

**The Relationship Between the Isometric Mid-Thigh Pull & Countermovement Jump and  
On-Ice Sprint Performance in Hockey Players**

by

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## ABSTRACT

On-ice sprint performance is a significant predictor and requirement for playing at the highest levels of hockey. It is important to understand the relationship between on-ice sprint performance and off-ice force production capabilities in order to appropriately design off-ice training programs. This will help to ensure proper adaptations are being pursued and optimal transfer of training from the conditioning room to the ice. The purpose of this study was to determine the relationship between maximum and dynamic strength measures and on-ice sprint performance from both an absolute and relative perspective. Both male (n=18) and female (n=13) hockey players from the University of Manitoba participated in this study. The off-ice measures included two assessment procedures utilizing a force plate; an isometric mid-thigh pull (IMTP) to assess maximum strength and a countermovement jump (CMJ) to assess dynamic strength. Both off-ice measures were analyzed from both a relative (CMJr and IMTPr) and absolute (CMJa and IMTPa) perspective. The on-ice measures were 15.42m and 7.71m sprint times. Pearson product moment correlations were used to quantify the relationships between variables. CMJa ( $r = -0.56$  to  $-0.61$ ), IMTPa ( $r = -0.65$  to  $-0.67$ ) and IMTPr ( $r = -0.55$ ) were significantly correlated ( $p < 0.05$ ) with on-ice sprint ability. When analyzed in groups of male and female only, no significant relationships were observed between CMJ measures and on-ice sprint times. No significant relationships were observed between IMTP measures and on-ice sprint times when individually analyzing male participants, while significant relationships ( $p < 0.05$ ) were observed in females between IMTPa ( $r = -0.70$  to  $-0.71$ ) and IMTPr ( $r = -0.68$  to  $-0.71$ ) and on-ice sprint times. Although previous research has found that on-ice sprint ability of varying distances has been related to other off-ice measures of dynamic strength (vertical jump height, off-ice sprint time), it has failed to adequately assess the role of maximum strength. It

was concluded that both maximum and dynamic strength are important factors in on-ice sprint performance in hockey players. Furthermore, it was concluded that maximum strength seems to be an important characteristic in on-ice sprint ability in females.

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## CHAPTER 1 – SCIENTIFIC FRAMEWORK

### 1.1 Introduction

Ice hockey is a high-speed, collision sport that requires the athlete to possess many athletic abilities. One of the most important abilities needed to play at the highest levels in ice-hockey is on-ice sprinting as players frequently need to reach high speeds in short amounts of time (Farlinger, Kruisselbrink, & Fowles, 2007; Peterson et al., 2015). Correlation of off-ice performance measures to on-ice skating performance is important for both the sport coach and strength and conditioning professional to properly design and monitor training program effectiveness during both the competitive season and off-season.

Studies have examined the relationship between off-ice performance tests and on-ice skating performance, finding significant correlational relationships between vertical jump height and 40-yard sprint tests with a variety of on-ice linear skating assessments (Behm, Wahl, Button, Power & Anderson, 2005; Burr et al., 2007; Janot, Beltz & Dalleck, 2015; Peterson et al., 2016). Multiple studies have assessed the relationship between on-ice sprint performance and tests of dynamic strength (vertical jump, broad jump) but have failed to adequately assess the relationship between on-ice sprint performance and tests of maximum strength (Behm, Wahl, Button, Power & Anderson, 2005; Bracko & George, 2001; Janot, Beltz & Dalleck, 2015; Runner, Lehnard, Butterfield, Tu & O'Neill, 2015). Investigating the relationship between maximum strength and on-ice sprint performance is important since past literature has indicated a strong relationship between maximum strength and sprinting ability (Thomas, Comfort, Chiang & Jones, 2015; Wang et al., 2016). Edman & Esping (2013), Janot, Beltz & Dalleck (2015), and Runner, Lehnard, Butterfield, Tu & O'Neill (2015) are the only studies to directly assess the

relationship between maximum strength and on-ice sprint ability; utilizing the 1-repetition maximum (1RM) squat and 17.5m, 6.1m and 90ft on-ice sprint tests, respectively. It is also important to note that only one of the three previously mentioned studies included female hockey players in their analysis. Recently, there has been the introduction of a new, more efficient method of assessing dynamic and maximum strength among strength and conditioning and sport science professionals: countermovement jump (CMJ) and isometric mid-thigh pull (IMTP) using force plate technology (Sheppard, Chapman & Taylor, 2011; Thomas, Comfort, Chiang & Jones, 2015).

The use of force plate testing procedures such as the IMTP and CMJ have been shown to be valid and reliable measures of lower body strength and power, respectively (Sheppard, Chapman & Taylor, 2011; Thomas, Comfort, Chiang & Jones, 2015; Haff et al., 1997). The IMTP correlates with the 1RM squat and 1RM deadlift exercises; two commonly used maximum strength assessments (Wang et al., 2016; De Witt et al., 2016). CMJ peak force output has been shown to be significantly correlated with vertical jump (VJ) height (Thomas, Jones, Rothwell, Chiang & Comfort, 2015).

A force plate allows the measurement of maximum and dynamic strength levels in a large group setting, typical of collegiate strength and conditioning programs. In the past, strength testing would be performed utilizing a variety of methods (such as 1-RM), all of which present varying levels of safety, planning, and time commitment issues. 1-RM testing requires the use of multiple spotters depending on the type of exercise being performed whereas force plate testing utilizing the IMTP and CMJ protocols presents relatively little safety concerns and one operator.

The relationship between on-ice sprint performance, IMTP and CMJ has not been investigated. The relationships between maximum and dynamic strength tests and dynamic

performance measures such as sprint and jump tests have been investigated (Wang et al., 2016; Sheppard, Chapman, & Taylor, 2011), but on-ice sprint performance has not been one of them. Furthermore, very limited research of this nature has been conducted with female hockey players. Due to increasing prevalence, utility and validity of force plate testing procedures, this relationship warrants further investigation the male and female hockey population. This information will showcase the relationship between on-ice sprint performance and two strength qualities: dynamic strength (assessed via CMJ) and maximum strength (assessed via IMTP) in male and female hockey players. This information will help to uncover the value of two types of strength (maximum strength or dynamic strength) in males and females for one aspect of the sport of hockey, specifically on-ice sprint performance. The purpose of this study is to evaluate the relationship between two off-ice testing variables utilizing a force plate (maximum strength via IMTP and dynamic strength via CMJ) and on-ice sprint performance.

## **1.2 Review of Literature**

Various physiological attributes contribute to successful ice-hockey performance with the combined interaction of the aerobic and anaerobic energy pathways, muscular strength, muscular power, coordination, flexibility and balance all being important. Skating performance is one of the fundamental skills of a successful hockey player yet there has been little investigation into the relationship between trainable qualities such as maximum and dynamic strength and on-ice sprint performance. Playing at the highest levels in hockey requires high-level skating ability, which requires high amounts of anaerobic power in order to maximize on-ice sprint performance (Peterson et al., 2016). Due to the lack of research investigating the relationship between on-ice sprint performance and off-ice maximum and dynamic strength, there are several unsupported theories and methods that guide off-ice training of hockey players which could be detrimental to

performance. The relationship between lower body maximum strength, lower body dynamic strength and on-ice sprint performance is one that warrants further investigation in order to better understand performance qualities associated with better on-ice sprint performance in males and females.

Lower body maximum strength is the absolute maximum amount of force (kilograms of force [kgf]) that can be produced by the lower body in a resisted setting and lower body dynamic strength is the maximum amount of force (kgf) that can be produced by the lower body in an unresisted setting (Sheppard, Chapman, & Taylor, 2011). Relative lower body maximum strength is the absolute maximum amount of force produced by the lower body in a resisted setting per kilogram of bodyweight (kgf/kg). Relative lower body dynamic strength is the absolute maximum amount of force produced by the lower body in an unresisted setting per kilogram of bodyweight (kgf/kg).

### **1.2.1 Sex Differences in Performance**

Hockey is a sport played by both males and females, with the female game growing rapidly in recent years. Previous research has demonstrated differences in skating sprint start kinematics between male and female hockey players (Shell et al., 2017). Despite this, the majority of previous research has failed to include females when investigating the relationship of maximum and dynamic strength with on-ice sprint performance. Prior to investigating the relationship between maximum and dynamic strength and on-ice sprint performance in both males and females, it is important to understand the differences between sexes and how these impact both maximum and dynamic strength.

Several approaches determine whether a true sex difference exists in maximum and dynamic strength. These evaluations relate to the muscle's cross-sectional area, an absolute basis

of strength, fiber-type characteristics and estimates of body composition. It is well known that males are often heavier and possess more skeletal muscle than females which would have a direct impact on maximum and dynamic strength levels. Haizlip, Harrison & Leinwand (2015) stated that human skeletal muscle, regardless of sex, generates a maximum of between 16 and 30 newtons (N) of force. Because we know that males tend to be heavier than females and possess more skeletal muscle, this would result in more force output in males compared to females. Ikai & Fukunaga (1968) found that muscle strength showed a linear relationship with muscle cross-sectional area, meaning that individuals with larger muscle cross-sectional area will generate the greatest absolute force. When comparing muscular strength on an absolute basis, results indicate that males possess considerably greater strength than females (Janot et al., 2015; Peterson, Alvar & Rhea, 2006; Rice et al., 2017). Another contributing factor to sex differences in maximum and dynamic strength is sex-based differences in skeletal muscle fiber-type composition. Haizlip, Harrison & Leinwand (2015) found that there is a higher prevalence of type-I and -IIA fibers in females compared with males. There are three main myosin heavy chain isoforms (MyHC-I, -IIA, -IIx) present in human skeletal muscle, which increase in contractile strength and speed in the presented order (Haizlip, Harrison & Leinwand, 2015). This difference in fiber-type distribution has implications on both maximum and dynamic strength as a higher prevalence of muscle fibers of the slow twitch variety will negatively impact a female's ability to produce force. Sex-related differences in performance can be attributed in part to a greater body mass, greater amount of muscle mass, fiber-type distribution and larger cross-sectional area when comparing males and females.

