Position-specific isometric strength tests and their relationship with dynamic performance in collegiate athletes

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Abstract

Dynamic performance is an essential part of many sports and its correlation with isometric strength tests has garnered substantial attention considering the practical utility of isometric testing. Practitioners have assessed maximal isometric strength in athletic populations predominantly using bilateral isometric pulling tests to reveal force-generating capabilities of athletes. However, there is a growing interest in exploring the relationship between dynamic performance and unilateral isometric pushing tests to enhance the specificity and correspondence, particularly in unilateral activities such as sprinting or jumping tasks. Moreover, the relationship between isometric strength and dynamic performance is influenced by biomechanical factors that emerge when conducting tests with different positions and equipment. Notably, while the biomechanics of isometric strength tests can be modified by the type of bar used, there remains a gap in the literature regarding a direct comparison of available bar types and pushing tests. This study aims to bridge this gap by investigating the relationship between dynamic performance and isometric strength, considering two unilateral pushing tests and the influence of two different bar types. **Purpose**: This study presents a twofold purpose: 1) to investigate and compare the relationships between relative peak force (rPF) obtained through unilateral maximal isometric strength tests using two different bar types including a safety squat bar (SSB) and a conventional barbell (CB); and dynamic sport-specific performance metrics in elite athletes and 2) to extract and compare rPF, rate of force development (RFD), and impulse (IP) from two unilateral pushing strength tests designed to mirror the acceleration and top speed phases of sprinting, the unilateral isometric squat ($_{uni}$ISqT) and the unilateral isometric calf raise ($_{uni}$ICalf), and examine their relationship with dynamic performance metrics. **Methods**: Forty-one male high-performance university athletes (age: 21.1 ± 2 yr, height: 184.7 ± 8.5 cm, mass:

95.5 ± 14.5 kg) volunteered to attend a single testing session. A standardized dynamic warm-up was followed by a sprint test and a counter-movement jump (CMJ) and finally isometric testing. In a randomized order, participants performed eight maximal $_{uni}$ISqT tests – four with a SSB and four with a CB, evenly distributed between dominant and non-dominant limbs. A custom apparatus and two force plates were used to assess rPF normalized to body weight. To evaluate sprint performance, a 40-yard sprint was conducted, and split times were recorded at 10 and 40 yards. Jump performance was assessed by measuring jump height and recording the modified reactive strength index (mRSI) during the CMJ performed on the force plates. A 2(bar) x 2(position) x 2(limb) repeated measures analysis of variance (RM ANOVA) was used to assess differences in rPF between bar types. Separate regression analyses were used to assess the relationships between dynamic performance variables (dependent variables: sprint splits, jump height, mRSI) and rPF variables (independent variables: dominant and non-dominant limb ISqT SSB and CB trials). To explore the relationship between the sprint-specific isometric strength testing positions, correlation and regression analyses were run for each unilateral test, using rPF from isometric tests to predict RFD, IP, sprint split times, jump height, and mRSI. If two or more isometric tests were significantly correlated, a Hittner's correlation comparison analysis was conducted to statistically compare the magnitude of correlation. **Results**: RM ANOVA revealed a main effect for bar type ($F_{1,40}=97.481$, $p<0.001$, $\eta^2_p=0.709$) with the SSB producing a higher rPF than CB (mean difference of 30.8% BW). Moreover, a main effect for position type ($F_{1,40}=81.171$, $p<0.001$, $\eta^2_p=0.670$) was revealed with the $_{uni}$ISqT producing a higher rPF than $_{uni}$ICalf (mean difference of 54.1% BW). Regression analyses showed all equations using $_{uni}$ISqT to predict sprint split times were significant ($p<0.01$; Table 3) while those predicting jump height and mRSI were not. In each significant regression equation, the rPF from the SSB trial was a significant predictor of dynamic performance ($p<0.05$) while the CB trial was not. Regression analyses reveal that the $_{uni}$ISqT position accounted for more variance than the $_{uni}$ICalf position in the 10 and 40 yard sprint performances. Hittner's follow-up tests showed no significant magnitude of correlation difference across any of the performance metrics. **Conclusion:** This study revealed that the choice of testing position and bar type significantly impacts rPF production. Furthermore, this study revealed a strong relationship between unilateral isometric tests and dynamic performance, with $_{uni}$ISqT emerging as a better predictor than $_{uni}$ICalf on sprinting split times, jump height, and mRSI. This study introduces an efficient, replicable, and low-injury-risk strength assessment method for athletes. The application of this work extends beyond performance measurement, offering potential insight in return-to-play scenarios, and for the development of safer and more effective athlete rehabilitation strategies.

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Glossary of Terms

Terms	**Definition**
Isometric	Muscle length and joint angle remains constant during contraction
Isoinertial	Muscle action performed with a constant resistance
MVIC	Highest voluntary force achieved during muscle contraction
MUDR	Motor unit discharge rate - frequency a motor neuron fires
Dorsiflexion	Action of flexing the foot towards the shin
Plantarflexion	Action of extending the foot away from the shin

Chapter One

INTRODUCTION AND REVIEW OF LITERATURE

1.0 Introduction

Lower limb maximum force-generating capacity and the rate of force development (RFD) calculated from force-time curves acquired during isometric (i.e., static) strength tests are commonly used to describe an athlete's various strength qualities and can be compared and/or correlated to dynamic performance (Suchomel et al., 2016; Brady et al., 2020; Lum et al., 2020; Haff et al., 2005; Stone et al., 2002). Characteristics such as isometric peak force and the initial rate of force development are known to differentiate athlete performance levels and correlate to an athlete's playing time across a variety of sports (Suchomel et al., 2017).

Most prior research exploring the relationship between performance characteristics from isometric strength tests and dynamic performance has focused on bilateral isometric positions (Lum et al., 2020; Suchomel et al., 2019). There is little to no research focusing on various unilateral isometric positions during strength tests and their relationship to dynamic performance metrics. When considering the principle of specificity or transfer of training, unilateral isometric strength tests offer a higher level of specificity compared to the bilateral position since common athletic skills such as sprinting involve combinations of unilateral movements. The question of whether isometric unilateral strength can predict performance was examined from two perspectives. First, we examined the relationship between the unilateral squat isometric strength tests extracted using a Safety Squat Bar (SSB) and Conventional Barbell (CB) with dynamic tasks (i.e., sprinting and vertical jumping), and second, we interpreted the relationship between isometric strength from two unilateral testing positions (squat and calf raise) with unilateral dynamic tasks (i.e., sprinting and vertical jumping) using the bar type which accounted for more variance in the dynamic task during the first analysis. The following review of literature will summarize the current state of knowledge regarding isometric peak force and force-time characteristics, various isometric positions to obtain performance characteristics, and the relationship between different isometric strength positions and dynamic performance and a discussion on bar types for isometric testing. Despite the numerous studies supporting the relationship between dynamic performance and performance characteristics derived from isometric strength tests, there is still a critical disconnect regarding specificity (i.e., unilateral vs. bilateral positions) and the magnitude of the relationship between isometric strength and dynamic performance, which informed the objectives of the current research project.

1.1 Review of Literature

1.2 Importance of Strength

A position statement by the National Strength and Conditioning Association defines muscular strength as the ability to produce force against a resistance (NSCA, 1993). In the context of the strength and conditioning profession, strength is commonly considered the tide that rises all ships. Athletes who possess greater muscular strength show improved jumping, sprinting, and change of direction performance relative to weaker athletes, and are more often 'starters' in field-based team sports (Suchomel et al., 2016; Stone et al., 2003). Based on the concept of strength reserve, which is the difference between the maximum strength an individual can generate and the actual strength required to perform a specific task or movement, this implies that having a greater strength capacity than what is strictly necessary for a given action can enhance efficiency and performance (Suchomel et al., 2016). Increased muscular strength is also associated with a reduced risk of sport-related injury (Suchomel et al., 2016; Lehnhard et al., 1996). Previous reviews have highlighted both the importance, and ability of practitioners to measure their athlete's maximum force-generating abilities in three ways: dynamic, reactive, or isometric muscle contractions (Brady et al., 2020; Lum et al., 2020; Suchomel et al., 2016). Throughout the literature, there are limited reliable methods for assessing all three types of strength. In practical settings, the one-repetition maximum (1RM) test is widely considered the gold standard for assessing dynamic muscular strength (Grgic et al., 2020). However, previous authors have suggested that dynamic feats of strength such as the 1RM testing battery are merely skills that can be improved with practice and recommend isometric testing for a more precise assessment of maximal strength (Buckner et al., 2017). In a recent review by Brady et al. (2020), the authors concluded that "when testing maximal strength, the joint angle should be consistent, replicated between trials, testing sessions, and studies, to ensure a consistent length-tension relationship." Understanding of the force-length relationship, where a change in muscle length coincides with a change in force production capability, supports the argument for isometric testing over 1RM testing (Gordon, Huxley, & Julian 1966). Furthermore, isometric tests are less likely to result in injury than dynamic tests like the 1RM due to their reduction in joint stress and induced fatigue which make them safer and more controlled (Lum & Barbosa, 2019). Additionally, isometric tests are less time-consuming, involve low physiological cost, and show high test-retest reliability, particularly when assessed using force-plate technology (Comfort et al., 2019; Brady et al., 2020; Lum et al., 2020; Drake et al., 2018; Suchomel et al., 2016; Comfort et al., 2015).

1.1.1 Isometric Peak Force and Force-Time Characteristics

An athlete's PF and RFD extracted during an isometric assessment describe their ability to generate force during dynamic performance (Lum et al., 2020). Athletes with superior performance levels in these characteristics often secure longer playing times, indicating their vital role and impact in a variety of sports (Suchomel et al., 2017). This suggests that these attributes are crucial for determining an athlete's significance and contribution to the game. Therefore, an athlete's maximum force-generating capability (i.e., peak isometric force), and the peak or initial slope of the isometric force-time curve (i.e., indices of RFD), are important metrics identified in the literature. Many prior studies have compared or correlated these characteristics to an athlete's dynamic performance (Suchomel et al., 2016; Brady et al., 2020; Lum et al., 2020; Haff et al., 2005; Stone et al., 2002).

1.1.2 How Peak Force and Force-Time Characteristics Are Calculated

Previous research has predominantly focused on extracting PF and force-time characteristics from the isometric mid-thigh pull (IMTP). Considering PF as the outcome metric has garnered some generalizability concerns due to the lack of standardized reporting on absolute or relative values (Brady et al., 2020). For example, PF is commonly measured as the maximum force expressed in newtons (N), generated along the axis of the applied force during a maximal voluntary isometric contraction (MVIC) (Brady et al., 2020; Lum et al., 2020). Although, PF can be further stratified and reported in various ways. Absolute peak force (aPF) is expressed as the maximum force generated in the vertical axis minus the participant’s body weight. Relative peak force (rPF) is reported as the maximum force in the vertical component relative to body mass (N/Kg) (Brady et al., 2017, Stone et al., 2004). Both PF metrics describe the maximal force-generating capabilities of an athlete and are highly reliable (Brady et al., 2020; Comfort et al., 2019). RFD is the change in force divided by the change in time and can be applied to specific epochs such as 0 to 10, 0 to 20, 0 to 50, 0 to 100, 0 to 150, and 0 to 200 ms (Comfort et al., 2019; Brady et al., 2020). RFD calculated during epochs of 0 to 100, 0 to 150, and 0 to 200 ms seem to be the most reliable, with a coefficient of variation (CV) at or below 10%; while epochs such 0 to 10, 0 to 20, 0 to 50 ms are less reliable with a CV greater than 15% (Comfort et al., 2019). These approaches to analyze PF and RFD generated from isometric strength tests are the most common (Comfort et al. 2019), but there is not a standardized method for calculating the metrics derived from the force-time recordings. However, there is a recent shift toward reporting relative values to increase precision and reproducibility across studies (Brady et al., 2020).

1.2 Isometric Strength Positions and Relationship with Dynamic Performance

1.2.1 Common Positions to Obtain Isometric Strength Characteristics

A recent review by Comfort et al. (2019) highlighted the common use of the Isometric mid-thigh pull (IMTP) and the Isometric Squat (ISqT) to measure athlete's isometric strength characteristics (Brady et al., 2020; Juneja, Verma, and Khanna. 2010). However, relative force measures from IMTP could be limited by upper body strength, particularly in females (Yanovich et al., 2008). In a comparison of the two tests, females were able to generate significantly more peak force in the ISqT versus the IMTP, whereas there were no significant differences among the male group, potentially due to upper body strength differences when pulling on the bar (Brady et al., 2018; Nuzzo et al., 2008). This evidence has given rise to the increasing popularity of ISqTs, which appear more reliable when considering sex differences, isometric peak force, and force-time metrics. Furthermore, based on the higher correlations to sport-specific tasks such as sprinting, jumping, and change of direction; authors have considered ISqTs more appropriate to predict dynamic performance (Lum et al., 2020; Brady et al., 2019; Kuki et al., 2019).

