiently (supporting
the increase in maximal ratio of force observed in the on-ice RST group). Prior literature suggests that faster ice skaters adopt a more knee flexed position at touchdown and throughout the stance phase which may carry over to the other ice skating improvements observed in the present study (i.e., 30-meter top speed and s-cornering agility drill completion times for the on-ice RST group but not for other groups) (Budarick et al., 2018; Chang et al., 2009; Upjohn et al., 2008).

**MUSCLE ACTIVITY**

Vastus lateralis muscle activity (%MVIC) increased for the overground (5%) and on-ice (3%) RST groups during the overground sprint, while the on-ice RST displayed a 10% increase in VL muscle activity during ice skating (Figures 4.34 & 4.60). Recent literature reports increased knee extensor muscle activity as a result of increasing RST load compared to unresisted sprinting (Zabaloy et al., 2020). This may coincide with the body position adopted to overcome increasing loads during the acceleration phase of sprinting (i.e. increased trunk flexion angle and knee flexion angle at touchdown) (Maulder et al., 2008; Monte et al., 2017). Indeed, running with increased flexion of the knees, sometimes termed “groucho running” may partially explain the increased VL and decreased BF muscle activity observed due to RST (McMahon et al., 1987; Zabaloy et al., 2020). Increased muscle activity may reflect adapted neural drive with increased motor unit recruitment and/or firing frequency, thereby increasing the muscle force during movement (Gabriel et al., 2006; Judge et al., 2003). Additional alterations could include changes in agonist-antagonist coactivation during specific sprint phases (contributing to increased agonist force during key movement phases) or changes at the neuromuscular junction (Deschenes, 2019; Folland & Williams, 2007). During ice skating, players adopt a forward lean position through both the acceleration and glide phases of ice skating (Budarick et al., 2018;
Chang et al., 2009). The reliance on knee extensors (such as the VL) over knee flexors (such as the BF) during ice skating, particularly during the propulsive phase, may explain the lack of changes observed in BF muscle activity as a consequence of the RST program (Behm et al., 2005; Buckeridge et al., 2015; Kaartinen et al., 2021). In fact, knee extensors appear paramount to attaining higher ice skating speeds, as faster ice skaters demonstrated quicker knee extension during the propulsive phase of maximal linear ice skating (Robbins et al., 2018).

During overground sprinting, the lack of change in BF muscle activity changes was surprising. Increased running speeds are associated with higher muscle activity of the BF as a powerful hip extensor accompanied by quick knee flexion to reposition the lower limb for subsequent ground contact (Higashihara et al., 2010; Howard et al., 2017). For instance, Morin and colleagues reported increased horizontal ground reaction forces (a known determinant of sprint speed) were associated with higher BF muscle activity during sprinting (Morin et al., 2015). Interestingly, during RST, as load increases, BF muscle activity decreases likely due to decreased hip range of motion and shorter stride length (Zabaloy et al., 2020). In our study only the BF was measured among the hamstring muscle group (semimembranosus, semitendinosus, biceps femoris). Prior literature suggests that muscles within the hamstring group are preferentially recruited during different phases of overground sprinting (Higashihara et al., 2015, Higashihara et al., 2018). Moreover, authors suggest given the synergistic nature of hamstrings muscle, one muscle could exhibit adaptations to training despite an absence in another (Tillaar et al., 2017). Consequently, it is plausible that in the present study, the semitendinosus and semimembranosus displayed positive adaptations to RST despite the lack of findings for the BF. Lastly, albeit cross-sectional in nature, one study demonstrated a lack of BF and VL muscle activity alterations following increased RST loads; partially supporting the lack of BF muscle
activity alteration noted in the present study (Cochrane & Monaghan, 2021). Future research will seek to elucidate on this important subject.