### **1.2.2 Relationship Between Maximum Strength and Dynamic Performance Ability**

Lower body maximum strength is the absolute maximum amount of force (kilograms of force [kgf]) that can be produced by the lower body in a resisted setting and lower body dynamic strength is the maximum amount of force (kgf) that can be produced by the lower body in an unresisted setting (Sheppard, Chapman, & Taylor, 2011). A review of the literature indicates a beneficial connection between closed kinetic chain lower body maximum strength levels and a variety of dynamic performance assessments such as the VJ, broad jump and sprinting (Baker & Nance, 1999; Peterson, Alvar & Rhea, 2006; Wang et al., 2016). A fundamental relationship exists between maximum strength and dynamic performance abilities, which dictates that an individual cannot possess superior abilities in dynamic performance tests without first being strong.

Maximal and dynamic strength has been measured at multiple levels such as the single-cell level, whole muscle level, single- and multi-joint level. Regardless of the approach, the characteristic hyperbola can be used to describe the inverse relationship between force and velocity of concentric muscle action (Cormie, McGuigan & Newton, 2011). Muscle mechanics, specifically the force-velocity relationship and length-tension relationship can have major impacts on muscular strength. The force-velocity relationship states that as the velocity of muscular contraction is increased, less force is capable of being generated during that contraction (Tihanyi, Apor & Fekete, 1982). The amount of force produced by a muscle is dictated by the number of actin-myosin cross-bridges that form and the speed at which they attach and detach. As the velocity of muscle contraction increases, the number of cross-bridges that can form to produce force will decrease. The length-tension relationship states that the ability of skeletal muscle to generate force is critically dependent on sarcomere length (Gordon, Huxley & Julian, 1966). The greatest potential for force production exists when the sarcomere length provides for

optimal overlap between the actin and myosin filaments, which allows for maximal cross-bridge interaction (Gordon, Huxley & Julian, 1966).

The force-velocity relationship observed in muscle mechanics is the reason why the IMTP and CMJ produce varying amounts of force. The IMTP is a measure of maximum lower body strength and produces the highest amounts of force as a result of time and the presence of external resistance. The IMTP is performed over 5-seconds which leads to maximal force production. This is in contrast to the CMJ which is a measure of dynamic lower body strength and produces less force as a result of lack of time and lack of external resistance. The CMJ is performed over 0.20-0.30-seconds which does not allow for maximal actin-myosin cross-bridging to occur which leads to submaximal force production (McMahon, Rej & Comfort, 2017). The assertion that maximal strength capabilities underpin dynamic performance abilities can be demonstrated by the force-velocity relationship. By improving maximal strength, you improve force production capabilities, and when force production increases, the entire force-velocity hyperbola shifts up and to the right (Cormie, McGuigan & Newton, 2011). This results in higher force being exerted at higher velocities. When this is achieved in dynamic performance tests such as sprinting, we would expect to see increased ground reaction forces resulting in increased rates of horizontal velocity.

The assertion that maximal strength underpins dynamic performance abilities is further supported by the relationship that exists between maximum strength and dynamic performance abilities between elite and sub-elite athletes. Cormie, McBride & McCaulley (2009) compared the strength and power capabilities of Division 1 male athletes (football and track) and untrained males. The Division 1 male athletes produced both significantly higher 1RM back squat (kg/kg bodyweight) scores and significantly higher maximum power (Watts/kg) in the CMJ performed

on a force plate compared to the untrained males. McBride et al., (1999) investigated the effect of involvement in powerlifting, Olympic weightlifting and sprint training compared to a control group of recreationally active men. They found that all 3 trained groups produced significantly higher 1RM squat (kg/kg bodyweight) and vertical jump power outputs (W/kg) compared to the control group (McBride et al., 1999). These findings demonstrate that enhanced maximum strength adaptations underpin enhanced dynamic performance abilities. These findings also demonstrate that individuals who engage in strength training tend to produce superior results in dynamic performance assessments compared to individuals who do not engage in strength training.

The relationship between lower body maximum strength and dynamic performance abilities in athletes further showcases the importance of lower body maximum strength. Peterson, Alvar & Rhea (2006) investigated the relationship between lower body maximum strength and several fundamental dynamic performance abilities in 54 collegiate athletes ( $N=55$ , 36 female) from several sports such as basketball, volleyball, baseball and softball. Lower body maximum strength was assessed with the 1-RM back squat while jump performance was assessed with the VJ (meters [m]) and broad jump (m) and sprint performance was assessed with a 20m and 40m sprint (m/sec). The authors found that both the relative and absolute 1-RM back squat produced large and significant correlations with all dynamic performance measures. Relative 1RM back squat (1RM back squat/bodyweight) produced significant correlations with 20m sprint velocity ( $r = 0.876, p < 0.01$ ), 40m sprint velocity ( $r = 0.881, p < 0.01$ ), agility T-test ( $r = 0.805, p < 0.01$ ), broad jump ( $r = -0.814, p < 0.01$ ) and VJ ( $r = 0.852, p < 0.01$ ). Absolute 1RM back squat produced significant correlations with 20m sprint ( $r = 0.820, p < 0.01$ ), 40m sprint ( $r = 0.854, p < 0.01$ ), agility T-test ( $r = -0.784, p < 0.01$ ), broad jump ( $r = 0.767, p < 0.01$ ) and VJ ( $r = 0.859, p < 0.01$ ). It

is important to note that the authors found a significant correlation between both absolute and relative maximal strength abilities and both 20m and 40m sprint velocity which highlights the positive relationship between maximal strength and sprint velocity in team-sport athletes. This research demonstrates that absolute and relative maximum strength are related to dynamic performance abilities.

Baker & Nance (1999) conducted performance testing (10m and 40m sprint time) on 20 professional male rugby players and looked at the correlation with tests of lower body strength (loaded jump squats, 3RM back squat & 3RM hang power clean). The correlation between the absolute scores of lower body strength variables and 10m sprint velocity were all non-significant ( $r = -0.03$  to  $-0.36$ ;  $p > 0.05$ ). Interestingly, the correlation between relative scores of lower body strength variables and 10m sprint velocity were significant except the relative back squat 3RM (Range:  $r = -0.39$  to  $-0.67$  [ $p < 0.05$ ]). This suggests that relative maximum strength levels are related to 10m sprint ability. Similar correlations were noted where the absolute lower body strength variables and 40m sprint time were not significant ( $r = -0.02$  to  $-0.24$ ,  $p > 0.05$ ), while relative measures of lower body strength variables all showed significant correlations with 40m sprint velocity and ranged from  $r = -0.52$  to  $-0.75$  ( $p < 0.05$ ). It is also important to note that the relative 3RM hang power clean – which has an almost identical starting position as the IMTP – had the second highest correlation with 10m sprint velocity ( $r = -0.57$ ,  $p < 0.05$ ) and 40m sprint velocity ( $r = -0.72$ ,  $p < 0.05$ ). This is likely due to the fact that the hang power clean is predominantly a concentric, extension-based activity and has similar knee angles to a standing sprint start. There is a significant relationship between an individual's relative maximum lower body strength and their dynamic strength as measured in VJ and sprint tests (Baker & Nance, 1999; Peterson, Alvar & Rhea, 2016). Thus, it seems that a requisite amount of strength is

needed to apply high amounts of force into the ground which impacts an individual's ability to jump high and/or sprint fast.

A study by Wang et al. (2016) examined the relationship between IMTP force and strength, agility and sprint performance in male collegiate rugby players. Testing was performed on 3 days separated by 48 hours of rest, where the first 2 testing sessions were IMTP and back squat 1RM respectively, and the third testing session, included both agility and sprint tests which were performed outdoors on a rugby pitch. Significant correlation was found between 0-5m sprint velocity and IMTP force ( $r = 0.539, p < 0.05$ ) which showcases a positive relationship between maximum strength and 0-5m sprint velocity. The positive relationship between IMTP force and 0-5m sprint velocity signifies that as one variable increases, the other will increase.

Further, Barr (2012) conducted a study that had collegiate football players take part in a 16-week Olympic weightlifting style program aimed at enhancing their CMJ height. Over the 16 weeks a statistically significant improvement of 4.7cm was seen in the CMJ height of the group along with significant increases in the group's clean, clean/kg of body mass, front squat and front squat/kg of body mass (Barr, 2012). This study effectively showed how increasing an athlete's relative and absolute maximum strength can positively impact dynamic performance measures. Also, a study by Thomas, Comfort, Chiang & Jones (2015) investigated the use of isometric strength testing as a determinant of sprint and change of direction performance in male collegiate soccer and rugby players ( $N=14$ ). Significant correlations were found between absolute IMTP peak force and both 5m- ( $r = -0.57, p < 0.01$ ) and 20m-sprint velocity ( $r = -0.69, p < 0.05$ ) (Thomas et al., 2015). This finding again showcases the strong relationship between maximum strength and dynamic performance measures. Finally, a study by Morin et al. (2015) looked at the ground reaction forces (r-GRF's) during different phases of a 40m sprint in 9 elite male sprinters by

placing a force plate at 10m, 15m, 20m, 30m & 40m markings. Morin et al. (2015) found r-GRF's to be highest in the first 20m of a 40m sprint test and found when comparing elite and amateur sprinters, elite sprinters applied higher r-GRF than amateur sprinters and produced faster sprint times.

It seems that in order to accelerate, sprint fast and jump high, an athlete must apply high levels of force into the ground to propel themselves forward and/or upward. High levels of force application into the ground requires high levels of maximum strength. Cross-sectional comparisons have revealed that individuals with higher strength levels showcase markedly superior dynamic performance abilities than those with a low level of maximum strength.

### **1.2.3 Relationship Between Dynamic Strength and Dynamic Performance Ability**

Studies have identified that VJ and off-ice sprint performance of varying distances are related to on-ice sprint performance of varying distances (Bracko & George, 2001; Farlinger et al., 2007; Janot et al., 2015; Runner et al., 2015). Janot et al., (2015) conducted a study to determine if off-ice performance variables could predict on-ice sprint performance in 26 Division III male and female collegiate hockey players. Off-ice tests included VJ, 40-yard sprint, 1RM squat, pro-agility or 5-10-5 test, Wingate cycle ergometer test and a 1.5-mile run. On-ice skating tests included a 6.1m acceleration, an agility cornering S-turn test (sec), a 44.80m speed test (sec) and 15.24m full speed test (sec). The results produced significant correlations between VJ and 40-yard sprint and the on-ice 44.80m speed test. These findings demonstrate that off-ice tests of jump and sprint ability are associated with on-ice sprint performance in Division III collegiate male and female hockey players.