1.2.2 Relationship Between Isometric Test Positions and Dynamic Performance

Dynamic performance involves a series of athletic efforts that consist of adjusting the body to the changing demands of a particular sport. Many sports require the ability to jump, change directions quickly, accelerate, and sprint. Since dynamic performance is strongly correlated with isometric strength tests (Comfort et al., 2019), exercise and sport scientists have become increasingly interested in practical assessments of maximum isometric strength in athletic populations that involve the ability to analyze peak force and force-time metrics (Haff et al., 2005; Haff et al., 2015; Stone et al., 2003; Lum et al., 2020). A recent meta-analysis by Lum et al. (2020) investigated the relationship between bilateral lower limb isometric tests such as the IMTP and ISqT and 1RM testing as well as dynamic performance such as jumping, change of direction, and acceleration. Of the estimated 38 studies that have investigated this relationship, 19 investigated the isometric peak force relationship with jumping, eight with 1RM lower limb strength, three for change of direction, and eight with acceleration (Lum et al., 2020). The results of Lum et al.'s meta-analysis suggest that 1RM back squat strength and ISqT PF ($r = 0.688 – 0.864$) or IMTP PF ($r = 0.705 – 0.970$) are highly correlated with one another. In addition, ISqT and IMTP force-time characteristics are highly correlated with various jumping ($r = 0.346 – 0.820$), sprinting ($r = 0.420 – 0.780$), and change of direction performances ($r = 0.410 – 0.854$). According to the data presented by Comfort et al. (2019), there is a good to excellent relationship ($r = 0.62-0.99$) between IMTP and maximal isometric (i.e., PF) and dynamic strength (i.e., 1RM in kg) for the power snatch, power clean, snatch, clean and jerk, back squat, and deadlift. Maximal isometric strength (i.e., PF) also exhibits a good to excellent correlation ($r = 0.50 – 0.87$) with direct sports performance metrics such as shot-put distance (m), 25m split time track cycling (s), 250m split time track cycling (s), 5m sprint time (s), 20m sprint time (s), pro agility change of direction time (s), countermovement jump height (m), and squat jump height (m) (Comfort et al., 2019). While most research has been conducted on the IMTP, many authors have confirmed these relationships using the ISqT variation (Nuzzo et al., 2008; Lum et al., 2020; Brady et al., 2020). However, a majority of current literature has focused on bilateral pulling tests. A comprehensive literature synopsis table on the various studies that have compared these relationships can be found in Appendix N.

1.2.3 Gap in the Isometric Strength Literature

Despite several recent reviews documenting these relationships, there seems to be a disconnect between the currently available research data on isometric peak force and dynamic performance, particularly sprinting, where previous literature has only considered the initial acceleration phase of sprinting 0-20m (Lum et al., 2020; Comfort et al., 2019). In sprinting, two phases are observed: the acceleration phase (steps: 1 to 3) and maximum velocity phase (steps: 17 to 25) (von Lieres Und Wilkau et al., 2020). These phases are related to specific body positions, such as flexed knee and hip joint angles (shank/trunk angle), to project forward during acceleration. To sprinting at maximal velocity, the stretch-shortening cycle (SSC) must be utilized and supported by an extended knee and hip joint angle strength and elastic ability to project vertically off the ground (Young et al., 1995). With respect to sprinting, current multi-joint isometric strength research is confined to the acceleration phase, and to the authors' knowledge, no research has investigated the relationship between top-speed sprinting (>30 m) and metrics from these isometric tests. As the ground contact times are longer during the acceleration phase than at maximum velocity sprinting (Morin et al., 2011; Weyand et al., 2010), the force vectors between the two running phases are different. Maximum velocity sprinting has a very different force vector in comparison with acceleration (Weyand et al., 2010). Sprinting performance is achieved through a combination of high vertical and horizontal propulsive forces while also resisting gravity and braking propulsive force (Morin et al., 2011). The kinematic principles of sprinting consist of alternating both unilateral stance and swing phases, highlighting the coordination of the ankle, knee, and hip (Ansari et al., 2012). Sprinting, along with other dynamic performances are not performed using simultaneous bilateral movements, nor do they involve "pulling" efforts. As shown previously, the trend of current literature has focused almost solely on bilateral isometric pulling tests as the intervention or applied metric. There is limited research examining unilateral testing with two previous studies using isometric unilateral pulling tests as the applied metric, not considering pushing tests. Kuki et al. (2019) investigated the relationship between unilateral IMTP and sprint acceleration performance in male collegiate soccer athletes (n=20). Kuki et al. reported the unilateral absolute PF of IMTP in both dominant and non-dominant leg positions were significantly correlated with the 30m sprint time (dominant leg: $r=-0.456$, $p<0.05$; non-dominant leg: $r=-0.452$, $p<0.05$), and relative PF in the non-dominant limb was significantly correlated with 10m sprinting time ($r=-0.447$, $p<0.05$). Finally, Thomas et al. (2016) found that while both legs were individually correlated with sprinting performance, the PF extracted from the IMTP using the right limb displayed the strongest relationship with sprinting. Interestingly, they found that there was no significant relationship between bilateral stance IMTP PF and sprint performance. Researchers should therefore focus on developing methods that consider strength performance metrics derived from unilateral isometric pushing activities and their relationship with dynamic performance.

1.3 Training and Testing Specificity

1.3.1 Components of sprinting

It has been proposed that the acceleration of the body center of mass during a sprint trial is determined by three external forces: ground reaction force (GRF), gravitational force, and wind resistance (Hunter et al., 2005). Furthermore, it has been determined that faster running speeds are achieved with greater ground reaction forces (Weyand et al., 2000), suggesting that more force production and ability to withstand forces during mid-stance is crucial for sprinting speed (Figure 1). Moreover, three phases within a sprint have been recognized (von Lieres Und Wilkau et al., 2020). Steps one to three have been defined as the initial acceleration phase, steps 6-13 as the transition phase, and steps 17-25 as the maximal velocity phase (von Lieres Und Wilkau et al., 2020). When considering specific distances to measure speed, the NFL combine 40-yard dash becomes a relevant distance, as a recent YouTube video observation I conducted showed the test is generally completed in 18-24 steps (Top 40-Yard Dash Times NFL Combine 2022), therefore evaluating both acceleration and maximal velocity phases. However, even if two athletes complete the sprint in the same number of steps, they may have vastly different times. This is due to variations in stride frequency and distance (Schubert et al., 2014). During investigations into normative GRF data during high-speed sprinting, greater propulsive forces and lower braking forces were determinants of sprinting speed, and during those trials GRF surpassed three times body weight on average (Nagahara et al., 2018, Munro et al., 1987). Therefore, athletes who are unable to withstand these high-impact forces may reduce their stride length or frequency; these kinematic differences may be a consequence of not being able to produce adequate time-specific propulsive force. Ground reaction force as a predictor of sprinting speed has gained popularity, however, due to the cost and practicality of force plate devices to measure GRF, it is not feasible in all environments. Therefore, measuring lower limb strength gives an understanding of the underlying physical qualities to generate propulsive forces and resist impact forces.

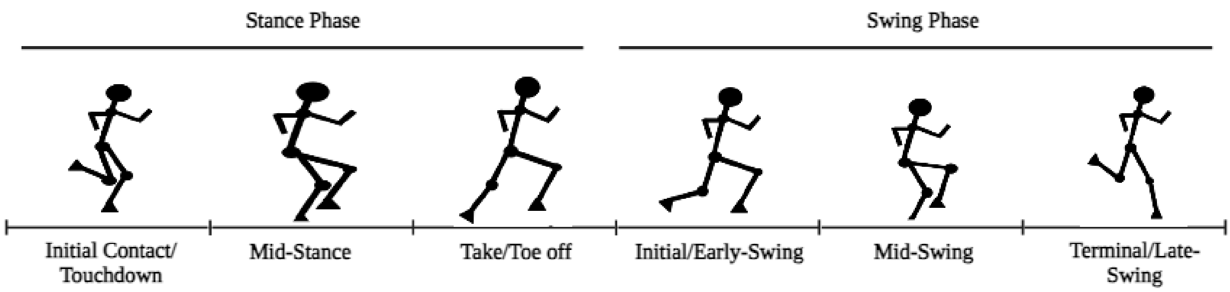
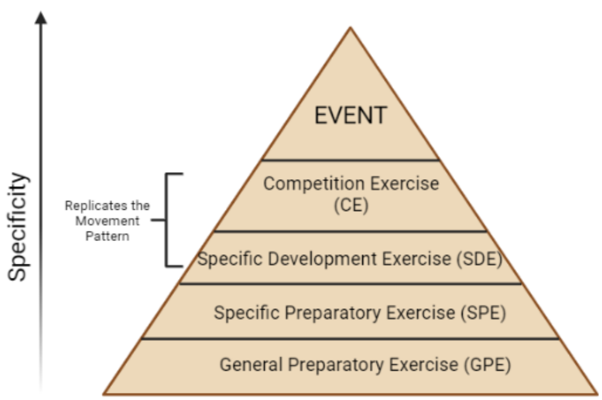


Figure 1. Phases of a Sprinting Gait Cycle. During mid-stance forces in the lower limb must be generated to counteract the forces acting on the body through acceleration and gravity (adapted from Kalkhoven et al., 2023)

1.3.2 Dynamic correspondence of training

Dynamic correspondence is the ability of an exercise or training program to directly impact athletic performance. Training specificity and dynamic correspondence can only be maximized by understanding the biomechanics and demands of the sport. Many athlete preparation models are based on the principle of specificity. Training specificity refers to using methods that reflect the movements and the physical demands performed in the sport, but do not replicate the sport itself (DeWeese et al., 2015b, 2015a). One system has been introduced (Figure 2), which categorizes exercises into four distinct types based on their features for transferring to a target task. These include General Preparatory Exercises, Specific Preparatory Exercises, Specialized Development Exercises, and Competition Exercises (Brearley & Bishop, 2019). However, it is difficult to predict and assess how resistance training will affect sports performance, and which exercises fall into such categories (Suarez et al., 2019). Therefore, several recent reviews have provided guidelines to establish a transfer of training effect (Suarez et al., 2019; DeWeese et al., 2015a, 2015b; Brearley & Bishop, 2019). A set of characteristics have been established to optimize the transfer of training effect. This concept is called *dynamic correspondence* which uses a set of five criteria to discern where an exercise will fall into a respective category: A) Amplitude and Direction of Movement, B) Accentuated Force Production Regions, C) Dynamics of the Effort, D) Maximum Force Production Rate and Time, and E) Regime of Muscular Work (Figure 2).



Dynamic Correspondence Training Criteria	
Amplitude & Direction of Movement	Amplitude refers to the degree of displacement during a movement. Direction of movement refers to the direction of force application.
Accentuated Regions of Force Production	Refers to the specific points in a movement where maximum force is required.
Dynamics of Effort	Force-Velocity Characteristics of Training and how they relate to athletic movements. Combinations of high-load, low-velocity, and the reverse optimize performance in athletic movements.
Rate and Time of Maximal Force Production	Involves the importance of the time constraints at which the target task occurs. Sprinting for example, time specific force must be produced, due to ground contact time limitations. i.e., Slow grinding movements are sub-optimal.
Regime of Muscular Work	Type of muscle contraction occurring during the target task. Eccentric (lengthening), Isometric (no change), and Concentric (shortening) of the muscle-tendon unit.

Figure 2. Bondarchuck Classification of Exercises & Dynamic Correspondence Criteria for Training Adapted from Saurez et al., 2019; A.P Bondarchuk 2010.