LIMITATIONS

The limited strength and conditioning experience of subjects presents a substantial limitation of the study. Thus, all subjects responded to a structured strength and conditioning program. This limitation may have impeded the study’s capacity to fully elucidate the impact of different training interventions on outcome measures. Additionally, provided the age range of subjects (14-18 years old) - there likely exists differences in maturation across all subjects, specifically, age at peak height velocity (Koziel & Melina 2018). These differences were not accounted for in the present study and may have impacted sprinting and ice skating study findings (Oliver et al. 2013). Methods to account for maturation differences include a non-evasive practical method predicting years from peak height velocity (a maturity offset value) by using anthropometric variables and recently used in resisted sprint literature (Cahill et al. 2019; Mirwald et al. 2002). In brief, research collect mass, sitting height, standing height, and leg length with the following equation provided: maturity offset (years) = - 9.236 + ((0.0002708 x (leg length x sitting height)) + (-0.001663 x (age x leg length)) + (0.007216 x (age x sitting height)) + (0.02292 x (mass by stature ratio x 100)) (Mirwald et al. 2002). Additional non-evasive equations are also published in the sport medicine literature (Koziel & Melina 2018; Malina et al. 2015). Researchers also incorporate radiography to determine skeletal age, stage of pubic hair, and x-ray of the left wrist to account for maturity differences, yet these methods may present barriers for most sports scientists and practitioners (Malina et al. 2012; Materne et al. 2021; Muller et al. 2015). Future studies building upon the present work should strongly consider implementing one or more of these approaches.
Study findings are specific to youth male ice hockey players and thus extrapolating findings to other populations should be done with extreme caution. For instance, prior research indicates ice skating kinematic differences between males and females (Budarick et al., 2018; Shell et al., 2017) and differences in sprint (kinetic) profile components between males and females (Baena-Raya et al., 2021; Nagahara et al., 2021). Moreover, research indicates sprint (kinetic) profile components can differ across sport types (Jiménez-Reyes et al., 2018; Stavridis et al., 2019). Therefore, findings should be interpreted as it pertains to male youth ice hockey athletes.

The study only observed sprint and ice skating kinematics from a 2-dimensional perspective. This limits the overall kinematic information obtained during these types of locomotion. Prior studies, even in ice skating, implemented a 3-dimensional perspective (Budarick et al., 2018; Renaud et al., 2017; Robbins et al., 2018; Shell et al., 2017). However, it should be noted that most 3-dimensional ice skating studies stem from one research laboratory (Department of Kinesiology and Physical Education, Faculty of Education, McGill University, Montreal, Canada). Yet, the present study did not have access to the costly equipment and the time-intensive commitment this approach requires.

Moreover, equipment availability did not allow the measurement of additional muscle activity during overground and ice skating acceleration sprints. Prior literature indicates the importance of lower limb muscles, such as the gastrocnemius and gluteus maximus during both types of locomotion (Buckeridge et al., 2015; Howard et al., 2017; Kaartinen et al., 2021). For instance, plantar flexors appear important during the first few steps of ice skating acceleration to aid in propulsion and then diminish their activity following those initial steps (Buckeridge et al., 2015). During overground sprinting, plantar flexors are vital in overcoming gravity during the
maximal velocity phase, resulting in reduced contact time and faster sprint completion times (Howard et al., 2017).

Authors acknowledge the lack of morphological measures (fascicle length, pennation angle, cross-sectional area). These appear to change when exposed to sprint training and are known to be associated with the speed one can attain during maximal running (Abe et al., 2001; Abe et al., 2000; Luteberget et al., 2015). For instance, after 10-weeks of RST, authors reported a decrease in pennation angle (6%) which correlated highly (r = 0.92) to 10-meter overground sprint completion time (Luteberget et al., 2015).

Lastly, the study was statistically powered (80% power) to detect anticipated changes in the primary study outcome; changes in ice skating completion time (Cohen’s d = 0.68). Thus, the study is likely statistically underpowered to detect changes across all study measures of interests (potentially resulting in false negatives) (Nuzzo, 2016).

**FUTURE DIRECTIONS**

Ice skating research among ice hockey players is still in its infancy relative to other team-based sports. Consequently, there are many unanswered and exciting questions that researchers can undertake. Future studies should explore kinetics, kinematics, and muscle activity across a variety of ice skating movements, such as backwards and cornering ice skating. To our knowledge, this remains to be explored.