Bracko & George (2001) conducted a study to identify the off-ice variables associated with skating acceleration, speed, agility and anaerobic capacity and power in women's hockey

players. Sixty-one players participated during their off-season and completed skating tests including the 6.1m acceleration, 47.85m speed, agility cornering S-turn and a repeated sprint skate test. Off-ice variables included flexibility, VJ, 40-yard dash, sit-ups and push-ups. Correlations found that the 40-yard dash had the strongest correlation ( $r = 0.72, p < 0.05$ ) with on-ice speed over 47.85m (Bracko & George, 2001) which means that athletes that were faster off-ice also tended to be faster on-ice.

Behm et al. (2005) looked at the relationship between maximum forward skating speed and off-ice performance measures (40-yard sprint, concentric squat jump, drop jump, 1RM leg press and balance). Correlations were used to quantify the relationships between the variables in 30 high school and junior-level male hockey players. Behm et al. (2005) identified that hockey skating placed a greater emphasis on impulse (producing force without a rapid eccentric pre-stretch) rather than the stretch-shortening cycle (producing force with a rapid eccentric pre-stretch) and therefore, hypothesized that maximum lower body strength might be more important than reactive strength for skating speed. Contrary to the hypothesis, the strength measure (1RM leg press) did not demonstrate significant correlations with skating speed. Only the 40-yard sprint and concentric squat jump produced strong correlations with forward skating speed. This may be due to the fact that the leg press occurs with an athlete lying on their back, pushing against a resistance at an angle, which is much different than exerting force in the universal athletic position (standing on two feet with flexion in the hips, knees and ankles).

Runner et al., (2015) examined the relationship between off-ice performance variables such as VJ, broad jump, 40-yard sprint and 1RM back squat with on-ice skating tests: 90-foot acceleration test ( $m/sec^2$ ), 90-foot backward acceleration test ( $m/sec^2$ ), and the 50-foot flying top speed test ( $m/sec$ ) from 40 male National Collegiate Athletic Association Division 1 hockey

players. The strength of association between off-ice and on-ice performance variables was measured via Pearson correlation coefficients. VJ ( $r = -0.51$  to  $-0.55$ ,  $p < 0.05$ ) and 40-yard sprint ( $r = 0.37$  to  $0.46$ ,  $p < 0.05$ ) were consistently related to all 3 on-ice performance variables. There was a negative relationship between VJ and the 3 on-ice performance tests which means the higher an athlete can jump the faster he/she will perform the 90-foot acceleration test, 90-foot backward acceleration test and the 50-foot flying top speed test (Runner et al., 2015). The research demonstrates a strong relationship between VJ and sprinting abilities with on-ice sprint performance in hockey players of various levels of play and sex (Behm et al., 2005; Bracko & George, 2001; Janot et al., 2015; Runner et al., 2015). This relationship provides evidence of the importance of off-ice dynamic strength levels in hockey players and their relationship with on-ice sprint ability.

Previous research has demonstrated that athletes that showcase the best sprinting and jumping abilities off-ice tend to perform better in tests of on-ice sprint performance (Behm et al., 2005; Bracko & George, 2001; Janot et al., 2015; Runner et al., 2015). Investigating the relationship between peak force production in the CMJ (dynamic strength) and on-ice sprint performance will allow practitioners to identify qualities to be targeted during training and provide insight into the relationship between on-ice sprint performance and the force-velocity relationship.

#### **1.2.4 IMTP Validity and Reliability**

The accurate assessment of strength qualities is an important aspect of strength and conditioning and sport science. The purpose of assessing strength and power qualities in hockey players, and their relationship with on-ice sprint ability is to gain insight into the training needs

of the hockey population. Previous research has established that the IMTP is a valid measure of assessing strength qualities in the lower body (De Witt et al., 2016; Haff et al., 1997; Wang et al., 2016). De Witt et al. (2016) found that the IMTP is a reliable and valid predictor of deadlift 1RM and lower body peak force production. The subjects took part in 1 familiarization session, followed by 2 testing sessions separated by 72 hours which consisted of 3 IMTP trials followed by deadlift 1RM assessment (De Witt et al., 2016). IMTP peak force was reproducible both within (ICC = 0.98) and between (ICC = 0.89) testing sessions and the IMTP peak force was significantly correlated ( $r=0.88, p<0.05$ ) with deadlift 1RM (De Witt et al., 2016). Haff et al. (1997) examined the force-time characteristics and correlation of various aspects of dynamic and isometric muscle actions, represented by an isometric clean pull (same as IMTP), CMJ and squat jump (SJ). The authors found that isometric peak force and isometric rate of force development during the isometric clean pull had strong correlations (ICC = 0.92) and a lack of significant difference between trials which showcases strong repeatability (Haff et al., 1997). They also found the peak force on the clean pull to be highly correlated ( $r = 0.95, p<0.05$ ) with participants' power clean 1RM scores which is a blend of lower body maximum and dynamic strength. These results showcase the reliability and validity of the IMTP as an indicator of lower body maximum strength. Wang et al. (2016) assessed the relationship between IMTP and strength, speed and agility performance in 15 university rugby players. The players performed strength, speed and agility testing on 3 separate days which consisted of a 1RM squat, IMTP, 40-m sprint, pro-agility test and T-test. Wang et al. (2016) reported a Pearson product moment correlation of  $r=0.866, p<0.05$  between IMTP peak force and 1RM squat which showcases the validity of the IMTP for maximal strength testing. The results of these studies have demonstrated

that the IMTP test is a valid measure of assessing maximum strength qualities in the lower body (De Witt et al., 2016; Haff et al., 1997; Wang et al., 2016).

### **1.2.5 CMJ Validity and Reliability**

Conventionally, jump test protocols have been divided into 2 main categories of jump mechanics: a countermovement jump (CMJ) in which a pre-jump movement is permitted and a squat jump (SJ) in which a pre-jump movement is not. Burr, Jamnik, Dogra & Gledhill (2007) conducted a study on the top 95 National Hockey League (NHL) draft picks entering the NHL draft to determine the most appropriate jump test protocol to assess lower body dynamic strength in elite hockey players. Testing was performed in a fitness testing combine in which the Vertec (Sports Imports, Hilliard, Ohio) and Just Jump (Just Jump, Probotics, Huntsville, Alabama) test protocols were separated by a test of trunk flexibility so participants were not required to perform both jumps consecutively and fatigue was not a factor (Burr et al., 2007). All jump test protocols produced very high test-retest reliability ( $ICC=0.979-0.997$ ) and there were no significant differences between SJ and CMJ power outputs on either the Just Jump or Vertec jump test protocols (Burr et al., 2007). Both the CMJ and SJ are acceptable and reliable measures of lower body dynamic strength in hockey players (Burr et al., 2007). The criterion measurement device for jump assessment protocols is a laboratory grade force plate (Buckthorpe, Morris & Folland, 2012). Buckthorpe et al. (2012) compared several commonly utilized jump test measurement tools (VerTec, belt mat, contact mat, portable force plate) with a countermovement jump test performed on a laboratory grade force plate (Type 9281B Kistler, Instrument AG, Winterthur, Switzerland). The laboratory grade force plate recorded the highest jumps while the portable force plate was within 1cm of each jump (Buckthorpe et al., 2012). Markovic, Dizdar,

Jukic & Cardinale (2004) conducted a study to determine the reliability of the SJ and CMJ tests in 93 college-aged, male physical education students. It was found that the CMJ was the most reliable jumping test when being compared to 5 other popular methods (standing long jump, Sargent's jump, squat jump, standing triple jump, Abakakow's vertical jump with and without arm swing) of assessing lower body dynamic strength qualities (ICC = 0.98) (Markovic et al., 2004). Sheppard, Cormack, McGuigan, Taylor & Newton (2008) assessed the reliability of loaded and unloaded CMJ utilizing a force plate in 26 high performance male athletes who were part of full-time high-performance sport training programs from the volleyball and Australian rules football National Development teams. Reliability assessments were conducted at the same time of day, 1-week apart with physical activity standardized 48-hours prior to assessment to reduce potential impact on test performance (Sheppard et al., 2008). Sheppard et al. (2008) reported a 1.8% change in mean CMJ score for the 2 trials and a variance of 3.5% for the 2 CMJ trials. The results of the reliability assessment of the CMJ separated by 1-week was an ICC of 0.96. It has been demonstrated that the CMJ test performed on a laboratory grade force plate is a valid and reliable measure of lower body dynamic strength (Buckthorpe et al., 2012; Burr et al., 2007; Markovic et al., 2004; Sheppard et al., 2008).

To my knowledge, the relationship between on-ice sprint ability and tests of lower body dynamic (CMJ) and maximum strength (IMTP) utilizing a force plate with hockey players has never been investigated. This is important due to the increasing prevalence of force plate testing procedures and to better guide training program design as it relates to peak force production abilities of hockey players. Past literature has provided some evidence of the importance of off-ice dynamic strength levels in hockey players and their relationship with on-ice sprint ability of varying distances (Behm et al., 2005; Bracko & George, 2001; Janot, Beltz & Dalleck, 2015;

Runner et al., 2015). It has been demonstrated that the CMJ test performed on a laboratory grade force plate is a valid and reliable measure of lower body dynamic strength (Buckthorpe et al., 2012; Burr et al., 2007; Markovic et al., 2004; Sheppard et al., 2008). The literature has demonstrated that the IMTP test is a valid measure of assessing maximum strength qualities in the lower body (De Witt et al., 2016; Haff et al., 1997; Wang et al., 2016). Multiple studies have indicated the importance of the ability to produce force for successful performance in hockey (Farlinger, Kruisselbrink, & Fowles, 2007; Peterson et al., 2015; Potteiger, Smith, Maier, & Foster, 2010) yet these studies have failed to utilize the increasingly common and versatile tool that is the force plate. The majority of research in ice hockey employs on-ice sprint assessment protocols that are much longer or shorter distances than those observed during gameplay (Lignell, Fransson, Krustup & Mohr, 2018). In the present study, we utilized a standardized ice-skating sprint distance (blue line to blue line on a regulation North American ice surface) to determine on-ice sprint ability and its relationship with tests of lower body maximum (IMTP) and dynamic strength (CMJ). The purpose of this study is to evaluate the relationship between lower body maximum and dynamic strength utilizing the IMTP and CMJ, with on-ice sprint ability.

### **1.3 Statement of the Problem**

To my knowledge, the relationship between on-ice sprint performance and tests of lower body maximum (IMTP) and dynamic (CMJ) strength utilizing a force plate with hockey players has never been investigated. More research is needed to understand what type of lower body performance qualities are best correlated with on-ice sprint performance which may improve transfer of training from the training facility to the ice. The purpose of this study is to evaluate

the relationship between two off-ice testing variables utilizing a force plate (maximum strength via IMTP and dynamic strength via CMJ) and on-ice sprint performance in collegiate level hockey players to better understand the relationship between peak force production and on-ice sprint performance.