First, considering the amplitude and direction, which is a fundamental concept in sports science, emphasizes the need to tailor training or testing to the target task (Suarez et al., 2019). Training adaptations are highly specific, so athletes should mimic their sport's movements and requirements for optimal performance (DeWeese et al., 2015b, 2015a). The amplitude refers to the range or joint displacement that occurs during the target task. For sprinting, there is a good rationale that a co-contraction occurs to hold the joints in position to withstand and redirect the force created by a GRF (Van Hooren et al., 2016; 2018). The direction refers to the force vector direction during the target task, during sprinting and jumping, force is being directed vertically into the ground (Suarez et al., 2019). Second, accentuated force production emphasizes the deliberate focus on training specific aspects of force production within a given movement or exercise. This recognizes that force production is not uniform throughout an entire range of motion or across all phases of a movement (Suarez et al., 2019). Instead, force production varies at different joint angles and during different portions of a movement. The goal of accentuated force production is to target and enhance force production at specific points or phases of a movement to improve the correspondence to the target task (DeWeese et al., 2015b, 2015a). For example, a calf-raise position simulates the forces acted on the body during the max velocity phase of the knee, hip, and torso at impact of ground contact which is relevant to maintaining vertical force production and stiffness during longer sprints (Wild et al., 2011). Meanwhile, a squat position simulates greater hip and knee flexion angles (compared to the calf-raise) similar to the acceleration phase of sprinting. The trunk is more flexed forward during the acceleration phase of sprinting than during max velocity sprinting, requiring higher hip and knee flexion angles which emphasizes force production at joint angles relevant to the drive phase of acceleration, crucial for shorter sprints where horizontal force generation is paramount. The third characteristic, dynamics of effort, can be described in training by adapting intensity to match the dynamic requirements of a sport, including speed and power, to prepare athletes effectively (Suarez et al., 2019). Testing protocols that require athletes to exert maximal effort during an isometric test, could be similar to the effort level utilized with each ground contact during maximal effort sprinting. Specifically, where athletic performance is dependent on an ability to apply or withstand greater than body weigh forces at varying magnitudes.

Fourth, the rate and time of maximum force production should be aligned to the speed of the movement with the target athletic performance (Suarez et al., 2019). Testing protocols that require athletes to push "as hard and as fast as possible" to mimic a ground contact during a sprint or jump are likely the most appropriate. A ground contact for team sport athletes, in particular, international rugby league players is approx. 0.174 ± 0.02 (s) during the acceleration phase and as low as 0.111 ± 0.01 (s) during maximal velocity sprinting (Barr et al., 2013).

Finally, the regime of muscular work considers how muscle contractions occur during target movements and how it may impact correspondence (Suarez et al., 2019). Traditionally, the concept of sprinting has been associated with a complete isotonic movement, involving eccentric, isometric, and concentric phases from touchdown to toe-off (Morin et al., 2011). However, Van Hooren and Bosch's research (2016 and 2018) challenges this conventional belief by critically reviewing hamstring actions during the swing phase of high-speed running. Their findings questioned the existence of an eccentric phase during swing phase in running and suggested the presence of an isometric action of the hamstrings. This insight not only challenges traditional training practices but also highlights the potential significance of isometric components in high-speed running. Additionally, animal and computational models have demonstrated an alternative relationship between muscle strain patterns and activation during locomotion (Lai et al., 2016; Gillis et al., 2005). Considering these findings, a rationale can be made for an isometric strength and training assessment due to proposed isometric muscle function during sprinting. Isometric assessments may offer valuable insights into muscle-tendon interactions in the potential absence of a clear eccentric phase. However, when fixing specific joint angles, it does not ensure a pure isometric contraction, due to the concept of tendon creep, which suggests that when constant load is applied to the tendon unit, it will elongate over time, this may cause the muscles to shorten as a consequence (Oranchuk et al., 2019).

1.3.3 Various Bar Choices

In previous research, changing the joint angle position has been found to enhance or diminish the force generating capability during isometric strength testing (Beckham et al., 2018; Lum et al., 2020). Despite this, there is limited research comparing the effects of bar types on isometric MVIC testing. Influence of bar type should be examined considering body positioning is subject to change in response to the various shapes, sizes, and distribution of weight per bar type. Different bar choices could offer participants a more biomechanically appropriate position for dynamic activities such as sprinting or jumping. For example, a major drawback of the conventional barbell is that athletes with a lack of shoulder range of motion are forced into external rotation at the glenohumeral joint when holding onto the bar (Figure 3). This issue will work down the chain causing the rib cage to lift and reduce the alignment at the torso. Those athletes who have this lack of range of motion may find themselves compromised when attempting to produce maximal force. In either case, this can stem from discomfort or a biomechanical alignment issue. An alternative bar option is the Safety Squat Bar, which reduces external rotation at the glenohumeral joint and rib cage (Figure 3). By creating a more desirable position, force can be generated more effectively.

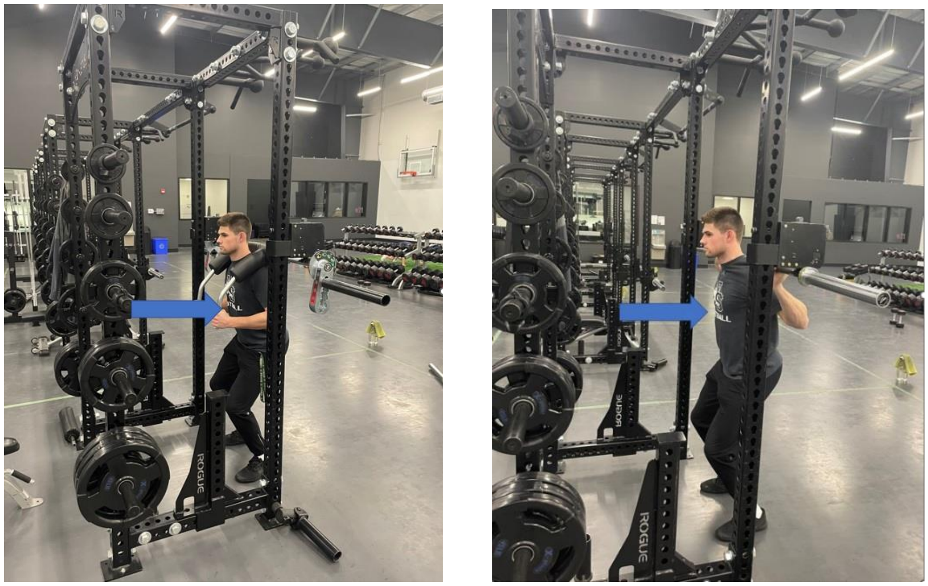


Figure 3. Safety Squat Bar (Left): A well-aligned rib cage allows for the optimal position when producing torso pressure and vertical force. Conventional Barbell (Right): external rotation of the torso, allows the potential for force dissipation due to an inability to create pressure in the torso.

1.4 Statement of the Problem

There is minimal research into isometric peak force and force-time performance characteristics from single-leg (i.e., unilateral) test variations and their correlation to dynamic athletic movements, and this is important to address in order to develop better strength testing for athlete populations. Other than Bishop et al. (2021), Kuki et al. (2019), and Thomas et al. (2016) there is a need for further comparison between the dominant and non-dominant limbs and their relationship with dynamic performance. This is due to common risk of injury thresholds, which are commonly set at 10% asymmetry. Moreover, dynamic athletic movements take place unilaterally; therefore, establishing an easily repeatable method, feasible in a training environment, that produces reliable measurement of isometric peak force in unilateral positions will enable us to fill these gaps. Another major gap in the literature is that little research focuses on unilateral isometric "pushing" tests as a metric to predict or relate to dynamic sprinting performance, and the current literature has been confined to the acceleration phase of sprinting, neglecting the maximal velocity phase (>30m). Addressing pushing tests and incorporating maximal velocity metrics would better align with the principle of specificity and with real-world performance.

1.5 Purpose and Objectives

The purpose of this research was to explore rPF from a variety of unilateral isometric test positions using two different barbells, and their relationship with dynamic performance metrics. When considering the principle of specificity or transfer of training, the unilateral test position offers a higher level of specificity compared to bilateral test positions for some movements, since sport-specific tasks like sprinting involve combinations of unilateral movements. The question of whether isometric strength can be transferred to dynamic performance outcomes will be examined from two perspectives. In the first, I examined the magnitude of isometric strength correlation with a Safety Squat Bar (SSB) and Conventional Barbell (CB), while in the second, I interpreted the magnitude of isometric strength from two unilateral isometric positions (squat and calf-raise) and determine the correlation with unilateral dynamic performance (i.e., Sprinting and jumping tasks). Due to a large amount of literature reported on the relationship between bilateral IMTP or ISqT tests and dynamic performance (Appendix N), our objectives were driven by the novelty of examining unilateral strength tests in comparison with dynamic performance. The principle of specificity and transfer of strength is the main driver of this research and has informed our objectives. Importantly, the bilateral "pushing" movement of the ISqT has been shown to have a higher correlation with acceleration than the "pulling" movement of the bilateral IMTP (Brady et al., 2019). As such, we expect that the PF derived from the unilateral ISqT will have a higher correlation to running acceleration performance than the previously reported bilateral pulling exercise. As there are strong correlations between the unilateral IMTP and acceleration performance, one of our proposed novel approaches is to examine the unilateral ISqT (Bishop et al., 2021; Kuki et al., 2019) and the novel unilateral Isometric Calf Raise ($_{uni}$ICalf) in a 'pushing' effort rather than a 'pulling' effort. This is logical given the idea that a "pushing" movement is more precise than a "pulling" movement when considering dynamic performance (Suarez et al. 2019). Another novel aspect is to examine the differences in bar types on dynamic performance. The ISqT and ICalf will be tested in two conditions 1) SSB and 2) CB (Figure 3). I predict that the SSB will have a stronger relationship with sprinting, due to the removal of constraints commonly seen in the CB condition such as external rotation of the shoulders and upper torso while gripping the bar allowing for the athlete to find the proper alignment when exerting force. In addition, the current literature regarding isometric tests has been confined to the acceleration phase of the sprint (0 to 10m, 20m or 30m). In addition to the acceleration phase, we aim to explore the relationship between isometric peak force in the unilateral ISqT and ICalf with maximum sprinting velocity (40 yards). I hypothesize that PF in the unilateral ICalf will show a higher correlation to maximum velocity sprinting as compared to the acceleration phase (< 20 yards) as the ground contact times are longer during the acceleration phase, which aligns with the joint angles during the ISqT testing (Morin et al., 2011, Weyand et al., 2010), and the joint angles during max velocity sprinting are more comparable with calf testing than squat testing. Maximum velocity sprinting has a very similar joint angle range to the $_{uni}$ICalf test in the mid-stance phase of the sprint (Weyand et al., 2010). It is our goal to determine if peak force extracted from isometric strengths tests with these similarities will correlate to maximum velocity sprinting.

1.6 Objectives and Hypotheses

Objective 1: THE RELATIONSHIP BETWEEN ISOMETRIC STRENGTH TESTS AND DYNAMIC PERFORMANCE: A COMPARISON OF TWO BAR TYPES

The first objective is to determine and compare the relationships between rPF derived from unilateral maximal isometric tests (dominant or non-dominant SSB, or dominant or non-dominant CB) and dynamic sport-specific performance metrics (derived from the CMJ and 40-yrd (36.6m) sprint) in high-performance athletes. For each limb, I explored which unilateral isometric testing implement (bar) is the strongest predictor of dynamic performance using regression. I also compared the difference in rPF derived from the tests with each bar type. Since ISqT task was expected to produce higher rPF than the ICalf task regardless of bar type, the ISqT will be used to explore objective 1.

Hypotheses 1: I hypothesize that for the dominant and non-dominant limb, the SSB will explain more variance (based on regression) in jumping and sprinting. The SSB bar is predicted to result in higher rPF during the strength tests. The rationale for both hypotheses is that the SSB removes constraints commonly associated with the CB such as external rotation of the shoulders and upper torso while gripping the bar.

Objective 2: THE RELATIONSHIP BETWEEN UNILATERAL ISOMETRIC STRENGTH TESTS AND DYNAMIC PERFORMANCE: A COMPARISON OF TWO POSITIONS

The second objective is to determine and compare the relationships between rPF derived from unilateral maximal isometric tests in two positions (ISqT and ICalf for each limb) and dynamic sport-specific performance metrics (derived from the CMJ and 40-yrd sprint) in high-performance athletes. For each limb, we will explore which unilateral isometric position is the strongest predictor of dynamic performance using regression. Emerging from the results of objective 1, rPF from the SSB was used to examine these relationships as part of objective 2.

Hypotheses 2: I hypothesize that both unilateral isometric positions (ISqT and ICalf) will be correlated with each dynamic performance outcome (CMJ, Sprint), but the dominant limb ICalf will be a stronger predictor of dynamic performance outcomes than the ISqT.

Chapter Two

METHODS

2.1.1 Study Design

I investigated the relationship between various unilateral isometric positions and dynamic performance using a design where participants engaged in one testing session, with a randomized testing order. Conditions on each testing day were controlled where feasible (e.g., time of day, time frame between tests, limitations on prior exercise and dietary factors known to influence performance outcomes). Test order was randomized to account for possible carry-over effects during testing, with the exception that the sprinting condition was always conducted first before the strength and CMJ tests.