The load used during the RST program for both groups is based on methodology used during overground RST (Cross et al., 2017; Cross et al., 2018). Although the load is suggested for maximal horizontal power improvements, the “best” load during on-ice RST remains to be elucidated. Therefore, researchers and practitioners seeking to implement RST with their athletes may seek to replicate this study utilizing a variety of different loading schemes.
CONCLUSION

In the present study, both RST interventions as well as the control group training program improved certain measures associated with ice skating completion time (i.e., vertical jump height, broad jump distance, maximal force during IMTP, overground sprint completion times). However, only the RST groups improved in 1) overground Sprint (Kinetic) Profile components, 2) on-ice Sprint (Kinetic) Profile components, 3) increased muscle activity of vastus lateralis during overground sprinting and ice skating, and 4) altered certain kinematics during sprinting and ice skating. Collectively these changes in the RST groups may underpin the improvements noted among all ice skating completion times; with the on-ice RST group being superior (30-meter top speed, s-cornering agility drill, 9.14-meter and 36-meter acceleration ice skating sprint) compared to the off-ice RST group. Therefore, findings suggest that ice hockey coaches should incorporate on-ice RST to improve ice skating completion time across various ice skating scenarios. When on-ice RST is not feasible, overground RST appears to be an effective alternative for inducing comparable changes across most measures. Lastly, both forms of RST produce greater improvements in ice skating completion times and other measures of interest compared to the control group.
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*Frontiers in Sports and Active Living, 1, 26.*


APPENDIX A: EXERCISE QUESTIONNAIRE

Exercise Participation Questionnaire

1. Over the past 8 weeks, how many days per week of moderate to vigorous exercise?
   0  1  2  3  4  5  6  7

2. On average, minutes per day of exercise at this level?
   0  10  20  30  40  50  60  90  120  150+

3a. How many activities do you do per week to accomplish this exercise?
   (e.g. sports practice, P.E. class, conditioning workout, playing at the park, skateboarding, walking etc.)
   1  2  3  4  5+

3b. List the activities noted above.
   □ Sport _______________
   □ Sport _______________
   □ Sport _______________
   □ Other _______________
   □ Team conditioning
   □ Personal workout
   □ P.E. gym class
   □ Other _______________

Gender:  □ Female  □ Male
Age:  ________
Grade:  ________
APPENDIX B: IRB APPROVAL LETTER

July 6, 2021

Dear Martin:

Your study entitled, “Impact of Resisted Speed Training on Ice Hockey Performance”, IRB 
#S21 - 13, has been received, reviewed, and approved. It has met the expectation of IRB 
protocols and is approved for one year from the date of this letter.

Please keep a copy of this approval in your records along with any other documentation 
regarding this project. We request that you update us on any changes to the project for our 
records. Should a change in your research approach or methodology change, please contact 
our office for assistance or re-evaluation. Please feel free to proceed with your project.

Best Regards,

Susan Ward, Ph.D.
IRB Director
July 1, 2021

Brigham Young University – Idaho
Institutional Review Board
525 South Center St.
Rexburg, Idaho

Dear Brigham Young University – Idaho IRB:

The purpose of this letter is to grant Martin Dietze-Hermosa, a professor and researcher at the Brigham Young University – Idaho permission to conduct research in collaboration with the Teton Valley Foundation at the Kolter Ice Arena and outdoor space. The project, “Impact of Resisted Speed Training on Ice Hockey Performance” entails periodic assessment of ice hockey players for physical performance measures. Coaches and staff will aid in the recruitment of athletes. It is anticipated that around 20-30 athletes will participate in the assessments. BYU – Idaho undergraduate students will aid Martin Dietze-Hermosa with data collection on agreed upon dates, scheduled during training sessions of athletes. Collecting data on ice hockey athletes will be beneficial to the Teton Valley Foundation, specifically high school athletes, as reliable and periodically collected data will provide performance information currently not available to ice hockey coaches and staff. At the same time Martin Dietze-Hermosa will be able to use collected data for scientific purposes furthering the field of ice hockey performance.

BYU-Idaho agrees to assume all liability connected with this program, to (1) fully defend and indemnify TVF and its employees and board from any claims brought against us by any athlete, family, or other person due to the misconduct or negligence of the professor, graduate students or other employee, contractor, representative or other agent of BYU-Idaho; and (2) tender all such claims to BYU-Idaho’s insurance carrier as the primary insurer.

I, Amy Fradley, do hereby grant permission for Martin Dietze-Hermosa to conduct data collection sessions at the Kolter Ice Arena as a part of the “Impact of Resisted Speed Training on Ice Hockey Performance” project.

Sincerely,

Amy Fradley, Executive Director
APPENDIX D: COMBINED SUBJECT INFORMED CONSENT/ASSENT FORMS

Brigham Young University – Idaho Institutional Review Board
Informed Consent Form for Research Involving Human Subjects

Protocol Title: Impact of Resistled Speed Training on Ice Hockey Performance
Principal Investigator: Martin Diatza-Hermosa
Brigham Young University Idaho: Department of Human Performance and Recreation

In this consent form, “you” always means the study subject. If you are a legally authorized representative, please remember that “you” refers to the study subject.