#### **1.4 Hypotheses**

The hypotheses of this study are:

- 1) That a significant negative correlation will be found between absolute dynamic strength and on-ice sprint time.
- 2) That a significant negative correlation will be found between relative dynamic strength and on-ice sprint time.
- 3) That a non-significant negative correlation will be found between absolute maximum strength and on-ice sprint time.
- 4) That a non-significant negative correlation will be found between relative maximum strength and on-ice sprint time.

## **CHAPTER 2 – METHODS**

### **2.1 Experimental Approach to the Problem**

The study was designed to investigate the relationship between off-ice force plate performance measures (IMTP and CMJ) with on-ice skating sprint speed in collegiate ice hockey players. To establish correlations between off-ice and on-ice variables, measurements consisted of the IMTP and CMJ which were performed, calculated, and compared to on-ice sprint ability

over 7.71m and 15.42m (time). Descriptive characteristics include age (years), height (m) and bodyweight (kg).

## 2.2 Participants

A sample size calculation was performed, and it was anticipated that to reach statistical significance at  $\alpha < 0.05$  and  $\beta = 0.80$ , with a previous correlation coefficient of  $r = -0.55$  (between vertical jump height and the on-ice skating velocity over 90 feet), that a sample size of 24 participants will be required for the current study (Runner et al., 2015). Athletes from the University of Manitoba Bison's men's and women's hockey team were recruited for participation in this study. The recruitment process involved seeking permission from respective Head Coaches to speak to each team, followed by a short presentation to each team and subsequent offer to participate (see Figure 1). Testing took place at Wayne Fleming Arena and the High-Performance Training Center at the University of Manitoba. Inclusion criteria included current participation as a student-athlete on the University of Manitoba men's or women's hockey team and 1-year of experience in a structured strength and conditioning program (Boland, Delude, Miele, 2017). Exclusion criteria required that the participants were free of any musculoskeletal injury that may inhibit maximal effort performance of all testing procedures, as determined by the team's Certified Athletic Therapist (CAT[C]). Randomization of testing order was implemented to protect against potential order effect and was implemented by randomizing the testing order of off-ice and on-ice testing and order of CMJ and IMTP testing. Participants were instructed to abstain from alcohol, vigorous physical activity and heavy weight-lifting 48 hours prior to testing. Participants were verbally informed of the procedures and were asked to

provide written informed consent prior to participation. The study received ethical approval from the University of Manitoba Education/Nursing Research Ethics Board.



**Figure 1 – Recruitment process flow chart.**

## **2.3 Procedures**

### **2.3.1 Off-Ice Procedures**

Height was measured prior to warm-up and weight was measured by the force plate software as part of the force plate testing procedures. Prior to testing the CMJ and IMTP, the athletes underwent a standardized warm-up consisting of a supervised, 5-minute dynamic warm-up followed by 2-repetitions of the CMJ (at maximal intensity) and 2-repetitions of the IMTP (where 1-repetition was held for 3-seconds at 50% of the athletes self-selected maximal intensity and 1-repetition was held for 3-seconds at 75% of the athletes self-selected maximal intensity). Both repetitions of the CMJ and IMTP allowed for familiarization and were separated by 1-minute of passive rest. Two trials of each test (CMJ and IMTP) were performed in a randomized

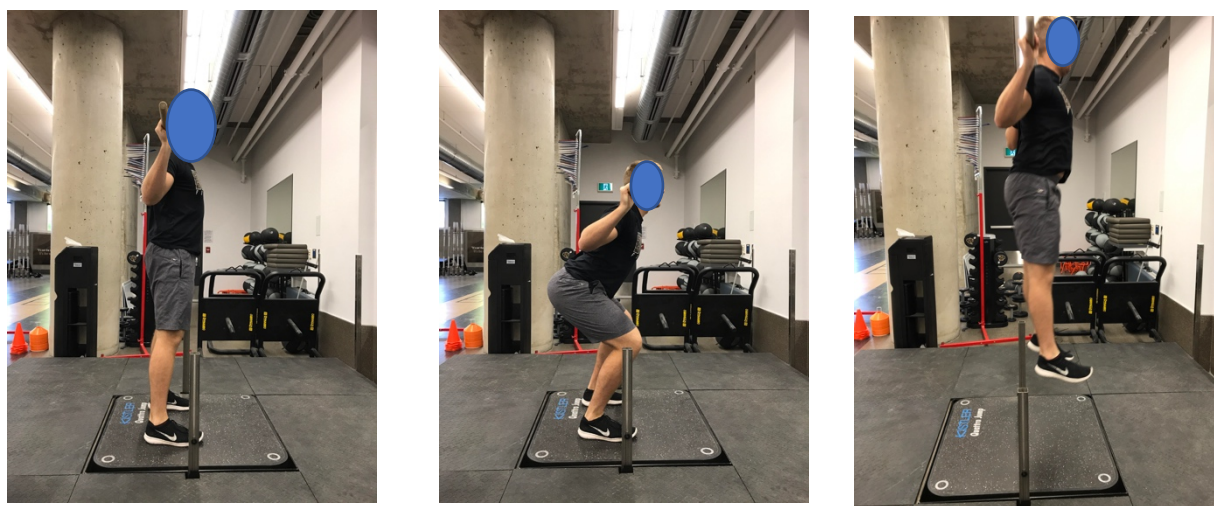
order and each trial was separated by 1-minute of passive rest. Upon completion of the first off-ice test, 5-minutes of passive recovery was given to allow for complete recovery of the phosphagen energy system. The participant then proceeded to complete the second off-ice test. The highest peak force produced for both the CMJ and IMTP was used for analysis. It is important to note that in addition to the familiarization trials, all participants were familiar and had completed these testing procedures previously as part of their regular team intake testing protocol.

The CMJ test required the athlete stand with a dowel on their back and their feet on the force plate (Quattro Jump, Kistler USA, Amherst, NY, USA) (see Figure 1A). A dowel was utilized to control for use of the upper body during the CMJ. The athlete self-selected their squat depth to produce a jump with the most power and height possible. The athlete was given a “ready” command, and then given a “go” command by the operator when the jump was to be initiated. Each athlete was instructed to jump as high as they could, as quickly as they could, all while keeping the dowel in contact with their shoulders and sticking their landing on the force plate. Rest time between trials was 1-minute.

The mid-thigh position was marked between the anterior superior iliac crest and patella by the primary investigator and the athletes self-selected their knee and hip angles (Wang et al., 2016). They were instructed visually and verbally to stand in the universal athletic position which requires “triple flexion” of the ankles, knees and hips, plus neutral spine position (see Figure 1B). They were then instructed visually and verbally to have the bar rest at the position at which they felt strongest (Wang et al., 2016). The IMTP bar used had the same width and diameter as a standard barbell. Participants were only allowed to utilize an overhand grip. Each participant was provided wrist straps to maintain their grip when executing the IMTP test and

were provided assistance in order to apply the straps appropriately. Once the athlete found their starting position on the force plate, they were given a “ready” command, and then given a “go” command by the operator at which point the participant exerted maximal downward vertical force for 5-seconds while maintaining a neutral spine position. Verbal encouragement was provided by the operator to ensure maximal effort was achieved. Each athlete was instructed to maintain their overhand grip, push through their feet into the force plate, maintain neutral spine posture and apply maximal force for the entire 5-seconds. A single repetition of the IMTP was performed and provided a proper warm-up is completed, this method has been shown to produce a valid assessment of maximum strength (De Witt et al., 2016).

For both the CMJ and IMTP, relative and absolute measures of dynamic and maximum strength, respectively, were analyzed. Absolute measures included peak kilograms of force (kgf) for both the IMTP and CMJ. Relative measures included peak kilograms of force/body mass (kgf/kg) for the IMTP and CMJ. This data was captured by a force plate (Quattro Jump, Kistler USA, Amherst, NY, USA) sampling at 500Hz.



**Figure 2A – Force plate CMJ demonstration.**



**Figure 2B – Force plate IMTP demonstration.**

### **2.3.2 On-Ice Procedures**

On-ice testing procedures took place at the Wayne Fleming hockey arena at the University of Manitoba. The athletes underwent a standardized warm-up consisting of a supervised, 5-minute off-ice dynamic warm-up plus a 3-minute warm-up of light skating and shooting. The on-ice testing was performed in full hockey equipment with skates sharpened to personal preference. Sprint ability was assessed by having the participant sprint, from a stationary start, blue line to blue line (distance = 15.24m). Similar protocols have been implemented in earlier research, and the method is considered a valid measure of sprint ability (Peterson et al., 2015; Bracko & George, 2001). The participant started by standing with their front skate directly behind the blue line (starting line), stick in hand. When the participant felt they were ready, they sprinted as fast as possible through the second blue line (finish line). Time was recorded by Smart Speed wireless timing gates (Fusion Sport, Chicago, IL, USA). Timing gates were placed at the beginning (0m), middle (7.71m) and end (15.42m) of the sprint distance.

The timing gate lasers were placed at chest level of the participants to ensure that the laser timed the body crossing the line, not the stick. In addition, participants were told to keep their sticks on the ice to ensure they did not prematurely trip the laser timer. Once the participant crossed the finish line, they coasted back to the start line and were given 5-minutes to recover. Participants performed 2 sprint trials and the best time was used for analysis as is common in similar past studies comparing sprint performance to other performance assessments (Farlinger et al., 2007; Peterson et al., 2015; Rey, Cabo & Fernandez-Penedo, 2016; Runner et al., 2015). The recovery time started when the participant returned to the starting line. Similar tests have been reported to have test-retest values of  $r=0.8$  (Bracko & George, 2001).

## **2.4 Statistical Analyses**

The Shapiro-Wilk test was conducted to test normality of each variable and it was found that all variables met the criteria for normalcy. Mean and standard deviation (*SD*) were calculated for all variables. Pearson product-moment correlation analysis was used for all variables. Variables used for analysis included each participant's peak force output in both the IMTP and CMJ and their best on-ice sprint times. Data were analyzed using SPSS v22.0 software (SPSS, Inc., Chicago, IL, USA). Correlations were evaluated using the following criteria: small = 0.1–0.29, moderate = 0.30–0.49, large = 0.50–0.69, very large = 0.70–0.89, nearly perfect = 0.90–0.99, and perfect = 1.0 (Hopkins, Marhsall, Batterham, & Hanan, 2009). An alpha level of  $p \leq 0.05$  was considered statistically significant for all comparisons.