2.1.2 Experimental Setup and Apparatus

Data collection occurred during the summer of 2022 (July-August). This was strategically planned to avoid disrupting any in-season training schedules. Forty-one participants (Table 1) were recruited to complete one testing session with the goal of recruiting enough participants for sufficient power in the correlation analyses. All participants were randomly assigned to one of six possible test orders after the dynamic warm-up and sprinting condition. The randomization was determined by three variables: 1) strength or power test (i.e., maximal isometric contraction or CMJ); and then for the strength tests; 2) the choice of the bar (conventional barbell or safety squat bar), and 3) position (isometric squat or isometric calf raise). In each randomized order for strength tests, the leg on which each participant began the testing order was counterbalanced. Fourteen participants were invited to a second testing session within 3 days of the initial testing session to investigate test-retest reliability between the ${}_{uni}$ISqT and ${}_{uni}$ICalf positions, the data is presented in Table 9.

Figure 4. The isometric strength protocol configuration. Conventional Barbell, CB (Top) Safety Squat Bar, SSB (Bottom).

2.2.1 Participants

Forty-one high-performance university athletes from the University of Saskatchewan attended a single or repeated testing session (Table 1). The inclusion criteria were current collegiate athletes between 18-30 years of age with >6 months of structured resistance training experience. Each participant completed a training history questionnaire (Appendix B). Anthropometric data were collected including height and weight (Table 1). Pre-testing criteria such as caffeine, alcohol, and supplement intake were tracked, and athletes were asked to repeat this criterion if they participated in a second testing session (Appendix C). All participants were made aware of the risks associated with participation in this investigation and provided written informed consent. This experiment was approved by the University of Saskatchewan's Research Ethics Board (Bio 3487).

Table 1. Participant Demographics

Measure	Mean ± SD
Age (years)	21.2 ± 2.0
Weight (kg)	95.5 ± 14.5
Height (cm)	187.7 ± 8.5
Training Status (days/wk)	5.2 ± 0.8

N = 41

2.2.2 Power Analysis

An a priori power analysis was conducted using G*Power version 3.1.9.7 (Faul et al., 2007) using data from previous meta-analyses that compared bilateral isometric tests to dynamic performance. In particular, the relationship between bilateral isometric strength, jumping, and sprinting resulted in an R-range of 0.346 – 0.820 (Lum et al., 2020; Comfort et al., 2019). A comparison of unilateral isometric strength measures with dynamic performance resulted in an R-value range of 0.4522 – 0.4556 (Kuki et al., 2019). Based on Cohen's (1988) criteria, these analyses had medium to large effect sizes. To run a bivariate correlation and two predictor regression equation with sufficient power, a sample size of N = 40-45 was necessary with a significance criterion of alpha = 0.05 and power = .80 (Faul et al., 2007).

2.3.1 Procedures

Each session began with a 15-minute standardized warm-up (Appendix G) involving a series of movements designed to increase heart rate, followed by general dynamic stretches, concluding with a series of exercises designed to stimulate the central nervous system (e.g., accelerations, repeat broad jump or repeat vertical jump). Following the standardized warm-up, participants first completed the sprinting protocol and thereafter were assigned to one of the five conditions to commence testing. This extensive standardized warm-up protocol was critical as the participants were involved in full-speed sprinting, maximum voluntary contractions, and maximal effort jumping.

2.3.2 Familiarization Protocol

A standardized familiarization protocol preceded all isometric strength conditions, which involved two submaximal pushing efforts in a bilateral stance at progressively increasing intensities of 50% and 75% of self-perceived effort, followed thereafter by one unilateral 90% self-perceived effort conducted on each limb. The participants were instructed to push 5-10% of their body weight in pretension while the investigator counted down from three, and on the ‘go’ call, they pushed as hard and fast as possible until told to stop. Participants completed both single-leg efforts in their individually randomized order followed by one to two minutes of rest between trials.

2.4 Measures

2.4.1 Isometric Strength Testing Protocol

Each unilateral isometric position was performed on an AMTI force plate (AMTI HP400600-HF-OP-2K, Watertown, MA) with a sampling rate of 2000 Hz. Data was acquired using MATLAB software (MATLAB 2019, Data Acquisition Toolbox, Mathworks, Natick, MA). The participants used a single-leg stance position with one foot on a force plate, and the other foot driving toward the chest, mirroring the 'A position,' which is a static position utilized to keep the athlete's pelvis in a neutral alignment (Figure 5). Regardless of the position ($_{uni}$ISqT or $_{uni}$ICalf), the participant held the assigned barbell on the upper back (SSB or CB). The $_{uni}$ISqT position required the knee and hip angles to simulate the 'acceleration' position of sprinting on the pushing leg (flexed trunk/shank angle), with the relative knee angle between 135-150° and the relative hip angle between 150-165°. While the $_{uni}$ICalf position mirrored the 'mid-stance' phase of sprinting (extended trunk/shank angle). During the $_{uni}$ICalf position the participants assumed an upright sprinting stature with the assigned barbell on their shoulders. They stood on a wooden plank placed on the force-plate devices, then were cued to allow a slight raise of the heel (5-30° plantarflexion), and the knee positioned at 150-170°. Knee and hip angles were measured by handheld goniometer devices to ensure the participant was within the bandwidth prior to the trial, then recorded on 'Coaches Eye' software (TechSmith, Okemos, MI, U.S.A. 2011) to detect specific joint angles and that band-width was held consistent for all participants. The participants were instructed to "push the slack out of the bar," creating a 5-10% BW of pretension in the force-plate simultaneously, then to push the bar "as hard and as fast as possible" continuously for five seconds while being provided with strong verbal encouragement, as described in James et al. (2017). Two maximal effort attempts were completed on each limb and separated by one to two minutes of passive recovery. In order to fulfill objectives 1 and 2, the highest relative PF (maximum force N/BW) summed across both force plates (if participant stood in the middle) was extracted using custom MATLAB scripts (Appendix T). All data was filtered using a 100 Hz 4th order Butterworth filter. RFD was calculated using the change in force/change in time and calculated in 50ms epochs. IP was calculated as the average force/change in time and calculated in 100ms epochs.

Figure 5. Unilateral ICalf CB condition (Left). Unilateral ICalf SSB (Middle) Unilateral ISqT CB condition (Right).

2.4.2 Sprinting Condition

The participants performed a 40-yard sprint, and split times were measured at 10 (9.14m) and 40 (36.6m) yards. The participants began the sprint in a 3-point starting position, which was classified as a static start. The three-point position was characterized by assuming a crouched stance with forward lean and maintaining three points of contact with the ground, including one hand, and both feet (Figure 6). A Zybek timing system was used to measure sprint time at 10 and 40 yards of the sprint distance. Participants were instructed to sprint through the gates as fast as possible. Two sprint trials were completed with a minimum of three minutes of passive rest between trials. The fastest 40yd sprint time (s) and the corresponding split time (s) at 10 yards were used for data analysis.

Figure 6. Indoor sprinting condition

2.4.3 Counter-Movement Jump (CMJ) Condition

Each athlete began their trial with two familiarization jumps at 50% and 75% self-perceived maximal effort, then completed two maximal effort jumps with 2 minutes of passive rest in between. The participants stood with feet placed at hip width apart on top of two force-plates (AMTI HP400600-HF-OP-2K, Watertown, MA, sampling frequency = 2000 Hz). Each participant held a wooden dowel in a high bar back squat position to remove the variability of arm swing. Each participant was asked to quickly squat down to a self-selected countermovement depth, followed by a jump as high as possible while being provided with strong verbal encouragement. Each participant had two trials followed by one to two minutes of passive recovery between trials. The following variables were considered: Modified reactive strength index (mRSI) and peak vertical jump height. Where jump height = (Take-off Velocity^2) / (2 * g). Where mRSI is calculated by dividing the jump height (m) by the contact time in seconds (beginning of the movement to take-off).

Figure 7. Countermovement Jump on Force-Plate

2.5 Statistical Analyses

The primary outcomes for the study were relative peak force (rPF) with body weight removed (Appendix T) derived from each unilateral isometric strength test position, sprint time splits (i.e., 10 yd, 40 yd), jump height (m), and modified reactive strength index (mRSI) extracted from the CMJ test. Secondary outcomes for the study were force-time metrics including RFD in epochs of 50ms up to 200ms and average impulse (IP) in epochs of 100ms up to 300ms.

Objective 1 compared the relationship between dynamic performance variables and the relative PF extracted from dominant and non-dominant CB and SSB conditions using Repeated

Measures ANOVA. Following this, a regression analysis was conducted to investigate the relationship between the SSB and CB on 10- and 40-yard sprint performance. Objective 2 compared the relationship between dynamic performance outcomes and the relative PF extracted from the $_{uni}$ISqT or $_{uni}$ICalf position (using the SSB which demonstrated the strongest correlations with dynamic performance from Objective 1) using a regression analysis. The regression analysis considered which position accounted for the most variance in the 10- and 40-yard sprint performance. Furthermore, between session reliability for rPF was calculated using the standard error of the measurement (SEM), the intraclass correlation coefficient (ICC) and the standard deviation (SD) of the sample: SEM = SD* $\sqrt{1\text{-ICC}}$ (Koo et al., 2016; Weir et al., 2005). The specific ICC formula used: Model (2-way mixed), Form (Average Measures), and Type (Consistency). Then the SEM was used to calculate the minimal detectable change (MDC) according to the formula MDC95 = SEM * $\sqrt{2}$ * 1.96. Furthermore, coefficient of variation % (CV%) using a method error calculation was used to compare to previous literature (Appendix S). Using the bivariate correlations, a Hittner's follow-up test was used to investigate the difference in magnitude of correlation between all performance metrics and dynamic performance variables, with the intent to determine which metrics are more closely related to dynamic performance. Specifically, a Hittner's Test was used to compare the strength of two relationships involving a common variable. It determines if the correlation between one variable pair (e.g., X and Y) significantly differs from another pair (X and Z), offering insight into which relationship is stronger. Possible covariates such as age and training experience were explored. All metrics were computed using SPSS software with an acceptable significance of $P<0.05$.

Chapter Three

RESULTS

3.0 Results

3.1 Objective 1

THE RELATIONSHIP BETWEEN ISOMETRIC STRENGTH TESTS AND DYNAMIC PERFORMANCE: A COMPARISON OF TWO BAR TYPES

3.1.1 Comparison of Bar Types: SSB versus CB

A RM ANOVA was used to explore the differences in rPF extracted from the $_{uni}$ISqT test on both the dominant and non-dominant limbs while using a SSB or CB. Descriptive statistics for the $_{uni}$ISqT combinations of limbs and bar types are shown in Table 2. The RM ANOVA revealed a main effect for bar type ($F_{1,40}$=97.481, p<0.001, η^2_p=0.709) with the SSB producing higher rPF. Pairwise comparison reveals an average difference of .308 units of BW in newtons (mean difference of 30.8% rPF), indicating that the bar type had a significant impact on isometric squat performance measured by rPF. However, there was no effect of limb side ($F_{1,40}$=.004, p = .950, η^2_p=0.000), nor did the interaction between the bar type and limb side ($F_{1,40}$=.026, p=.872, η^2_p=0.001). Overall, these findings reveal that there is a significant difference in isometric strength between bar type. Refer to Appendix L for ANOVA output.

Table 2. Descriptive Statistics for Objective 1: Comparison of rPF (PF newtons/BW newtons) by Bar Type, Position, and Limb.

		SSB*		CB	
		Mean	SD	Mean	SD
$_{uni}$ISqT	Dominant Limb (rPF)	2.725	.443	2.447	.459
	Non-Dominant Limb (rPF)	2.701	.471	2.430	.505
$_{uni}$ICalf	Dominant Limb (rPF)	2.189	.398	1.858	.441
	Non-Dominant Limb (rPF)	2.222	.454	1.872	.447

SSB; Safety Squat Bar, CB; Conventional Barbell, D; Dominant Limb, ND; Non-Dominant Limb, RM; Relative to BW Maximum PF, SD; Standard Deviation
*SSB was significantly greater than CB polled across task and limb.