Introduction

You are being asked to take part voluntarily in the research project described below. You are encouraged to take your time in making your decision. It is important that you read the information that describes the study. Please ask the study researcher or the study staff to explain any words or information that you do not clearly understand.

Why is this study being done?

The overarching aim of the proposed study is to monitor changes in the physical performance of ice hockey athletes throughout the athlete's season and to assess physical performance adaptations after participation in strength and conditioning training.

Approximately, twenty-four subjects will be enrolling in this study at the Kolter Ice Arena and surrounding facility space.

You are being asked to be in the study because you are an ice hockey player of the Teton Valley Foundation.

If you decide to enroll in this study, your involvement will last for the duration of your active enrollment in the 2021-2022 Teton Valley Foundation Ice Hockey Program. Two assessments are planned: 1) at the beginning of the season (October 2021), 2) around 8 weeks later, depending on competition scheduling, 3) more assessments later in the season may occur as directed by schedule availability and upon consultation with coaches. Assessments will be carried over the course of two-three days. Each visit will last around 2-3 hours at a time.
dependent on the facility schedule. You will also engage in the resisted speed training program twice a week during the weeks between pre and post assessments. The strength and conditioning sessions will last around 1 hour.

**What is involved in the study?**

If you agree to take part in this study, the research team will: collect measures of athletic performance associated with ice hockey performance. Height, weight, age, position, and leg length will be obtained. Athletic performance measures during vertical jump, board jump, isometric mid-thigh pull, on-ice and overground 30-meter sprint acceleration and 30-meter sprint-through data will be obtained. You will also engage in a strength and conditioning program aimed at increasing the athletic performance measures associated with ice hockey. All data collection and program implementation will take place at the Kolter Ice Arena and surrounding space. During both the on-ice and overground sprints a video recording from the side view will be obtained. The video recording will be used to calculate important measures of interest (sprint profile and sprint kinematics) associated with sprint performance. However, given the distance and angle of the video recording, you will not be identifiable.

The anthropometric and athletic performance assessments will be administered during your scheduled training sessions at the Kolter Ice Arena. Scheduling the assessment sessions will take place in close collaboration with the Teton Valley Foundation Director and team coaches to ensure the least minimal disruption to the competitive season.

You will: Engage in three assessment sessions of pre- and post-testing. During these testing sessions you will complete three trials of each test. During the first session, anthropometrics (height, weight, leg length), isometric mid-thigh pull performance. During the second session, you will perform the vertical jump and broad jump. During the last testing session, you will perform both the on-ice and overground sprints. The same testing order will be followed for post-testing. Each testing session will last around 2-3 hours. You will also engage in the strength and conditioning program twice a week at the Kolter Ice Arena. The sessions will last around 60 minutes and will be conducted on non-consecutive days.

**What are the risks and discomforts of the study?**
The risks associated with this research are no greater than those already involved when performing the ice hockey athletic sessions or strength and conditioning program sessions. However, there might be minor discomfort such as soreness, fatigue, muscle cramps, or minor strains that may result from the pre- and post-testing or the strength and conditioning training program. You will do a 5-8 minutes jog warm up at a comfortable pace to reduce the risk of muscular injury or discomfort. The testing will stop if there is a risk of injury, pain or if the researcher believes you should not continue. There will always be qualified personnel supervising the testing and training sessions. You will also perform a cool-down at the end of each session to help reduce the risk of soreness. The researchers will strive to provide maximum safety to the participants. However, there is a potential risk of musculoskeletal injury that is inherent in sports performance participation, training, and testing. All assessment sessions will be supervised by Martin Dietze-Hermosa. The team of coaches and researchers will supervise all athletes for appropriate technical execution of exercises to minimize the risk of injury. Therefore, the risks associated with this research are minimal and no greater than those involved in daily sports activities.

What will happen if I am injured in this study?

Brigham Young University – Idaho and its affiliates do not offer to pay for or cover the cost of medical treatment for research related illness or injury. No funds have been set aside to pay or reimburse you in the event of such injury or illness. You will not give up any of your legal rights by signing this consent form. You should report any such injury to Martin Dietze-Hermosa at (208-243-4312) and to Susan Ward of the BYU Institutional Review Board (IRB) at (208-496-2400) or email: wards@byui.edu

Are there benefits to taking part in this study?