# **RESULTS**

## **3.1 Participant Characteristics**

Descriptive statistics of participants are depicted in Table 1. Briefly, a total of 31 U sport hockey players ( $n=13$  females,  $n=18$  males) from the University of Manitoba participated in the study.

**Table 1** Participant Descriptive Characteristics for Females ( $n=13$ ) and Males ( $n=18$ ). Data are means  $\pm$  SD.

Characteristic	Combined (N=31)	Males ( $n=18$ )	Females ( $n=13$ )
Age (years)	22.3 $\pm$ 2.1	23.7 $\pm$ 1.1	20.4 $\pm$ 1.3
Height (cm)	152.8 $\pm$ 8.6	158.4 $\pm$ 5.3	145.1 $\pm$ 5.7
Weight (kg)	79.9 $\pm$ 12.7	88.8 $\pm$ 8.4	67.6 $\pm$ 4.6

Descriptive statistics for 7.71m sprint, 15.42m sprint, CMJ and IMTP results are depicted in Table 2.

**Table 2** On-Ice and Off-Ice Tests Descriptive Characteristics

Mean off-ice and on-ice variable responses for females ( $n=13$ ), males ( $n=18$ ), and combined data (N=31).

Variables		Females		Males		Combined	
		Mean	SD	Mean	SD	Mean	SD
Off-ice	CMJa (kgf)	153.07*	16.80	211.94	25.61	187.26	36.83
	CMJr (kgf/kg)	2.26*	0.16	2.39	0.22	2.34	0.21
	IMTPa (kgf)	225.23*	35.84	333.06	45.61	287.84	67.96
	IMTPr (kgf/kg)	3.31*	0.32	3.77	0.50	3.58	0.48
On-ice	7.71m (sec)	1.64*	0.09	1.55	0.05	1.59	0.08
	15.42m (sec)	2.80*	0.12	2.66	0.89	2.72	0.12

\*Significantly different from Males ( $p<0.05$ ).

Note: CMJa = Countermovement jump absolute, CMJr = countermovement jump relative, IMTPa = Isometric mid-thigh pull absolute, IMTPr = Isometric mid-thigh pull relative.

The results of the correlational analyses between the 7.71m sprint, 15.42m sprint, CMJ and IMTP for all participants are reported in Table 3. The results of the correlational analyses for

males can be found in Table 4. The results of the correlational analyses for females can be found in Table 5.

### **3.2 The Relationship Between On-Ice Sprint Performance and CMJ**

When females and males were analyzed as a whole group, 15.42m and 7.71m on-ice sprint times significantly correlated with CMJa peak force ( $r = -0.61, p < 0.05$ ;  $r = -0.56, p < 0.05$ ); Table 3. CMJr peak force produced a non-significant correlation with 7.71m and 15.42m on-ice sprint time, respectively ( $r = -0.26, p > 0.05$ ;  $r = -0.31, p > 0.05$ ); Table 3.

The results of the correlational analysis when only taking into account male participants produced no significant relationships between dynamic strength (as determined by the CMJ) on-ice sprint times.

The results of the correlational analysis when only taking into account female participants produced no significant relationships between on-ice sprint times and CMJ variables as seen in Table 5.

### **3.3 The Relationship Between On-Ice Sprint Performance and IMTP**

When all participants were analyzed as a whole group, all measures of the IMTP were significantly correlated with both 15.42m and 7.71m on-ice sprint times. IMTPa peak force ( $r = -0.67, p < 0.05$ ) and IMTPr peak force ( $r = -0.55, p < 0.05$ ) were significantly correlated with 15.42m on-ice sprint time. IMTPa peak force ( $r = -0.65, p < 0.05$ ) and IMTPr peak force ( $r = -0.55, p < 0.05$ ) were significantly correlated with 7.71m on-ice sprint time.

The results of the correlational analysis when only taking into account male participants produced no significant relationships between maximum strength (as determined by the IMTP) and on-ice sprint times.

The results of the correlational analysis when only taking into account female participants produced significant relationships between maximum strength and on-ice sprint times. IMTPa ( $r = -0.71$ ,  $p < 0.05$ ) and IMTPr ( $r = -0.68$ ,  $p < 0.05$ ) were significantly correlated with 15.42m on-ice sprint time. IMTPa ( $r = -0.70$ ,  $p < 0.05$ ) and IMTPr ( $r = -0.71$ ,  $p < 0.05$ ) were significantly correlated with 7.71m on-ice sprint time.

**Table 3** Correlational Analysis of On-Ice and Off-Ice Tests for Males (n=18) and Females (n=13) Combined (n=31).

Off-Ice Variables	On-Ice Variables	
	7.71m	15.42m
CMJa	-0.56*	-0.61*
CMJr	-0.26	-0.31
IMTPa	-0.65*	-0.67*
IMTPr	-0.55*	-0.55*

\* $p < 0.05$

Note: CMJa = Countermovement jump absolute, CMJr = countermovement jump relative, IMTPa = Isometric mid-thigh pull absolute, IMTPr = Isometric mid-thigh pull relative.

**Table 4** Correlational Analysis of Males (n=18) On-Ice and Off-Ice Variables

Off-Ice Variables	On-Ice Variables	
	7.71m	15.42m
CMJa	-0.34	-0.37
CMJr	-0.38	-0.30
IMTPa	-0.20	-0.27
IMTPr	-0.26	-0.28

\* $p < 0.05$

Note: CMJa = Countermovement jump absolute, CMJr = countermovement jump relative, IMTPa = Isometric mid-thigh pull absolute, IMTPr = Isometric mid-thigh pull relative.

**Table 5** Correlational Analysis of Females (n=13) On-Ice and Off-Ice Variables

Off-Ice Variables	On-Ice Variables	
	7.71m	15.42m
CMJa	-0.32	-0.35
CMJr	-0.13	-0.11
IMTPa	-0.70*	-0.71*
IMTPr	-0.71*	-0.68*

\* $p < 0.05$

Note: CMJa = Countermovement jump absolute, CMJr = countermovement jump relative, IMTPa = Isometric mid-thigh pull absolute, IMTPr = Isometric mid-thigh pull relative.

## DISCUSSION

The primary purpose of this study was to investigate the associations between IMTP and CMJ peak force production and on-ice sprint performance in collegiate ice-hockey players. It was hypothesized that measures of dynamic strength (CMJa and CMJr) would be significantly correlated with on-ice sprint performance and that measures of maximum strength (IMTPa and IMTPr) would not be significantly correlated with on-ice sprint performance. The results of the analysis of all participants combined indicated that IMTPa, IMTPr and CMJa were significantly correlated with 15.42m and 7.71m on-ice sprint times. However, no significant correlations were found between CMJr and on-ice sprint times. It is noteworthy that this is the first study to compare force plate strength testing protocols and on-ice sprint performance.

### 4.1 CMJ and On-Ice Sprint Performance

Absolute lower body dynamic strength (CMJa) was related to on-ice sprint performance when all participants were analyzed which agrees with the hypothesis of the study. The present study produced large and significant correlations between CMJa and both 15.42m and 7.71m on-ice sprint times. This is consistent with previous results in which VJ was shown to significantly

correlate with on-ice sprint performance of similar distances (Farlinger et al., 2007; Runner et al., 2015).

Some research indicates that on-ice sprint performance is an important characteristic of elite level hockey players (Bracko & George, 2001). Despite this, there has been little investigation into the strength qualities associated with on-ice sprint performance. Fortunately, more effort has been expended in identifying the strength qualities associated with sprinting in competitive sprinters and field sport athletes (Cronin & Hansen, 2005; Cronin, Ogden, Lawton & Brughelli, 2007; Loturco et al., 2015; McBride et al., 2009). Though sprinting on ice with skates and sprinting on ground with shoes are different tasks, previous research has shown that off-ice sprint performance is related to on-ice sprint performance (Bracko & George, 2001; Farlinger et al., 2007; Krause et al., 2012). Furthermore, the same 2 factors that contribute to both on-ice and off-ice sprint performance are stride rate and stride length, so comparisons can be drawn between both tasks (Farlinger et al., 2007). A strong relationship between off-ice and on-ice sprint performance is observed because they are tasks that require both leg power which directly affects stride length, and leg speed which directly affects stride rate (Mascaro, Seaver & Swanson, 1992). Krause et al., (2012) found the off-ice 40-yard sprint time to be the best predictor of the on-ice 34.5m sprint time in elite high school male hockey players. Though the task requires different biomechanical qualities, the relationship between dynamic strength and both on-ice and off-ice sprint performance seems to be similar. The similarities between off-ice and on-ice sprint performance will aid in the understanding of the strength qualities associated with on-ice sprint performance.

Off-ice and on-ice sprint performance consistently showcase strong relationships with tests of dynamic strength such as the VJ measured in height or the CMJ measured in peak force

output. The present study found a significant relationship between CMJ peak force output and on-ice sprint performance, meaning that the participants who produced higher absolute peak force during the CMJ also tended to skate faster over both 7.71m and 15.42m. In support of these findings, Loturco et al., (2015) found that CMJ height was significantly correlated with sprint velocity over 10m, 30m and 50m in elite sprinters. Moreover, the authors demonstrated that improvements in vertical jump height in the elite sprinter population resulted in improved sprint performance (Loturco et al., 2015). Requena et al., (2011) found that CMJ height was largely and significantly correlated with 20m, 30m, 40m sprint times. Marques & Izquierdo (2014) found that CMJ peak force was significantly correlated with 10m sprint performance in athletes from several sports. Cronin & Hansen (2005) found that 3 different jump measures consistently predicted sprint speed across 5m, 10m and 30m distances with CMJ height being the best correlate of sprint performance over 10m and 30m. It appears that CMJ performance and the ability to dynamically express force is related to sprint performance. As off-ice and on-ice sprinting share many characteristics, we can surmise that improvements in absolute peak force production in the CMJ could result in improved on-ice sprint performance. Based on the results from Runner et al., (2015) in which the VJ height was found to be the best off-ice predictor of on-ice speed and the current study, we can conclude that absolute lower body dynamic strength is related to on-ice sprint ability. The results from the current study produce a strong correlation between dynamic strength peak force production and on-ice sprint performance. Due to this relationship, implementation of protocols aimed at enhancing dynamic strength abilities in hockey players should be utilized. Protocols that progress along the force-velocity curve from maximum strength training toward dynamic strength training could produce improvements which may benefit on-ice sprint performance in hockey players. Further study in skating athletes

who participated in a training regime focused on developing lower body dynamic strength abilities would be needed to confirm such a statement.