3.1.2 Bar Type and Limb Side for Predicting Performance: 10-yard sprint performance

Outcomes of a regression analysis aimed at investigating the relationships between predictor variables extracted from the $_{uni}$ISqT including SSB dominant-limb, SSB non-dominant limb, CB dominant limb, and CB non-dominant limb on 10-yard sprint performance are presented in Table 3. Age and varsity experience were not correlated with the performance metrics and therefore were not used as covariates in the regression model (Appendix M). This analysis explored the extent to which the SSB or CB predictor variables from both dominant/non-dominant limbs contribute to the observed variability in 10-yard sprint performance. Correlations between each limb and the bar types with 10-yard sprint performance are shown in Table 4 and scatter plots of the relationships are shown in Appendix U. The regression analysis for the SSB and the CB in the dominant limb accounted for a significant proportion of the variance in 10-yard sprint performance, R^2=0.207, $F_{2, 38}$=4.947, p=.008. SSB dominant-limb (β=-.645, p=0.008) accounted for more variance in the 10-yard sprint performance than the CB on the dominant limb (β=.298, p=0.200), indicating that greater rPF values extracted from SSB dominant limb were associated with faster 10-yard sprint performance. The regression analysis for the SSB and the CB in the non-dominant limb accounted for a significant proportion of the variance in 10-yard sprint performance, R^2=0.257, $F_{2, 38}$ =6.555, p=.004. SSB non-dominant-limb (β=-.799, p=0.005) accounted for more variance in the 10-yard sprint performance than the CB non-dominant limb (β=.392, p=0.155), indicating that greater rPF values extracted from SSB non-dominant-limb were associated with faster 10-yard sprint performance. Furthermore, both regression analyses satisfied the assumptions for multicollinearity; collinearity tolerance (CT) was .399, variance inflation factor (VIF) was 2.506, and condition index (CI) was 12.917 for the SSB on the dominant limb and 21.767 for the CB on the dominant limb. Moreover, the non-dominant side also satisfied the assumptions for multicollinearity; CT was 0.268, VIF was 3.733, and CI was 11.581 for the SSB on the non-dominant limb and 25.049 for the CB on the nondominant limb. These findings contribute to our understanding of the factors influencing 10-yard sprint performance and highlight the significance of bar differences in sprint performance prediction.

Table 3. Summary table for the regression analysis and regression coefficients for Objective 1 (bar type).

Dominant Limb rPF vs 10-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.208	.101	2,38	4.947	.012*
	B	***SE***	**β**	***t***	**p**
Intercept	2.114	.101		21.006	<.001
rPF SSB	-.161	.057	-.645	-2.819	.008*
rPF CB	.072	.055	.298	1.304	.200
Non-Dominant Limb rPF vs 10-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.257	.098	2,38	6.555	.004*
	B	***SE***	**β**	***t***	**p**
Intercept	2.150	.090		23.853	<.001
rPF SSB	-.188	.064	-.799	-2.958	.005*
rPF CB	.086	.059	.392	1.450	.155
Dominant Limb rPF vs 40-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.271	.275	2,38	7.050	.002*
	B	***SE***	**β**	***t***	**p**
Intercept	6.399	.378		22.009	<.001
rPF SSB	-.518	.155	-.731	-3.331	.002*
rPF CB	.233	.150	.326	1.487	.145
Non-Dominant Limb rPF vs 40-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.222	.284	2,38	5.438	.008*
	B	***SE***	**β**	***t***	**P**
Intercept	5.972	.262		22.829	<.001
rPF SSB	-.469	.184	-.703	-2.542	.015*
rPF CB	.188	.172	.301	1.090	.282
Dominant Limb rPF vs Jump Height					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.024	.077	2,38	.468	.630
	B	***SE***	**β**	***t***	**P**
Intercept	.336	.077		4.384	<.001
rPF SSB	.028	.044	.164	.648	.521
rPF CB	-.002	.042	-.012	-.048	.962
Non-Dominant Limb rPF vs Jump Height					

	R Square	*SE Estimate*	**df**	***F***	**p**
ANOVA	.015	.077	2,38	.291	.749
	B	***SE***	**β**	***t***	**P**
Intercept	.357	.071		5.007	<.001
rPF SSB	.011	.050	.066	.211	.834
rPF CB	.009	.047	.062	.199	.843
Dominant Limb rPF vs mRSI					
	R Square	*SE Estimate*	**df**	***F***	**p**
ANOVA	.119	.115	2,38	2.567	.090
	B	***SE***	**β**	***t***	**P**
Intercept	.268	.114		2.345	<.001
rPF SSB	.094	.065	.349	1.449	.156
rPF CB	-.001	.063	-.006	-.023	.982
Non-Dominant Limb rPF vs mRSI					
	R Square	*SE Estimate*	**df**	***F***	**p**
ANOVA	.084	.117	2,38	1.744	.189
	B	***SE***	**β**	***t***	**P**
Intercept	.327	.108		3.030	<.001
rPF SSB	.051	.076	.201	.670	.507
rPF CB	.023	.071	.099	.329	.744

Notes: *Indicates a significant regression equation and a significant predictor of the dependent variable. Definitions: B, Unstandardized Beta Coefficient; SE, Standard Error; b, standardized beta coefficients; rPF, relative peak force.

Table 4. Correlation matrix for $_{uni}$ISqT rPF relationship with 10-yard sprint performance.

Correlations

	SSB Dominant Limb	SSB Non Dominant Limb	CB Dominant Limb	CB Non Dominant Limb	10 Yrds
SSB Dominant Limb	1	.841	.775	.739	-.414
SSB Non Dominant Limb		1	.806	.856	-.464
CB Dominant Limb			1	.933	-.202
CB Non Dominant Limb				1	-.292

SSB; Safety Squat Bar, CB; Conventional Barbell. The correlations between CB Dominant/Non-dominant and 10 yrds are non-significant. All other correlations are significant at $p < 0.001$.

3.1.3 Bar Type and Limb Side for Predicting Performance: 40-yard sprint performance

Outcomes of a regression analysis aimed at investigating the relationships between predictor variables extracted from the $_{uni}$ISqT including SSB dominant-limb, SSB non-dominant limb, CB dominant limb, and CB non-dominant limb on 40-yard sprint performance are presented in Table 3. Again, age and varsity experience were not correlated with the performance metrics and therefore were not used as covariates in the regression model (Appendix M). This analysis explored the extent to which the SSB or CB predictor variables on the dominant/non-dominant limbs contribute to the observed variability in 40-yard sprint performance. Correlations for each limb and between bar types on the 40-yard sprint performance shown in Table 5 and scatter plots of the relationships are shown in Appendix U. For the dominant limb, the regression analysis accounted for a significant proportion of the variance in 40-yard sprint performance between the SSB and the CB, R^2=0.271, $F_{2, 38}$=7.050, p=.002. SSB dominant-limb (β=-.731, p=0.002) accounted for more variance in the 40-yard sprint performance than the CB on the dominant limb (β=.326, p=0.145), indicating that greater rPF values extracted from SSB dominant limb were associated with faster 40-yard sprint performance. For the non-dominant limb, the regression analysis accounted for a significant proportion of the variance in 40-yard sprint performance between the SSB and the CB, R^2=0.222, $F_{2, 38}$ =5.428, p=.008. SSB on the non-dominant-limb (β=-.703, p=0.015) accounted for more variance in the 40-yard sprint performance than the CB on the non-dominant limb (β=.301, p=0.282), indicating that greater rPF values extracted from SSB non-dominant limb were associated with faster 40-yard sprint performance. Furthermore, both regression analyses satisfied the assumptions for multicollinearity; CT was .399, VIF was 2.506, and CI was 12.917 for the SSB on the dominant limb and 21.767 for the CB on the dominant limb. Moreover, the non-dominant side satisfied the assumptions for multicollinearity; CT was 0.268, VIF was 3.733, and CI was 11.581 for the SSB on the non-dominant limb and 25.049 for the CB on the nondominant limb. These findings contribute to our understanding of the factors influencing 40-yard sprint performance and highlight the significance of bar differences in sprint performance prediction.

Table 5. Correlation matrix for $_{uni}$ISqT rPF relationship with 40-yard sprint performance. All correlations significant at $p < 0.001$.

Correlations

	SSB Dominant Limb	SSB Non Dominant Limb	CB Dominant Limb	CB Non Dominant Limb	40 Yrds
SSB Dominant Limb	1	.841	.775	.739	-.478
SSB Non Dominant Limb		1	.806	.856	-.445
CB Dominant Limb			1	.933	-.240
CB Non Dominant Limb					-.300

SSB; Safety Squat Bar, CB; Conventional Barbell. The correlations between CB Dominant/Non-dominant and 40 yrds are non-significant. All other correlations are significant at $p < 0.001$

3.2 Objective 2

THE RELATIONSHIP BETWEEN UNILATERAL ISOMETRIC STRENGTH TESTS AND DYNAMIC PERFORMANCE: A COMPARISON OF TWO POSITIONS

3.2.1 Comparison of Positions: $_{uni}$ISqT versus $_{uni}$ICalf

A RM ANOVA was used to explore the differences in rPF extracted from the $_{uni}$ISqT test and $_{uni}$ICalf on both the dominant and non-dominant limbs while using a SSB. Descriptive statistics for the positions and limbs are shown in Table 6. The RM ANOVA revealed a main effect for position type ($F_{1,40}$=81.171, p<0.001, η^2_p=0.670) with the $_{uni}$ISqT producing higher rPF. Pairwise comparison reveals an average difference of .541 units of BW (mean difference of 54.1% BW), indicating that the position type had a significant impact on maximal force generating ability by rPF. However, the main effect of limb side did not reach statistical significance ($F_{1,40}$=.004, p = .950, η^2_p=0.000), nor did the interaction between the position type and limb side ($F_{1,40}$=2.103, p = .155, η^2_p=0.050). Overall, these findings reveal that there is a significant difference in the position type choice during isometric strength testing (Appendix L).

Table 6. Descriptive Statistics for Objective 2. Comparison of rPF (PF/BW) for each limb by Position.

		SSB	
		Mean	SD
$_{uni}$ISqT	Dominant Limb (rPF)	2.725	.443
	Non-Dominant Limb (rPF)	2.701	.471
$_{uni}$ICalf	Dominant Limb (rPF)	2.189	.398
	Non-Dominant Limb (rPF)	2.222	.454

Table 7. Summary table for the regression analysis and regression coefficients for Objective 2 (position type). Both positions extracted rPF using the SSB.

Dominant Limb rPF vs 10-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.277	.100	2,38	5.592	.007*
	B	***SE***	**β**	***t***	**p**
Intercept	2.236	.116		19.245	<.001
$_{uni}$ISqT	-.086	.037	-.344	-2.312	.026*
$_{uni}$ICalf	-0.69	.041	-.247	-1.664	.104
Non-Dominant Limb rPF vs 10-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.232	.100	2,38	5.738	.007*
	B	***SE***	**β**	***t***	**P**
Intercept	2.182	.100		21.845	<.001
$_{uni}$ISqT	-.188	.038	-.379	-2.380	.018*
$_{uni}$ICalf	.086	.039	-.145	-.905	.370
Dominant Limb rPF vs 40-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.304	.269	2,38	8.282	.001*
	B	***SE***	**β**	***t***	**P**
Intercept	6.423	.313		20.520	<.001
$_{uni}$ISqT	-.281	.100	-.397	-2.811	.008*
$_{uni}$ICalf	-.226	.111	-.286	-2.028	.050
Non-Dominant Limb rPF vs 40-yard Split					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.229	.284	2,38	5.655	.007*
	B	***SE***	**β**	***t***	**P**
Intercept	6.104	.284		21.501	<.001
$_{uni}$ISqT	-.235	.107	-.353	-2.198	.034*
$_{uni}$ICalf	-.138	.111	-.200	-1.246	.220
Dominant Limb rPF vs Jump Height					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.030	.076	2,38	.580	.565
	B	***SE***	**β**	***t***	**P**
Intercept	.313	.089		3.502	<.001
$_{uni}$ISqT	.023	.029	.133	.797	.431
$_{uni}$ICalf	.015	.032	.078	.469	.642
Non-Dominant Limb rPF vs Jump Height					

	R Square	*SE Estimate*	**df**	*F*	**p**
ANOVA	.018	.077	2,38	.352	.706
	B	***SE***	**β**	***t***	**P**
Intercept	.378	.089		4.252	<.001
$_{uni}$ISqT	.020	.026	.126	.778	.441
$_{uni}$ICalf	-1.162	.000	-.064	-.398	.693
Dominant Limb rPF vs mRSI					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.120	.115	2,38	2.590	.088
	B	***SE***	**β**	***t***	**P**
Intercept	.282	.134		2.111	<.001
$_{uni}$ISqT	.095	.043	.354	2.232	.032*
$_{uni}$ICalf	-.010	.048	-.032	-.203	.840
Non-Dominant Limb rPF vs mRSI					
	R Square	***SE Estimate***	**df**	***F***	**p**
ANOVA	.083	.117	2,38	1.718	.193
	B	***SE***	**β**	***t***	**P**
Intercept	.338	.118		2.867	<.001
$_{uni}$ISqT	.077	.044	.305	1.745	.089
$_{uni}$ICalf	-.011	.046	-.043	-.248	.805

Notes: *Indicates a significant regression equation and a significant predictor of the dependent variable. Definitions: B, Unstandardized Beta Coefficient; SE, Standard Error; b, standardized beta coefficients; relative peak force; rPF.