Participating athletes may benefit indirectly by acquiring knowledge and understanding of their own athletic performance. As the research team analyzes the collected assessment data, information can be shared with the coaches leading to proper adjustments in programming, resulting in improved sports performance of the athletes. Repeated assessments over multi-year period will allow tracking detailed sports performance variables and allowing training sessions to better focus on individual performance goals. The long-term benefits include an improved competition performance of the volunteering ice hockey athletes. At the same time,
collected data will enable the research team to contribute to the sport sciences literature and provide scientific presentations at sports science conferences.

**What are my costs?**

There are no direct costs.

**Will I be paid to participate in this study?**

You will not be compensated for taking part in this research study.

**What other options are there?**

You have the option not to take part in this study. There will be no penalties involved if you choose not to take part in this study.

**What if I want to withdraw, or am asked to withdraw from this study?**

Taking part in this study is voluntary. You have the right to choose not to take part in this study. If you do not take part in the study, there will be no penalty or loss of benefit.

If you choose to take part, you have the right to stop at any time. However, we encourage you to talk to a member of the research group so that they know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them.

The researcher may decide to stop your participation without your permission, if he or she thinks that being in the study may cause you harm.

**Who do I call if I have questions or problems?**

You may ask any questions you have now. If you have questions later, you may call Martin Dietze-Hermosa at (208-243-4312) or email at dietzehermosam@byui.edu or Susan Ward of the BYUI Institutional Review Board (IRB) at (208-496-2400) or email: wards@byui.edu
What about confidentiality?

Your part in this study is confidential. The following procedures will be followed to keep their personal information confidential. Your information will be collected by the primary investigator, Martin Dietze-Hermosa. You will be assigned an identification number, so your personal information is not exposed. When the data is collected, your information will be added to an excel sheet that will be encrypted with a password and saved in a computer. No one will have access to the information other than the primary investigator.

The results of this research study may be presented at meetings or in publications; however, your name will not be disclosed in those presentations.

All records will be stored in a computer that will be password secured. The computer will be kept and locked in the Brigham Young University – Idaho Hart Building, Room 244C. Only the primary investigator will have access to the files.

Mandatory reporting

If information is revealed about child abuse or neglect, or potentially dangerous future behavior to others, the law requires that this information be reported to the proper authorities.

Authorization Statement

1- Child Assent
I have read each page of this paper about the study (or it was read to me). I will be given a copy of the form to keep. I know I can stop being in this study without penalty. I know that being in this study is voluntary and I choose to be in this study.

Child’s Printed Name: __________________________________________

Child’s Signature: ____________________________________________ Date: ______________

Witness or Mediator: __________________________________________ Date: ______________
I have explained the research at a level that is understandable by the child and believe that the child understands what is expected during this study.

Signature of Person Obtaining Assent:

_________________________________________________________ Date: __________

I agree that the research team may record video footage and collect photography that may include identifying features such as my face and body and that these images may be used in publication, presentations, and academic social media pages that are managed by the research team. I understand that a pseudonym may be assigned to me but that my confidentiality is not guaranteed due to the possible use and distribution of my likeness.

_________________________________________________________
Child’s Name (printed)

____________________________________ Date
Child’s Signature

2- Parental Consent

I would like for my child to be in this study.

_________________________________________________________
Child’s Name (printed)

_________________________________________________________
Parent/Guardian’s Name (printed)

____________________________________ Date
Parent/Guardian’s Signature

____________________________________ Date
Signature of Person Obtaining Consent
APPENDIX D: NSCA FOUNDATION GRANT APPROVAL NOTICE LETTER

05/12/2021

Dear Martin;

Thank you for submitting your application to apply for an NSCA Foundation Grant. The NSCA Foundation Grant Review Committee solicited multiple independent reviews of your proposal. We are excited to inform you that your application for an NSCA Foundation Grant has been approved for funding.

Please log in to your dashboard and submit the required forms. Once forms have been submitted, we can begin to process your funding. Please note that the forms and an approved IRB must be completed in order to receive your funding. Should you wish to obtain the grant reviewers' notes, please email us at Foundation@nsca.com so we can run that report for you.