Relative lower body dynamic strength (CMJr) was not significantly correlated with on-ice sprint performance. This was not in agreement with the current study's hypothesis. Previous results have not included relative measures of dynamic performance measures in tests such as the VJ, CMJ or broad jump. The lack of association between CMJr and on-ice sprint performance is surprising since 1 of the 2 factors that affect skating performance is stride length which is enhanced by improving relative leg power (Mascaro, Seaver & Swanson, 1992). Furthermore, previous research has shown CMJ performance to be significantly correlated with off-ice sprint performance (Cronin & Hansen, 2005; Requena et al., 2011). Moreover, Baker & Nance (1999) found that relative dynamic and maximum strength measures showed stronger relationships to sprint performance in rugby players compared to absolute measures. A possible explanation could be the lack of friction experienced since skating occurs on an ice surface. Because the coefficient of friction experienced when skating is much lower than ground-based sprinting, there is much less opposing force to the athlete's stride(s). The lack of opposing force may play a factor in horizontal velocity. Skating athletes that apply the highest amounts of absolute force production may actually be at an advantage as greater absolute peak force production results in greater rates of horizontal velocity (Thomas, Comfort, Chiang & Jones, 2015; Wang et al., 2016). Athletes with the highest CMJa peak force outputs do not produce the highest CMJr peak force outputs due to the effect of body weight which is another potential reason for the lack of correlation observed between CMJr and on-ice sprint performance. Thus the athlete who jumps higher by applying more absolute peak force into the ground seems to skate faster. Another possible explanation would be the lower variability in bodyweight within the subjects of the

current study in comparison to the variability within the subjects' CMJa peak force production of the lower body. It is well known among statisticians that, other things being equal, the value of  $r$  will be greater if there is more variability among the observations than if there is less variability (Goodwin & Leach, 2006). With regards to the present study, more variability was observed in CMJa peak force values compared to bodyweight values. Perhaps if bodyweight values showcased the same or similar amount of variability as CMJa peak force, we may have observed a higher value of  $r$  for CMJr and on-ice sprint performance. This is more of a statistical issue or weakness rather than a lack of correlation between CMJr and on-ice sprint ability. The present study found that CMJa peak force production had a stronger relationship with on-ice sprint performance compared to CMJr peak force production.

There seems to be a relationship between absolute dynamic strength and on-ice sprint performance. Previous research has demonstrated that there is a meaningful relationship between vertical jump performance and both on-ice and off-ice sprint performance. The present study reveals deeper insight into the relationship between jump and sprint performance by demonstrating that CMJ absolute peak force has a stronger relationship with on-sprint performance compared to CMJ relative peak force.

#### **4.2 Relationship Between CMJ and On-Ice Sprint Performance in Males and Females**

It was found that measures of dynamic strength have a non-significant association with on-ice sprint performance when males and females were analyzed separately. This contrasts the results of Farlinger et al., (2007) and Runner et al., (2015) where both studies found significant correlations between VJ and on-ice sprint performance; however, it should be noted that the on-ice sprint distances considered in each situation were different between the studies and range

from 7.71m to 35m. Furthermore, peak force (kgf) in the CMJ was compared with on-ice sprint time in the current study compared to VJ height (cm) in previous studies. Though measuring peak force compared to jump height is different, they have been shown to be related as athletes who produced higher jump heights in the CMJ, also produced the highest peak force outputs at key points during the CMJ (Kraska et al., 2009). Peterson et al., (2006) also found that VJ height and VJ peak power produced correlations that were strong and significant in a large group of male and female collegiate athletes which is important as high peak power production requires high amounts of peak force production. Previous research shows that peak force production and vertical jump height are related, though this difference in variables examined (peak force vs. jump height) could have potentially caused the large shift seen in the strength of association between dynamic strength and on-ice sprint time. Despite this difference in variables examined, we expected to see similarities in the strength of association between the studies since all tests are tests of the same physical ability: dynamic strength.

It was surprising to find a lack of significant correlations between CMJa and CMJr with on-ice sprint performance in males specifically since multiple previous investigations showcased a strong relationship between jump ability and on-ice sprint performance (Farlinger et al., 2007; Runner et al., 2015). Kawamori, Nasaka & Newton (2013) found that the direction of impulse application is more important to achieve better sprint acceleration than simply producing larger magnitude of (resultant) impulse irrespective of its direction during ground contact. This is a possible explanation as to why CMJ peak force values produced no significant correlations with on-ice sprint performance in male hockey players. The direction of force application measured in the CMJ is vertical, whereas the direction of force application during on-ice sprint performance is a combination of vertical, horizontal and lateral. This difference in direction of force

application may be a reason we did not observe a relationship between CMJ peak force values and on-ice sprint time.

### **4.3 IMTP and On-Ice Sprint Performance**

Absolute and relative lower body maximum strength (IMTPa and IMTPr) were shown to be significantly correlated with on-ice sprint performance. This result is not in agreement with the present studies' hypotheses. Based on previous research that assessed the relationship between maximum strength and on-ice sprint performance, we did not hypothesize that IMTP peak force values would significantly correlate with on-ice sprint performance (Behm et al., 2005; Janot et al., 2015; Runner et al., 2015). Despite our hypothesis, a relationship seems to exist between maximum strength and on-ice sprint performance, and previous research has shown that maximum strength is associated with off-ice sprint ability.

A strength base is considered critical to sprint ability, and consequently, a great deal of time is spent developing the maximal force production capabilities of athletes within strength and conditioning programs (Cronin et al., 2007). Previous studies (Baker & Nance, 1999; Blazevich et al., 2002; Wang et al., 2016) have shown the relationship between maximal strength and off-ice sprint performance, but few have investigated this relationship in ice hockey, where sprinting occurs on-ice and with skates on, which potentially changes this relationship. Strong and significant correlations were observed between IMTPa and 15.42m ( $r = -0.65$ ,  $p < 0.05$ ) and 7.71m ( $r = -0.67$ ,  $p < 0.05$ ) on-ice sprint times. From this data, though it is correlational, we can infer that there is a potentially meaningful relationship between lower body maximal strength and on-ice sprint performance. Though we cannot associate cause and effect, or if maximal strength impacts on-ice sprint performance or vice versa, we can make an assumption based off of the plethora of correlational research within strength and conditioning, that there is a

meaningful relationship between these two variables. Due to the paucity of literature, connections will have to be made from literature outside of the sport of ice hockey to help illustrate the relationship between maximal strength and sprint performance.

Blazevich et al. (2002) had 10 nationally ranked junior male sprinters complete a 7-week resistance training program with a focus on 1-RM squat and 20m sprint. The average percent change in 1-RM squat was significantly increased by 12.1% and 20m sprint time was significantly decreased by 3.5% thus, improvements in lower body maximal strength improved 20m sprint performance. McBride et al., (2009) had 26 male athletes complete an 8-week resistance training program with the primary exercise being a jump squat at 80% 1-RM. 1-RM squat increased by 9.2% while 5m, 10m and 20m sprint times improved by -0.9% to -1.6%. Chelly et al., (2009) compared the effects of a back-squat training program on jump and sprint performance in junior soccer players. The resistance training group experienced significantly different percent changes in 1-RM back squat (resistance trained group [RTG] = 25%, control group [CG] = 4%,  $p < 0.05$ ), squat jump height (RTG = 10%, CG = 3%,  $p < 0.05$ ) and sprint velocity in first 5-steps (RTG = 7%, CG = 0.5%,  $p < 0.05$ ) compared to the control group. Baker & Nance (1999) assessed the relationship between maximal strength and sprint performance in elite level rugby players. They found that the 3RM squat/kg body mass significantly correlated with 40m sprint performance ( $r = -0.66$ ,  $p < 0.05$ ). Sprint performance seems to be associated with relative lower body maximum strength. Edman & Esping (2013) analyzed the relationship between 1-RM squat and 17.5m on-ice sprint in Elite Junior Swedish hockey players (average age = 17.8 $\pm$ 0.8). A statistically significant relationship was observed between absolute 1-RM squat ( $r = -0.60$ ,  $p < 0.05$ ) and relative 1-RM squat ( $r = -0.61$ ,  $p < 0.05$ ) with 17.5m on-ice sprint ability. Athletes that engage in lower body strength training experience improvements in lower

body maximal strength, jump ability and sprint ability. Therefore, there is previous literature which corroborates the findings of the present study and provides preliminary evidence that lower body maximum strength is related to on-ice sprint performance in hockey players.

Current research has shown that if there is an improvement in lower body strength, measures of sprint and jump performance improve as well (Barr, 2012; Blazeovich et al., 2012; Chelly et al., 2009). It has been demonstrated that maximum strength is related to sprint performance, specifically with running but also with skating based on the relationships observed in the present study between the IMTP measures and on-ice sprint times. Thus, if an athlete is looking to improve on-ice sprint performance, it is advisable to improve lower body strength in order to enhance peak force production in the IMTP test.

#### **4.4 Relationship Between IMTP and On-Ice Sprint Performance in Males and Females**

It was found that measures of maximum lower body strength have a much larger strength of association with on-ice sprint performance in females compared to males. For females, both IMTPa and IMTPr were significantly correlated with on-ice sprint performance. For males, none of the measures of maximum strength were significantly correlated with on-ice sprint performance. This result was somewhat surprising as the hypothesis was based off previous research (Janot et al., 2015; Runner et al., 2015), which included both male and female subjects, but was predominantly male. Both studies found a small strength of association between 1RM back squat and on-ice sprint performance but only one study included females in their analysis. The present study's hypothesis was that maximum strength would not be significantly correlated with on-ice sprint performance. However, the studies that informed our hypothesis, and specifically the two referenced above, analyzed the relationship between maximum strength and

on-ice sprint performance in predominantly males only. On the contrary, very little research of this nature has been conducted with females which makes this an interesting and novel finding.