3.2.1 The Predictor of Dynamic Performance Metrics: $_{uni}$ISqT and $_{uni}$ICalf

3.2.2 Dominant Limb

Descriptive statistics for the $_{uni}$ISqT and ICalf positions for each limb are shown in Table 6. In this section, we present the outcomes of a regression analysis aimed at investigating the testing position ($_{uni}$ISqT or $_{uni}$ICalf) on 10-yard and 40-yard sprint performance extracted from the dominant limb (Table 7). For the dominant limb, the regression analysis accounted for a significant proportion of the variance in 10-yard sprint performance between the $_{uni}$ISqT and the $_{uni}$ICalf, R^2=0.277, $F_{2, 38}$=5.592, p =.007. The results of the regression analysis demonstrated that

$_{uni}$ISqT (β=-.344, p=0.026) accounted for more variance in the 10-yard sprint performance than the $_{uni}$ICalf on the dominant limb (β=-.247, p=0.104), indicating that greater rPF values extracted from $_{uni}$ISqT dominant limb were associated with faster 10-yard sprint performance. For the dominant limb, the regression analysis accounted for a significant proportion of the variance in 40-yard sprint performance between the $_{uni}$ISqT and the $_{uni}$ICalf, R^2=0.304, $F_{2, 38}$ = 8.282, p=.001. The results of the regression analysis demonstrated that $_{uni}$ISqT (β=-.397, p=0.008) accounted for more variance in the 40-yard sprint performance than the $_{uni}$ICalf on the dominant limb (β=-.286, p=0.050), indicating that greater rPF values extracted from $_{uni}$ISqT dominant limb were associated with faster 40-yard sprint performance.

Furthermore, both regression analyses satisfied the assumptions for multicollinearity; CT was 0.920, VIF was 1.087, and CI was 11.989 for the $_{uni}$ISqT on the dominant limb and 15.855 for the $_{uni}$ICalf on the dominant limb. None of the regression models for CMJ height or mRSI reached statistical significance. This objective also involved a series of bivariate correlations which revealed the relationship between the $_{uni}$ISqT using the SSB and dynamic performance metrics considering dominant limbs. The analysis of the $_{uni}$ISqT test results for the dominant limb revealed significant negative correlations between rPF and sprint performance split times extracted from the 40-yard dash. For the 10-yard split time, R_{41} =-.493, p<.001. The 20-yard split time exhibited the largest significant negative correlation with rPF, resulting in R_{41}=-.532, p<.001. Likewise, the 40-yard dash time displayed the second-largest negative correlation with rPF, as indicated by R_{41}=-.511, p<.001. As for the force-time characteristics, rPF was negatively associated with Impulse at 100 (ms), R_{41}=-.332, p=.034. As for the jumping tests, rPF was positively correlated with mRSI extracted from the CMJ, R_{41}=.402, p=.009. Furthermore, RFD extracted from the $_{uni}$ISqT or $_{uni}$ICalf on the dominant limb had no significant relationship with dynamic performance. However, average impulse at 100, 200, and 300 (ms) showed a significant relationship with dynamic performance, in particular sprinting split times at 10 and 40 yards (Appendix O and Q). Correlation results as part of Hittner's follow up are displayed in Table 8. All correlations extracted from the dominant limb $_{uni}$ISqT and $_{uni}$ICalf are presented in Appendix O and Q. Finally, scatter plots of the relationships are shown in Appendix V.

A similar analytical approach was applied to investigate the relationship between rPF obtained from the $_{uni}$ICalf test using the SSB on the dominant limb and performance metrics related to the 40-yard dash. Negative correlations were identified between rPF and sprint performance metrics: specifically, for the 10-yard split time, a negative correlation was observed R_{41}=-.327, p=.037, followed by the 20-yard split time R_{41}=-.364, p=.019, and the overall 40-yard dash time R_{41}=-.370, p=.017. A comprehensive overview of the correlation findings is presented in Table 8 and Appendix O and Q and scatter plots in Appendix V.

3.2.3 Non-Dominant Limb

Outcomes of a regression analysis aimed at investigating the position (ISqT or ICalf) on 10-yard and 40-yard sprint performance extracted from the non-dominant limb are presented in Table 7. The first regression analysis accounted for a significant proportion of the variance in 10-yard sprint performance between the $_{uni}$ISqT and the $_{uni}$ICalf on the non-dominant limb, R^2=0.232, $F_{2, 38}$=5.738, p=.007. The results of the regression analysis demonstrated that $_{uni}$ISqT (β=-.379, p=0.018) accounted for more variance in the 10-yard sprint performance than the $_{uni}$ICalf on the non-dominant limb (β=-.145, p=.370), indicating that greater rPF values extracted from $_{uni}$ISqT non dominant limb were associated with faster 10-yard sprint performance. The second regression analysis accounted for a significant proportion of the variance in 40-yard sprint performance between the $_{uni}$ISqT and the $_{uni}$ICalf on the non-dominant limb, R^2=0.229, $F_{2, 38}$=5.655, p=.007. The results of the regression analysis demonstrated that $_{uni}$ISqT (β=-.353, p=0.034) accounted for more variance in the 40-yard sprint performance than the $_{uni}$ICalf on the non-dominant limb (β=-.200, p=0.220), indicating that greater rPF values extracted from $_{uni}$ISqT non-dominant limb were associated with faster 40-yard sprint performance. Furthermore, the regression analysis did pass the assumptions for multicollinearity; CT was 0.788, VIF was 1.270, and CI was 11.943 for the $_{uni}$ISqT on the non-dominant limb and 14.327 for the $_{uni}$ICalf on the non-dominant limb. None of the regression models for CMJ height or mRSI reached statistical significance.

Correlation analysis was conducted to assess the relationship between rPF extracted from the $_{uni}$ISqT test utilizing the SSB and various performance metrics, and non-dominant limbs. For the non-dominant limb, positive correlations were observed between rPF and RFD in the 50-100 ms range R_{41}=.415, p=.007, as well as RFD in the 100-150 ms range R_{41}=.543, p<.001. Conversely, negative associations were found between rPF and Impulse at 100 ms R_{41}=-.448, p=.002. Moreover, rPF exhibited negative correlations with sprint performance measures: a negative relationship with the 10-yard split time R_{41}=-.518, p<.001, the 20-yard split time R_{41}=-.529, p<.001, and the overall 40-yard dash time R_{41}=-.478, p < .001. Furthermore, average impulse at 100, 200, and 300 were significantly correlated with 10 and 40 yard dash times (Appendix P). These findings are summarized in Table 8 and Appendix P.

Finally, for the $_{uni}$ICalf results extracted on the non-dominant limb using the SSB. Positive correlations emerged between rPF and RFD in the 50-100 ms range R_{41}=.328, p=.039 and RFD 100-150 ms R_{41}=.415, p=.008. There was also a positive correlation between rPF and Impulse at 300 ms R_{41}=-.320, p=.044. Additionally, concerning the relationship with sprint performance, negative correlations were evident for rPF with the 10-yard split time R_{41}=-.339, p=.030, the 20-yard split time R_{41}=-.363, p=.020, and the overall 40-yard dash time R_{41}=-.344, p=.028. No force-time characteristic correlations were significant (Appendix R). A comprehensive summary of these correlation outcomes is provided in Table 8.

3.2.4 Hittner's Follow up Results for all rPF Correlations with Performance Metrics

Despite seemingly large differences in the magnitude of correlations, Hittner's follow-up correlation analysis did not reveal any significant difference in the magnitude of the relationship between the rPF extracted from the $_{uni}$ISqT and the rPF extracted from the $_{uni}$ICalf on any of the performance metrics. All Hittner's follow up analyses are displayed in Table 8.

Table 8. Statistically significant correlation analyses between relative peak force during unilateral isometric tests (SSB), force time-metrics, and dynamic performance variables extracted from the first rep of testing to ensure consistency with comparison. Hittner's follow-up testing was used where two or more correlations were significant (BOLD). Z-score and corresponding (p-values) displayed. Hittner's follow-up analysis displayed in Z-Score.

	$_{uni}$ISqT		**$_{uni}$ICalf**		
Performance Metrics	**Dominant Limb (rPF)**	**Non-Dominant Limb (rPF)**	**Dominant Limb (rPF)**	**Non-Dominant Limb (rPF)**	**Hittner's Comparison (Z-Score)**
0-50 ms RFD	.154 (.336)	-.004 (.978)	.281 (.080)	.240 (.135)	N/A
50-100 ms RFD	.293 (.063)	**.415 (.007)**	.087 (.593)	**.328 (.039)**	Z=.569, P =.569
100-150 ms RFD	.249 (.116)	**.543 (<.001)**	.245 (.128)	**.415 (.008)**	Z=.905, P =.365
Impulse 100 ms	**-.332 (.034)**	**-.448 (.003)**	.021 (.898)	.115 (.479)	Z=1.891, P =.058
Impulse 200 ms	-.251 (.113)	-.297 (.059)	.068 (.675)	.221 (.171)	N/A
Impulse 300 ms	-.171 (.286)	-.065 (.685)	.136 (.401)	**.320 (.044)**	N/A
10-yard split	**-.493 (<.001)**	**-.518 (<.001)**	**-.327 (.037)**	**-.339 (.030)**	N.S
20-yard split	**-.532 (<.001)**	**-.529 (<.001)**	**-.364 (.019)**	**-.363 (.020)**	N.S
40-yard split	**-.511 (<.001)**	**-.478 (.002)**	**-.370 (.017)**	**-.344 (.028)**	N.S
Jump height	.292 (.064)	.228 (.152)	.228 (.152)	.231 (.147)	N/A
mRSI	**.402 (.009)**	**.341 (.029)**	.177 (.270)	.170 (.288)	Z=0.723, P =.469

Notes: Hittner's test was used on all possible correlations that reached significance P<0.05. Definitions: rPF, relative peak force; RFD, rate of force development; mRSI, modified reactive strength index; ms, milliseconds; N/A, non-applicable, less than two correlations reached significance; N.S; non-significant, all Z-scores were non-significant.

3.3 Between Session Reliability of rPF of both Limb and Bar

The assessment of the reliability and precision of measurements for both the $_{uni}$ISqT and $_{uni}$ICalf used three key metrics: standard error of the measurement (SEM), inter-class correlation (ICC), and the minimal detectable change (MDC). Results are presented in Table 9. CV% results displayed in Appendix S.

3.3.1 $_{uni}$ISqT Results

In the dominant limb, the SEM for CB indicated slightly higher variability in measurements compared to the SSB. Despite this, the ICC scores for both methods fell within the excellent reliability range, with SSB showing marginally better reliability (Koo & Li, 2016). The MDC values suggest that a larger change is required to discern a genuine difference when using the CB method. In the non-dominant limb, SEM values were larger in the CB. The reliability, as indicated by the ICC values, remained impressive for both methods, though SSB slightly outperformed CB. The difference in MDC values between SSB and CB was more pronounced in this limb, pointing to a higher threshold for detecting significant change in the CB. Refer to Table 9 for detailed values.

3.3.2 $_{uni}$ICalf Results

For the dominant limb, SEM values showed marginally higher variability for the SSB than for the CB, a reversal of the trend observed with the $_{uni}$ISqT. Despite this, the ICC values were closely matched, suggesting strong reliability across both methods. The MDC scores, however, favored the CB method, indicating a lower threshold for detecting genuine differences. Detailed values are available in Table 9. The non-dominant limb' results were in line with the dominant limb findings, with similar trends observed in SEM, ICC, and MDC values. CV% was also calculated and displayed in Appendix S.

Table 9. Reliability Statistics for Objective 2. Mean (SD) presented in rPF extracted from SSB. %MDC is expressed as MDC/Mean x 100.

		Day 1 *M*(SD)	Day 2 *M*(SD)	SSB				Day 1 *M*(SD)	Day 2 *M*(SD)	CB			
				SEM	ICC	MDC	%MDC			SEM	ICC	MDC	%MDC
$_{uni}$ISqT	Dominant Limb	2.71 (0.54)	2.81 (0.57)	.11	.95	.31	11.61	2.55 (0.51)	2.68 (0.54)	.15	.92	.44	16.38
	Non-Dominant Limb	2.68 (0.58)	2.76 (0.60)	.08	.98	.22	8.49	2.50 (0.62)	2.71 (0.53)	.14	.95	.38	15.10
$_{uni}$ICalf	Dominant Limb	2.10 (0.47)	2.24 (0.59)	.16	.87	.43	20.65	1.85 (0.46)	1.98 (0.44)	.14	.90	.40	21.38
	Non-Dominant Limb	2.10 (0.47)	2.29 (0.57)	.14	.91	.39	18.75	1.84 (0.49)	1.99 (0.53)	.15	.91	.41	22.25

SEM; Standard Error of the Measurement, ICC; inter-class correlation, MDC; minimal detectable change.

Chapter Four

Discussion

4.0 Discussion

A recent review by Lum et al. (2020) identified the need for further investigation into the relationship between unilateral pushing isometric strength assessments and their relationship with dynamic performance. A deeper understanding of this relationship can help coaches and strength and conditioning practitioners choose appropriate measures of performance within a gym-setting and track progress over time. Furthermore, improving our understanding of the influence of different bar choices for strength assessments and how it might change the relationship with dynamic performance will help coaches and practitioners design more effective programs for return-to-play situations and performance improvement.