Sincerely,

The NSCA Foundation
https://www.grantinterface.com/Home/Logon?urlkey=nsca
https://www.grantinterface.com/Home/ResetPassword?eqs=eyJ4-
TV3MEzXwF2KgF5_UwJ0Du0M29CSdP6tKiBxk2BxhVwudJx-
cZ_d9aYbpG8jv15tOtiDYvx1kFM_EpKLuf9HWK5bF4Y29z3NYOD63mqX5du6elebj14H2yX3GdB0

Applicant Information
Martin Dietze-Hermosa
240 Desert Pass Street Apartment #409
El Paso, Texas 79912

msdietzeher@miners.utep.edu
APPENDIX E: IMAGE/FIGURE COPYRIGHT PERMISSION

Figures 1.0.1, 1.0.2, 2.0.3, 2.0.6, 3.0.4, & 3.0.8

Keith,
Thank you for the timely response and your assistance. This is truly appreciated!

Manners, T. W. (2004). Sport-specific training for ice hockey. Strength & Conditioning Journal, 26(2), 16-21. (Figure 1a-c)


Gillenstam, K. M., Torsten, K., & Henriksson-Larsen, K. B. (2011). Physiological Correlates of Skating Performance in Women's and Men's Ice Hockey. The Journal of Strength & Conditioning Research, 25(6), 2133-2142. doi:10.1519/JSC.0b013e3181e0d72e (Figure 1a)


Kind Regards,

Thank you Martin,

The NSCA grants you permission to reprint the below requested materials in your dissertation.

Keith

Keith E. Ciesa, MA, CSCS,®D, NSCA-CPT,®D
Publications and Education Director
National Strength and Conditioning Association (NSCA)
1855 Bob Johnson Drive | Colorado Springs, CO 80906
P: 719 632 6722 | F: 719 632 6367
T: 800.815.6826 | keith.ciesa@nsca.com
everyone stronger | NSCA.com

Figures 2.0.2 & 2.0.4

Flude, Annabel <Annabel.Flude@tandf.co.uk>
Thu 5/5/2012 9:30 AM
To: Dietze-Hermosa, Martin
Cc: Flude, Annabel <Annabel.Flude@tandf.co.uk>

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"Figure 3a and 3b in Upjohn, T., Turcotta, R., Pearsall, D. J., & Loh, J. (2008). Three-dimensional kinematics of the lower limbs during forward ice hockey skating. Sports Biomech, 7(2), 206-221. doi:10.1080/14763140701841621"

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Thank you for your interest in our Journal.

With best wishes,
Hi Martin,

It's a pleasure to e-meet you. My apologies for the delay. Of course - feel free! I'm happy to make amendments if you would like something that better suits your needs. I haven't touched that article (or graphic) in a long time. Just let me know and I'll help however I can. Thank you!

Best,
Adam

Figures 2.0.7 & 2.0.8

Hi Martin,

Thanks for getting in touch. Of course, you have my permission for use in the thesis - thanks for asking.

Cheers,
Matt
VITA

Martin Sterling Dietze-Hermosa was born in Montreal, Canada. His passion for kinesiology led him to obtain a bachelor’s degree in Exercise Physiology from Brigham Young University-Idaho and a master’s degree in Exercise and Sport Science from the University of Utah. He continued his academic pursuits under the mentorship of Dr. Sandor Dorgo, as a student in the Interdisciplinary Health Sciences Ph.D. program at the University of Texas at El Paso. As a member of the Fitness Research Facility, Martin conducted research related to aging and exercise, unilateral exercise performance, and sprint training. Martin is an active member of the National Strength and Conditioning Association (NSCA) and the American College of Sports Medicine and presented at multiple of their conferences. Martin has published scientific papers in peer-reviewed journals. In 2018, 2019, and 2020, Martin received the esteemed Minority or Challenge Scholarship from the NSCA. He also received the extremely competitive NSCA Doctoral Research Grant to fund his dissertation project. In addition to actively engaging in human performance research in the Fitness Research Facility, Martin also served as an Assistant Instructor in the Department of Kinesiology during the 2020-2021 academic year teaching Group Exercise Techniques and Motor Behavior. Martin accepted a tenure-track faculty position starting Fall 2021 at Brigham Young University - Idaho while concluding his dissertation.

Contact Information: msdietzeher@miners.utep.edu
This dissertation was typed by Martin Sterling Dietze-Hermosa