Healy, Smith, Kenny & Harrison (2018) performed the same maximum strength assessment as the present study and assessed the relationship between absolute and relative peak force measures with 10m and 40m sprint performance in international and national level female sprinters. They found no significant correlations between IMTP measures and 10m and 40m sprint performance. It is very interesting that IMTP measures are strongly and significantly correlated with on-ice sprint performance in female hockey players yet show a very weak strength of association in female sprinters. Perhaps the differences in training history and training age between the two groups of subjects being analyzed contributed to the differing relationships. Peterson et al., (2006) conducted a study with Division 1 collegiate athletes in the United States, 35 of which were females, and assessed the relationship between maximum strength and sprint performance. The females in this study would be much more closely related to the females in the present study in the areas of training age and training history as both groups are of similar age and level of competition. Peterson et al., (2006) found that 1-RM squat was significantly correlated with sprint acceleration and sprint velocity which aligns with our findings. The previous study compared maximum strength to sprint acceleration rates over 20m and to sprint velocity rates over 40m, whereas the present study compared maximum strength with on-ice sprint times over 7.71m and 15.42m. This is important to note, as it is obvious that these tests are different in both distances covered and variables measured (time vs. m/sec), but still produce comparable data points as it has been shown previously that off-ice sprint performance is significantly correlated to on-ice sprint performance in female hockey players (Bracko & George, 2001; Janot et al., 2015). According to the present study results, maximum strength is

related to on-ice sprint performance in females. The present study found that IMTPa and IMTPr were significantly correlated with on-ice sprint performance in females. Previous research has found that maximum strength is significantly correlated with ground-based sprint acceleration and sprint velocity, which are two factors that have been shown to predict skating performance in female hockey players (Janot et al., 2015; Peterson et al., 2006).

When specifically analyzing males, our results support our hypothesis that maximum strength would not be significantly correlated to on-ice sprint performance. This hypothesis was based off previous research that found no significant correlations between tests of maximum strength and on-ice sprint performance of varying distances (Janot et al., 2015; Runner et al., 2015). Perhaps one reason for the large difference in the strength of association between maximum strength and on-ice sprint performance in males versus females is the differences observed in skating kinematics. Shell et al., (2017) compared movement kinematics of the skating start between elite male and female hockey players. It was found that males exhibited significantly greater knee flexion angles and hip abduction range of motion (Shell et al., 2017). The greater knee flexion angles observed in males may be a contributing factor to the lack of correlation observed between IMTP measures and on-ice sprint performance in males due to the limited knee flexion angles exhibited during IMTP testing protocols.

It is possible that females showcased a much stronger relationship between maximum strength and on-ice sprint performance due to specificity of the IMTP testing protocol as females exhibited significantly less knee flexion compared to males when accelerating during skating (Shell et al., 2017). This may be a key factor contributing to the large differences observed in the relationship between maximum strength and on-ice sprint performance in males and females. Because of the unique and novel blend of kinematic variables observed during the task of

skating, and the increased range of motion observed in males compared to females, factors such as skating technique and efficiency may play a larger role than maximum and dynamic strength qualities. Further study would be needed to confirm or deny such a statement, but when combining the findings of the present study and those of the aforementioned study, there is reasonable evidence.

#### **4.5 Limitations of the Study**

The findings of this study have to be seen in light of some limitations. This study was correlational in nature and therefore we cannot establish cause and effect, and the directionality of that relationship, with certainty.

Another limitation that was realized throughout the study was that we did not determine fat-free mass. This could have been done to aid in the assessment of amount of force produced per kilogram of fat-free mass and may have aided in the understanding of the relationship between off-ice maximum and dynamic strength with on-ice sprint performance.

Another potential limitation was in the variables that we examined from our off-ice force plate testing data. Because we were especially interested in the relationship between peak force production and on-ice sprint ability, we failed to assess other potentially significant variables related to off-ice force production (for example, rate of force production). Another limitation is the generalizability of the study as we only recruited athletes from the University of Manitoba which only consists of young adults from a high level of play.

### **CONCLUSION**

On-ice sprint performance can be crucial to a hockey player's success on the ice. Players with faster starts are more likely to create beneficial opportunities for their team that contribute

to winning. For example, players who excel at on-ice accelerations and sprints are more likely to win races to the puck, outmaneuver their opponents, and achieve tactical separation from defensive players. Overall, it seems that there is a relationship between a hockey player's dynamic and maximum strength abilities and on-ice sprint performance. This study confirms previous relationships relating off-ice jump performance to on-ice sprint performance and adds new insight to our understanding of the relationship between maximum strength and on-ice sprint performance. It is important to note, that a caveat must be placed on any conclusions regarding the relationship between off-ice maximum and dynamic strength abilities and on-ice sprint performance because of the complex nature of hockey skating, which itself, can limit players from performing at high levels. Just because a player can produce excellent scores in the off-ice test(s) that have the strongest correlation with on-ice sprint ability, certainly does not guarantee that they will be an elite level skater due to the complexity and skill required. The goal of the present analysis was to highlight the importance of dynamic and maximum strength as they relate to on-ice sprint performance. Future research is needed to investigate how changes in physical ability tests such as the IMTP and CMJ impact on-ice sprint performance.

### **5.1 Recommendations for Future Research**

Future investigation should look at how longitudinal changes in tests such as the IMTP and CMJ impact on-ice sprint performance. The present study revealed that both the IMTP and CMJ produced significant correlations with on-ice sprint time in collegiate hockey players. This would be the logical next step in the research process as longitudinal studies are more powerful than cross-sectional studies. Training programs specifically designed to enhance IMTP and/or CMJ peak force output could be applied to participants to gain a better understanding of the

effects of both types of training programs and how or if changes in off-ice dynamic and maximum strength impact on-ice variables.

Furthermore, future investigation could analyze more than one outcome variable; peak force. The exact same testing protocols could be utilized, which is key as it is both efficient and appropriate in the team setting, and rather than only analyzing peak force values and on-ice sprint times, the authors could dive deeper into the different phases of peak force application and other outcome variables. Within peak force application there is a myriad of outcome variables to analyze and compare to on-ice sprint performance. These outcome variables include but are not limited to rate of force development, contraction velocity and impulse. This information would allow practitioners to identify exact variables that are correlated with on-ice sprint performance and then build and test training programs to develop such capacities in hopes of enhancing on-ice sprint performance.

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**APPENDICES**

**APPENDIX A – Participant Informed Consent Form**



UNIVERSITY  
OF MANITOBA  
Faculty of Kinesiology  
and Recreation Management



### INFORMED CONSENT FORM

Title: The Relationship Between the Isometric Mid-Thigh Pull & Countermovement Jump with On-Ice Acceleration in Hockey Players.

PRINCIPAL INVESTIGATOR:

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**This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.**

SOURCE OF SUPPORT: NONE

**PURPOSE:**

You are being asked to participate in a research trial investigating the relationship between the isometric mid-thigh pull and countermovement jump test with on-ice acceleration in hockey players.

**DESCRIPTION:**

It is expected that a total of 24 participants will be recruited to participate in this study. As part of a performance testing protocol, participants will perform off-ice testing (CMJ and IMTP on force plate) and on-ice testing (15.24m acceleration). The CMJ force plate test provides us with a measure of your dynamic strength. The IMTP force plate test provides us with a measure of your maximum strength. The on-ice acceleration test provides us with a measure of your rate of acceleration. We then will analyze the data from all three tests to assess the strength of the correlational relationships between the off-ice and on-ice tests. We are asking you to provide written informed consent agreeing to participate in the off-ice and on-ice testing as part of this study.

**RISKS AND BENEFITS:**

There are physical risks associated with this study. Physical risk associated with this study include: the risks associated with performing maximal performance testing. A proper warm-up will be utilized with all participants which will reduce the risk of developing an increase in physical risks associated with the off-ice and on-ice testing. Furthermore, all the participants will perform all off-ice and on-ice performance tests in the past as part of the routine performance and intake analysis process within Bison Sport. All participants will be cleared by the teams' Certified Athletic Therapist which will indicate if there are any potential contraindications to performing the off-ice and on-ice tests with this population.

Maximal exertion will be required during the performance of all off-ice and on-ice tests. Participation in this experiment will not directly lead to any health benefits.

**COSTS AND PAYMENTS:**

There are no fees or charges to participate in this study. Participants will not receive any remuneration.

**DEBRIEFING:**

Feedback will be provided to participants after the completion of the study so they are aware of the results of the testing they completed. This will be done by the principal investigator (Stephen Cornish). Participants will be asked if they wish to receive copies of their data results and these will be sent out to them if they so desire (either by mail or email). A brief summary of the study results will be sent to those participants who so desire in aggregate form. This will be done at the end of the study once the data have been analyzed. Also, if more information on the study is desired by study participants then they will be able to contact the principal investigator of the study, Stephen Cornish or the graduate student involved in this project (Matthew Asmundson).

Furthermore, an optional presentation of the results of the study will be offered to the participants in fall 2018.

**VOLUNTARY CONSENT:**

Participation in this study is strictly on a voluntary basis, and you can withdraw from the study at any time during the study by contacting the principal investigator in person or email. If you do not wish to participate in the study, you are free to withdraw from the research study at any time without consequence and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

**TIME COMMITMENT:**

It is estimated that completion of all testing will take 2 hours.

**SPECIFIC EXERCISE PROTOCOLS:**

*Dynamic warm-up: 5-minutes, coach-led.* The participants will start with a 4x30m jog and 4x30m lateral shuffle. Once the thermal component of the warm-up is complete, we will transition into 3 total body dynamic stretches (lunge with reach 1x30m, lunge to in-step 1x30m, posterior chain sweep 1x30m). The final component will include a series of skips, jumps and bounds (linear A-skip 1x30m, lateral bounds 1x30m, skip for height 1x30m, drop squat to broad jump 1x30m).

*CMJ.* Two familiarization trials at self-selected intensity. The participants will then perform two trials of the CMJ test on the force plate, separated by 3-minutes of passive rest.

*IMTP.* Two familiarization trials at 75% (2-seconds) and 100% (2-seconds) maximal intensity. The participants will then perform two trials of the IMTP test on the force plate, separated by 3-minutes of passive rest.

*On-ice acceleration.* The on-ice testing will consist of the same 5-minute dynamic warm-up followed by 3-minutes of light skating and shooting. The participants will then perform two trials of the 15.24m acceleration (blue line to blue line on a regulation ice hockey rink) separated by 3-minutes of rest. The participants will start with their skates behind the blue line and stick on the ice and will choose when to accelerate.