To my knowledge, this was the first study to investigate gym-based testing positions and protocols that can compare to the three plus times body weight ground reaction forces placed on the body during acceleration and maximal velocity sprinting (Nagahara et al., 2018). Moreover, this was the first study to investigate the relationship between two unilateral isometric pushing assessments and the relationship with sprinting performance over > 30m. Additionally, to my knowledge this is the first study to explore the differences between isometric strength extracted from a CB and a SSB and the subsequent relationship with dynamic performance. Data show that using the SSB led to higher rPF compared to the CB, indicating that the choice of bar significantly impacted force output during isometric strength assessment. Another important finding is that using the SSB led to a stronger prediction for sprint times compared to the CB. When using the SSB, both the ${}_{uni}$ISqT and the ${}_{uni}$ICalf position showed a relationship with sprinting performance; however, when compared in a regression model the ${}_{uni}$ISqT accounted for more variance in sprinting performance than the ${}_{uni}$ICalf. Finally, while there was a relationship between the $_{uni}$ISqT and mRSI extracted from the CMJ, no regression equation reached statistical significance in either of the jumping metrics.

4.1 Comparison of Bar Types: SSB versus CB on Force Production

Results emphasize the difference of bar choice on maximal force output. Notably, our strength tests revealed a ~30% higher rPF output when using the SSB compared to the CB. This raises the possibility that the SSB facilitates a biomechanically superior position possibly involving reduced external rotation at the glenohumeral joint and enhanced alignment at the torso during an isometric contraction. Supporting this idea, Myer et al. (2014) highlighted some of the inherent limitations associated with the conventional barbell during a back squat. Specifically, they suggested that mobility and alignment issues in the trunk and thoracic regions can constrain the neuromuscular strength potential during the back squat exercise. Given the design of the SSB, with its centralized weight distribution and reduced demand for shoulder external rotation, it might mitigate some of these alignment challenges and offer a more desirable environment for force generation in an isometric contraction. In contrast to my findings, Vantrease et al. (2021) observed greater maximal strength using the conventional barbell (CB) compared to the SSB; but their study focused on isoinertial "free weight" contractions through a full range of motion which differs from my study which utilized isometric contractions. Vantrease et al. (2021) also highlighted that original SSB's have cambered handles, which can result in a forward shift in the weight during squats, which could have impacted maximal strength in their study. Years earlier, Gullett et al. (2009) demonstrated this anterior (forward) weight shift difference by showing that maximal loads during back squats, typically using a traditional barbell, are often higher than for front squats (inherently a more anterior bar position).

Another related finding is by Hecker et al. (2019) who identified that the CB led to increased muscle activation in the rectus abdominis during squats, in comparison to the SSB which had a lower 3RM capacity. One possible explanation for this is that the heightened activation of the core musculature with the CB might result from added strain on the torso from forced external rotation at the shoulder joint and external rotation of the ribcage. As for why the SSB resulted in a lower 3RM in the Hecker et al. study, again it could be related to an anterior shift in weight during a free weight squat exercise (Gullett et al., 2009) in comparison to an isometric exercise. Given the potential biomechanical advantages of the SSB, it's worth noting some challenges associated with the CB for athletes with limited range of motion who might experience added strain due to induced external rotation at the glenohumeral joint, changing the torso's alignment, as crucial for stability and pressure. Another major difference between the two bars is that the SSB is designed with foam padding for the shoulders (Figure 4) versus the conventional bar which does not. This could have impacted the comfort of the athlete and allowed for higher expression of force, especially in an isometric assessment. While my study highlighted the potential force advantages of the SSB, direct muscle activation and biomechanical comparisons were absent, emphasizing the need for future research into these possibilities. Investigations should contrast the CB and SSB across isometric and isoinertial exercise contexts using motion capture and EMG recordings to better understand their respective biomechanical implications.

4.1.1 Comparison of Bar Types: SSB versus CB on 10-yard and 40-yard Sprint Performance

Sprint performance serves as a pivotal performance indicator in numerous field and court sports, often dictating outcomes in competitive scenarios and influencing return-to-play decisions (Gualtieri et al., 2023; Haugen et al., 2019). When determining which bar type is more influential in predicting both acceleration and top-speed performance, our findings were clear: using the SSB led to stronger predictions of 10-yard and 40-yard sprint outcomes for both dominant and non-dominant limbs, when compared to the CB. In agreement with my hypothesis, rPF from the SSB was a superior predictor of sprint performance across both short and long sprint distances. The short sprint distance seems relevant for athletes in field-based sports, including football, soccer, and basketball. For example, Teramoto et al. (2016) stressed the relevance of the 10-yard dash in professional football, identifying it as a principal predictor of rushing yard performance. This demonstrated significance of sprinting capability, especially during the acceleration phase, aligns with earlier work by Weyand et al. (2000) who emphasized the relationship between lower body strength and sprint speed across many different sports. They concluded that initial sprint speed is a function of applying greater support forces to the ground during the stance phase of sprinting. Moreover, our findings reinforce the idea that greater force generating capacity accounts for a portion of the variance during sprinting. While research shows muscular strength is related to and could play a role in the rate of force development ability (Suchomel et al., 2016), our study shows that the enhanced isometric force production during the SSB accounted for more variance in the acceleration phase of a sprint, compared to the CB.

A noteworthy aspect of my study is its exploration of the correlation between each bar type and longer sprint performance. While the importance of acceleration in sprints under 20m is well-established (Lum et al., 2020; Comfort et al., 2019), research focusing on sprints beyond 30m is absent. My study bridges this knowledge gap by examining the relationship between peak force and split time for sprint distance of 40 yds (i.e., exactly 36.6m). However, current literature predominantly explores the acceleration phase, with little attention given to the maximum speed phase of sprints, especially those beyond 30m. It is generally thought that the maximal velocity phase of a sprint may only occur between 27-33m for team sport athletes (Barr et al., 2013). Considering our findings, there is a clear need for future investigations into the relationship between SSB and CB derived isometric rPF pushing capabilities and sprint performance at distances surpassing 30m and reaching 33m+. This will unveil the true relationship between isometric strength, sprint acceleration, and maximal velocity sprinting.

4.2 Relationship between Pushing Isometric Assessments and Dynamic Performance

The results of the study confirm the prediction that unilateral isometric pushing tests would be related to dynamic performance metrics. Specifically, I hypothesized that both unilateral isometric tests ($_{uni}$ISqT and $_{uni}$ICalf) would be correlated with metrics derived from dynamic performance tests (Sprint split times and CMJ metrics). I found a large relationship between unilateral isometric pushing positions and dynamic performance, in particular sprinting performance ($r=-.478$, $p=0.002$ to $r=-0.518$, $p<.001$) and a moderate relationship with mRSI extracted from the CMJ ($r=.341$, $p=0.029$ to $r=.402$, $p=0.009$). Only two previous studies have focused on a unilateral isometric test as the applied metric to correlate with sprinting, and in both cases the authors used a pulling assessment. Kuki et al. (2019) investigated the relationship between unilateral IMTP and sprint acceleration performance in male collegiate soccer athletes ($n=20$) and reported the absolute PF of $_{uni}$IMTP in both dominant and non-dominant leg positions. Only the dominant limb PF was correlated with the 30m sprint time (dominant leg: r=-0.456, p<0.05), and relative PF in the non-dominant limb was significantly correlated with 10m sprinting time (r=-0.447, p<0.05) and 30m sprinting time (r=-0.452, p<0.05). To my knowledge the only other study using unilateral assessments is Thomas et al. (2016), who investigated the relationship between isometric strength, sprint, and change of direction speed performance in academy cricket players (n=18). They found that while both the left and right leg were individually correlated with sprinting performance, the PF extracted from the IMTP using the right limb displayed the strongest relationship with sprint performance r = - 0.49 to -0.52. However, only correlational analyses were compared, which is not the best way to determine if a 'stronger relationship' exists. Interestingly, they also reported no significant relationship between bilateral stance IMTP PF and sprint performance. Similarly, comparing my results to these two published studies there is agreement where I found that the rPF extracted from the $_{uni}$ISqT SSB test had a moderate to a large relationship with sprinting at both 10 and 40 yards (r value range=-0.478 to -0.518) for both the dominant and non-dominant limbs. My results are comparable to both Kuki et al. who found the 30m sprint time and PF extracted from the dominant leg were related (r=-0.456, p<0.05), and Thomas et al. who found PF extracted from the IMTP using the right limb displayed the largest relationship with 5m and 20m sprint performance (r = - 0.49 to – 0.52, p<0.05). When considering my results within the literature investigating the relationship between bilateral isometric assessments and sprinting performance, our results are comparable. Eight different studies (refer to table in Appendix N) have investigated the relationship between bilateral isometric assessments and sprinting performance, and document significant relationships between the IMTP and 5m sprint performance (r = -0.57), 10m sprint performance (r = -0.37), and 20m sprint performance (r = -0.69) (Lum and Joseph et al., 2019, Thomas et al., 2015); and ISqT and 5m sprint performance (r = -0.714), 10m sprint performance (r = -0.62), and 20m sprint performance (r = -0.62) (Brady et al., 2019). Based on these collective findings, bilateral rPF from both the IMTP and ISqT tests have a robust relationship with sprinting performance and my current work adds to this by documenting the large relationship between $_{uni}$ISqT rPF and sprinting. Future research should incorporate a regression analysis to investigate the differences between bilateral and unilateral isometric strength testing and the relationship with dynamic tasks.

4.3 Position and Joint Angle Specificity On Predicting Sprinting Performance

I initially hypothesized that the $_{uni}$ICalf and $_{uni}$ISqT isometric positions would predict sprinting performance differently based on the distance of the sprint. Specifically, the $_{uni}$ICalf position would be a stronger predictor of longer sprinting distance, while the $_{uni}$ISqT position would be a stronger predictor of shorter sprinting distance. This hypothesis was rooted in the principles of dynamic correspondence and specificity outlined earlier (Figures 1 and 2), specifically, the amplitude and direction of movement is the same during these position-specific isometric assessments, and based on previous work the regime of muscular work may also be the same (Saurez et al., 2019, Gillis et al., 2005). Furthermore, it is established that during maximum velocity sprinting ground reaction forces can surpass body weight by over three times, therefore being stronger in specific positions of sprinting may lead to enhanced performance (Nagahara et al., 2018). Intriguingly, my results challenged this hypothesis, with the $_{uni}$ISqT position producing 54.1% more relative force in comparison with the $_{uni}$ICalf position (Appendix L). Furthermore, this resulted in accounting for more variance with both short and long-distance sprinting performance (r = -0.478 to -0.518) in comparison with the $_{uni}$ICalf position (r = -0.327

to -0.370), and with $_{uni}$ISqT emerging as a stronger predictor of sprinting acceleration (Table 7). Previous research has shown that changing the joint angle position in an IMTP has been found to enhance or diminish the correlation between isometric strength and dynamic performance (Beckham et al., 2018). When applying this idea to the differences in the $_{uni}$ISqT versus $_{uni}$ICalf, the more flexed joint angle yielded a greater force and displayed a stronger relationship with dynamic performance. One potential explanation is that increased force production during the $_{uni}$ISqT is dependent on the length-tension relationship of the triceps surae which can be altered by both the ankle and knee joint position. The ankle joint angle is slightly further into dorsiflexion during the $_{uni}$ISqT movement in comparison to the $_{uni}$ICalf which could provide an advantage for force production in the plantar flexors (Hali et al., 2021) during the ISqT test. Furthermore, a more flexed knee angle will have an improved length-tension relationship in the quadriceps. Hali et al. reported that during 100% MVC the motor unit discharge rate was greater in the medial gastrocnemius and soleus when the ankle was dorsiflexed instead of plantarflexed (Hali et al., 2021). When expanding to the broader literature comparing bilateral ISqT and IMTP positions with dynamic performance metrics, one study stands out. Nuzzo et al. (2008) investigated the relationship between CMJ performance and multi-joint isometric assessments including rPF from both the IMTP and ISqT at the same knee joint angle. Specifically, Nuzzo et al. showed that rPF extracted from the IMTP at a knee angle of 140° revealed a significant relationship ($r = 0.588$) while the rPF extracted from the ISqT at approximately the same knee angle did not reveal a significant relationship with CMJ metrics. This finding coupled with my results of increased force production in the $_{uni}$ISqT pushing test and a larger relationship with sprinting, supports the idea that joint angle position is important when considering the relationship between rPF and dynamic performance metrics.