#### CONFIDENTIALITY:

Confidentiality will be partially protected. The only place the participants name will appear is on the consent forms and a spreadsheet linking the participant's name with a unique identifying code which only the primary investigator will see. All consent forms and data collection sheets will be stored in a locked cabinet in room 117 of the Frank Kennedy Centre. A unique code consisting of letters and numbers will be used to identify each participant for their data collection trials and results. All data will be reported in aggregate form. Only Stephen Cornish (the primary investigator) will have access to this spreadsheet and it will be stored on a password protected computer in room 117 of the Frank Kennedy Centre at the University of Manitoba. This personal information will be kept in a locked cabinet, room 117 of the Frank Kennedy Centre at the University of Manitoba, which has limited access as it is the office of the primary investigator. All data collected will be securely stored for a period of seven years (approximately February 2025) All hard copies of the data will be confidentially shredded and all electronic copies of data will be erased from the hard drive on the computer it is stored on.

It is anticipated that the results of this research will be published in the form of a scientific publication journal article and will be used in the generation of a thesis document for partial fulfillment of the degree of Master of Science at the University of Manitoba. No personally identifiable information will be used to present the data in these formats.

A copy of this consent form has been given to you to keep for your records and reference.

**Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.**

**The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.**

**This research has been approved by the Education and Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or [humanethics@umanitoba.ca](mailto:humanethics@umanitoba.ca). A copy of this consent form has been given to you to keep for your records and reference.**

Participant's Name (printed): \_\_\_\_\_

Participant's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Researcher and/or Delegate's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

All individuals who participate in this study are eligible to receive information on the outcomes of the study, via a one-page synopsis of the key findings of the research as well as your personal data. If you would like to receive information on the results of this study please state your mailing address and email address below:

Address: \_\_\_\_\_

City: \_\_\_\_\_

Postal code: \_\_\_\_\_

Email: \_\_\_\_\_

**APPENDIX B – Coach Informed Consent Form**



UNIVERSITY  
OF MANITOBA  
Faculty of Kinesiology  
and Recreation Management



### INFORMED CONSENT FORM

**Title:** The Relationship Between the Isometric Mid-Thigh Pull & Countermovement Jump with On-Ice Acceleration in Hockey Players.

PRINCIPAL INVESTIGATOR:

Dr. Stephen Cornish  
Faculty of Kinesiology & Recreation Management  
Health, Leisure, & Human Performance Research  
Institute  
University of Manitoba  
[stephen.cornish@umanitoba.ca](mailto:stephen.cornish@umanitoba.ca)

OTHER INVESTIGATORS:

Matthew Asmundson  
Master of Science – student of the Faculty of Kinesiology &  
Recreation Management Health, Leisure, & Human  
Performance Research Institute  
University of Manitoba  
[asmundsm@myumanitoba.ca](mailto:asmundsm@myumanitoba.ca)

**This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.**

SOURCE OF SUPPORT: NONE

PURPOSE:

You are being asked permission to allow your team's athletes to be recruited for a research project. The purpose of the study is to investigate the relationship between the isometric mid-thigh pull and countermovement jump test with on-ice acceleration in hockey players.

We are asking for 10-minutes to read our recruitment script to your team members. At the conclusion of the reading of the recruitment script, we will then provide each athlete with a participant informed consent form and they can fill out if they indeed would like to participate in the study.

RISKS AND BENEFITS:

There are physical risks associated with this study. Physical risk associated with this study include: the risks associated with performing maximal performance testing. A proper warm-up will be utilized with all participants which will reduce the risk of developing an increase in physical risks associated with the off-ice and on-ice testing.

Furthermore, all the participants will perform all off-ice and on-ice performance tests in the past as part of the routine performance and intake analysis process within Bison Sport. All participants will be cleared by the teams' Certified Athletic Therapist which will indicate if there are any potential contraindications to performing the off-ice and on-ice tests with this population.

Maximal exertion will be required during the performance of all off-ice and on-ice tests. Participation in this experiment will not directly lead to any health benefits.

#### **COSTS AND PAYMENTS:**

There are no fees or charges to participate in this study. Participants will not receive any remuneration.

#### **DEBRIEFING:**

Feedback will be provided to participants after the completion of the study so they are aware of the results of the testing they completed. This will be done by the principal investigator (Stephen Cornish). Participants will be asked if they wish to receive copies of their data results and these will be sent out to them if they so desire (either by mail or email). A brief summary of the study results will be sent to those participants who so desire in aggregate form. This will be done at the end of the study once the data have been analyzed. Also, if more information on the study is desired by study participants then they will be able to contact the principal investigator of the study, Stephen Cornish or the graduate student involved in this project (Matthew Asmundson).

Furthermore, an optional presentation of the results of the study will be offered to the participants in fall 2018.

#### **VOLUNTARY CONSENT:**

Participation in this study is strictly on a voluntary basis, and you can withdraw from the study at any time during the study by contacting the principal investigator in person or email. If you do not wish to participate in the study, you are free to withdraw from the research study at any time without consequence and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

#### **TIME COMMITMENT:**

It is estimated that completion of all testing will take 2 hours.

#### **SPECIFIC EXERCISE PROTOCOLS:**

*Dynamic warm-up: 5-minutes, coach-led.* The participants will start with a 4x30m jog and 4x30m lateral shuffle. Once the thermal component of the warm-up is complete, we will transition into 3 total body dynamic stretches (lunge with reach 1x30m, lunge to in-step 1x30m, posterior chain sweep 1x30m). The final component will include a series of skips, jumps and bounds (linear A-skip 1x30m, lateral bounds 1x30m, skip for height 1x30m, drop squat to broad jump 1x30m).

*CMJ.* Two familiarization trials at self-selected intensity. The participants will then perform two trials of the CMJ test on the force plate, separated by 1-minute of passive rest.

*IMTP.* Two familiarization trials at 50% and 75% maximal intensity. The participants will then perform two trials of the IMTP test on the force plate, separated by 1-minute of passive rest.

*On-ice acceleration.* The on-ice testing will consist of the same 5-minute dynamic warm-up followed by 3-minutes of light skating and shooting. The participants will then perform two trials of the 15.24m acceleration (blue line to blue line on a regulation ice hockey rink) separated by 3-minutes of rest. The participants will start with their skates behind the blue line and stick on the ice and will choose when to accelerate.

#### RISKS AND BENEFITS:

There are physical risks associated with this study. Physical risk associated with this study include: the risks associated with performing maximal performance testing. A proper warm-up will be utilized with all participants which will reduce the risk of developing an increase in physical risks associated with the off-ice and on-ice testing. Furthermore, all the participants will perform all off-ice and on-ice performance tests in the past as part of the routine performance and intake analysis process within Bison Sport. All participants will be cleared by the teams' Certified Athletic Therapist which will indicate if there are any potential contraindications to performing the off-ice and on-ice tests with this population.

Maximal exertion will be required during the performance of all off-ice and on-ice tests.

#### CONFIDENTIALITY:

Confidentiality will be partially protected. The only place the participants name will appear is on the consent forms and a spreadsheet linking the participant's name with a unique identifying code which only the primary investigator will see. All consent forms and data collection sheets will be stored in a locked cabinet in room 117 of the Frank Kennedy Centre. A unique code consisting of letters and numbers will be used to identify each participant for their data collection trials and results. All data will be reported in aggregate form. Only Stephen Cornish (the primary investigator) will have access to this spreadsheet and it will be stored on a password protected computer in room 117 of the Frank Kennedy Centre at the University of Manitoba. This personal information will be kept in a locked cabinet, room 117 of the Frank Kennedy Centre at the University of Manitoba, which has limited access as it is the office of the primary investigator. All data collected will be securely stored for a period of seven years (approximately February 2025) All hard copies of the data will be confidentially shredded and all electronic copies of data will be erased from the hard drive on the computer it is stored on.

It is anticipated that the results of this research will be published in the form of a scientific publication journal article and will be used in the generation of a thesis document for partial fulfillment of the degree of Master of Science at the University of Manitoba. No personally identifiable information will be used to present the data in these formats.

A copy of this consent form has been given to you to keep for your records and reference.

**Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.**

**The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.**

**This research has been approved by the Education and Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human**

**Ethics Coordinator (HEC) at 474-7122 or [humanethics@umanitoba.ca](mailto:humanethics@umanitoba.ca). A copy of this consent form has been given to you to keep for your records and reference.**

It is anticipated that the results of this research will be published in the form of a scientific publication journal article and will be used in the generation of a thesis document for partial fulfillment of the degree of Master of Science at the University of Manitoba. No personally identifiable information will be used to present the data in these formats.

A copy of this consent form has been given to you to keep for your records and reference.

This study has been approved by the Education Nursing Research Ethics Board.

If you have any questions about your rights, or concerns about the study, please direct questions regarding your rights to the Human Ethics Coordinator at the Office of Research Ethics and Compliance at the University of Manitoba (Phone: 204-474-7122 or Email: [humanethics@umanitoba.ca](mailto:humanethics@umanitoba.ca)).

**Please read the following before signing this consent form:**

- I have read or have had this read to me and understood the consent form.
- I have had sufficient time to consider the information provided and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that all of the information collected will be kept confidential and that the result will only be used for scientific objectives.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I have been told that I will receive a dated and signed copy of this form.

Coach's Signature:

\_\_\_\_\_

Date:

\_\_\_\_\_

Primary Investigator Signature:

\_\_\_\_\_

Date:

\_\_\_\_\_

**APPENDIX C – Ethical Approval Certificate**



**Human Ethics**  
 208-194 Dafoe Road  
 Winnipeg, MB  
 Canada R3T 2N2  
 Phone +204-474-7122  
 Email: humanethics@umanitoba.ca

### PROTOCOL APPROVAL

**TO:** **Stephen Cornish**  
 Principal Investigator

**FROM:** **Zana Lutfiyya, Chair**  
 Education/Nursing Research Ethics Board (ENREB)

**Re:** **Protocol #E2018:027 (HS21634)**  
**“The Relationship Between the Isometric Mid-Thigh Pull and  
 Countermovement Jump with On-Ice Acceleration in Hockey Players”**

**Effective:** April 9, 2018

**Expiry:** April 9, 2019

**Education/Nursing Research Ethics Board (ENREB)** has reviewed and approved the above research. ENREB is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*.

This approval is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the research must be submitted to ENREB for approval before implementation.
3. Any deviations to the research or adverse events must be submitted to ENREB as soon as possible.
4. This approval is valid for one year only and a Renewal Request must be submitted and approved by the above expiry date.
5. A Study Closure form must be submitted to ENREB when the research is complete or terminated.
6. The University of Manitoba may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

**Funded Protocols:**

- **Please mail/e-mail a copy of this Approval, identifying the related UM Project Number, to the Research Grants Officer in ORS.**