4.4 Relationship between Isometric Strength and Jumping Performance

I hypothesized that there would be a relationship between rPF extracted from the unilateral isometric strength tasks and jump metrics extracted from the CMJ such as jump height and mRSI. My findings partially supported this hypothesis, where neither the $_{uni}$ISqT nor $_{uni}$ICalf position revealed a significant relationship with CMJ height; but both the dominant and non-dominant $_{uni}$ISqT was related to mRSI. A number of studies have examined the relationship between isometric strength, assessed through the bilateral ISqT, and jump height achieved in the CMJ (Appendix N). Young et al. (1999) reported no significant correlations between rPF determined using ISqT and CMJ jump height. Similarly, Nuzzo et al. (2008) and Wilson et al. (1995) found no significant correlation between absolute and relative PF measured during ISqT and CMJ jump height. My findings agree with prior research which suggests that there is no significant relationship between bilateral isometric strength and CMJ height. My research also expands upon previous findings and shows that there is no relationship between *unilateral* isometric strength and CMJ height. Interestingly, Young et al. (1999) proposed that the lack of relationship between bilateral rPF in the ISqT position with CMJ height may be due to the difference in knee angle between the two exercises. Young et al. (1999) had participants perform the ISqT using a knee angle of 120° but had them initiate force during the CMJ from a 90° knee angle. My sample of participants completed their CMJ from a self-selected countermovement depth, with the intent to push the floor away as hard as possible, but based on my observation of every test, it is likely that no participant reached a 90° knee angle depth (Note: this was not directly measured during CMJ). As for mRSI extracted from the CMJ, only the $_{uni}$ISqT rPF from both the dominant and non-dominant limb position was related (Appendix O, P), where no relationships emerged for the ${}_{uni}$ICalf position and mRSI. The mRSI is calculated as jump height divided by time to take off in a CMJ. Therefore, it may be that athletes who produce more force during the ${}_{uni}$ISqT also were able to produce force at a faster rate during the CMJ. It should be mentioned that like the Young et al. (1999) argument, the ${}_{uni}$ISqT position had athletes generating force at joint angles similar to that of a CMJ (Knee angles: 130-150°), while the ${}_{uni}$ICalf produced force in more extended joint angles (Knee angles: 150-170°). This inconsistency between positions could have impacted the initiation of force between the two positions and the overall relationship between tasks.

4.5 The Relationship between rPF, Rate of Force Development, and Dynamic Performance

Based on the previous literature suggesting that enhanced muscular strength is generally associated with greater RFD, improved jumping height, and faster sprinting time, it would be reasonable to assume that individuals who produce more force also have higher RFD (NSCA 1993, Suchomel et al., 2016, and Lum et al., 2020). Furthermore, dynamic efforts such as sprinting, jumping, and change of direction are all accomplished through unilateral lower-body efforts. Unexpectedly, my findings suggest there is no relationship between unilateral rPF and RFD in 50ms epochs up to 150ms, when extracted from the dominant limb, but there was a moderate to large relationship for both the ${}_{uni}$ISqT (r=.415 to .543, p<.001) and ${}_{uni}$ICalf (r=.328 to .415, p<.05) positions, when RFD was extracted from the non-dominant limb. This could potentially be due to the training status of the participants. Further, when considering the relationship between RFD and sprinting performance the relationship also does not seem to carry over. My data show no relationship between unilateral RFD in epochs of 50ms up to 150ms and sprinting split times at distances up to 40 yards. Kuki et al. (2019) show similar results where onset of force production at 100 ms was not related to sprint split times. Importantly though, Comfort et al. (2018) suggested that RFD can only reliably be obtained when a specific fast protocol is in place during the isometric strength test. My study and Kuki et al. both used a force generation protocol rather than a specific fast cue protocol. Two cueing strategies are currently understood, the 'fast' and the 'hard' cueing methods, as outlined by McCormick et al. (2021) and Comfort et al. (2019), respectively, emphasize different aspects of force application – speed and maximal effort. The 'fast' cueing strategy, focusing solely on the speed of force application, could potentially lead to greater rapid force production, a contrast to the combined 'hard and fast' approach used in my study. Comfort et al. (2019) suggests that these distinct cueing strategies, though producing similar peak force and rapid force production metrics, could influence the force-time curve characteristics differently. Therefore, employing a specific 'fast' cueing protocol might have revealed a different relationship between RFD and sprinting performance. A secondary factor includes the pre-tension protocol that was used, where athletes would maintain 5-10% BW in pre-tension before the maximum effort push, this introduces some pre-load variability between subjects and may have influenced the force-time variables. Therefore, factors such as cueing, time of effort, the unilateral vs. bilateral nature of the assessment, and pre-tension parameters all may play a crucial role in determining the relevance of these metrics to dynamic performance and could be an explanation for the lack of relationship between RFD and sprint times in the current study.

4.6 Reliability of Unilateral Isometric Strength Positions

This study used ICC, SEM, and MDC to evaluate the test-retest reliability of each unilateral isometric position (table 9) and CoV% (Method Error) to relate to previous literature

(Appendix S). Most previous research has investigated bilateral isometric testing positions such as the IMTP and ISqT, finding PF to be the most reliable (based on ICC and CoV%) metric extracted from a force-time curve (Brady et al., 2018; Lum et al., 2020; and James et al., 2017). ICC values in the range of 0.75 to 0.90 indicate good reliability, and values above 0.90 indicate excellent reliability and CoV% illustrates the amount of variation between testing time points (Koo et al., 2016). The literature shows that PF extracted from the bilateral ISqT and IMTP show good reliability; ICC ≥ 0.86 and CV≤ 9.4% (Brady et al., 2018). Bishop et al. (2021) investigated the reliability of a unilateral pushing isometric position (ISqT) with a setup similar to a CB, which showed excellent reliability (ICC = 0.93-0.94) and a low (CoV = 5.44-5.70%). However, this study only considered intra-day reliability, which is not a conservative form of reliability measurement as strength measures are generally more variable between days. To build on the data from Bishop et al. our inter-day findings also suggest excellent reliability and CoV for the $_{uni}$ISqT extracted using the SSB (CoV=4.34-5.84%; ICC=0.95-0.98) and the CB (CoV=6.70-7.96%; ICC=0.92-0.95). However, when considering the $_{uni}$ICalf, the values are much higher, suggesting more variability between days (Table 9). This could have been due to the added variability in the knee joint, as it was not completely extended at 180 degrees (Figure 5). Therefore, it is clear that the $_{uni}$ISqT is a reliable position to extract PF from inter-day testing protocols. Moreover, it is evident that using the SSB removes some variability day to day and may be a more reliable bar to use when measuring PF from a pushing position. This study adds to the literature investigating reliability of position specific isometric tests, using more conservative test-retest reliability metrics. In addition, to my knowledge, this study is the first to report a combination of SEM, ICC, and MDC for a more robust assessment of reliability. MDC is particularly useful as it provides a quantifiable measure of the smallest change that can be detected by a test, beyond the threshold of measurement error, indicating real change in performance. This is critical for coaches and practitioners in the field of strength and conditioning and rehabilitation professionals, as it enables them to determine whether observed changes in strength and performance are meaningful and not due to random variations or measurement inaccuracies. Therefore, coaches and practitioners will be able to test and monitor specific training goals and understand the measurement error associated with the tool.

4.7 Summary

My novel findings highlight the significance of specificity and dynamic correspondence in assessing unilateral isometric strength efforts and their relation to dynamic performance. My results suggest that unilateral pushing efforts offer robust relationships with dynamic performance outcomes. The current results show medium-large correlation values consistent with other studies using unilateral pulling efforts (Kuki et al., 2020; Thomas et al., 2015). Unfortunately, I cannot directly compare pushing and pulling tests because I did not measure pulling tests as in previous studies. However, this insight could shape the design of more effective training testing procedures, as the ISqT is more practical to test with large groups of athletes. This study provides more evidence that unilateral isometric strength assessments are predictive of dynamic performance. To my knowledge, this is the first unilateral strength study to incorporate both regression and correlation analyses to better understand prediction of performance, the first to compare unilateral pushing efforts and dynamic performance, and the first to compare two bar types in an isometric assessment. Additional investigations could delve into the underlying biomechanical and neuromuscular mechanisms that contribute to the observed relationships, providing deeper insights into training optimization.

4.8 Limitations

One major limitation of my study was the sample size. Although the sample was big enough to provide sufficient power to run correlational analyses and follow-up regression analyses with two predictors, it was not large enough to run regression analyses with three or more predictors, limiting my findings. Moreover, my study lacked female participants, primarily due to the time of year (July-August) when many women's sports were not in pre-season and athletes were not around the university. Furthermore, one of the target groups for the recruitment of women into the study (women's soccer) had just begun pre-season games which conflicted with the timing of data collection. My study also lacked a bilateral isometric assessment, preventing a direct comparison of the magnitude differences between unilateral and bilateral isometric strength and their respective relationships with dynamic performance outcomes. This remains an avenue for future research. Another limitation is that our study solely focused on pushing efforts. The exclusion of pulling efforts restricts the scale of our findings. Future research could incorporate both pushing and pulling assessments to comprehensively explore the impact of different force application directions on dynamic performance.

4.9 Conclusion

This study investigated the relationship between unilateral isometric strength tests and dynamic sport-specific performance in high-performance athletes, focusing on two aspects: bar type (Safety Squat Bar vs. Conventional Barbell) and isometric testing position ($_{uni}$ISqT vs. $_{uni}$ICalf). The Safety Squat Bar showed higher force output compared to the Conventional Barbell, which translated to larger relationships and a stronger prediction of sprinting split times. The study also confirmed a strong relationship between unilateral isometric tests and dynamic performance, with $_{uni}$ISqT emerging as a better predictor than $_{uni}$ICalf on sprinting split times, jump height, and mRSI. These findings help to inform training and injury prevention strategies by emphasizing the potential role of equipment and body position in predicting athletic performance. Future research should investigate the biomechanical and neuromuscular mechanisms for improved force generation in the SSB versus the CB.

5.0 Implications for Future Research

Future studies should continue to investigate gym-based testing positions and protocols that can compare to the ground reaction forces placed on the body during acceleration and maximal velocity sprinting. An interesting avenue of investigation might consider how an athlete's strength reserve could play a role in their performance. For example, if a hypothetical ground reaction force during max velocity sprinting is three times body weight, then it may be relevant to compare the performance of individuals who can generate 2.5-3x BW in specific positions versus athletes who can only generate 1.5x BW. Potentially, considering a combination of positions that replicate the forces assumed during dynamic performance. These could include positions that specifically focus on the forces assumed in the ankle, knee, and hip during ground contact at high speeds; therefore, bridging the gap between task specificity and dynamic performance. Furthermore, future work should consider the regime of muscular work and the rate and time of force production to be closer to ground contact at high-speed running. To truly harness the potential of these findings, a potential avenue may be using these positions in anterior cruciate ligament (ACL) or other major knee ligament rehabilitation protocols, as well as in strength asymmetry protocols. This could become a relevant multi-joint isometric assessment that can compare strength or force-time characteristics between limbs and profile rehabilitation throughout an injury.

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Appendices

Appendix A

Participant Demographics

Participant ID: _________

Age: ________

Biological Sex: _________

Height: _________

Weight: _________

Appendix B

Participant ID: ________________________

Date: ______ /_______ /_______

VARSITY TRAINING EXPERIENCE & PREVIOUS INJURY QUESTIONNAIRE

1. How many years have you participated in University Sport?

   1 2 3 4 5 6 7 8 9 ≥10

2. What is your primary sport?

3. What year of USPORTS eligibility are you using? (i.e., if you have used 3 years of eligibility, you are now USING your 4th year of USPORTS eligibility)

   1 2 3 4 5

4. How many days a week do you currently train? (Inclusive of all sport specific or related training)

5. If one month of resistance training is considered 3 times per week for 4 weeks, how much resistance training (in months) have you done?
   In the previous year? __________________
   In the past month? ____________________

6. What is the average number of minutes per training session?

7. Have you ever experienced an injury to your lower body that required immobilization for an extended period of time (i.e. more than one week)?
   YES NO

   B. If yes, what was the injury, when did it occur and what was the duration of this condition?

8. Do you have any neurological conditions or injuries to the nervous system that have affected the arms or legs?
   YES NO

B. If yes, what was the injury, when did it occur and what was the duration of this condition?

Appendix C

Participant ID: ________________________

Date: ______ /_______ /_______

Pre-testing Criteria Questionnaire

1. Have you consumed any alcohol in the past 24 hours?

   YES NO (circle one)

   If you have answered YES, please include the type and amount:

2. Have you consumed any caffeine in the past 24 hours?

   YES NO (circle one)
   If you have answered YES, please include the type and amount:

3. Have you consumed any supplements in the past 24 hours that are NOT taken consistently?

   YES NO (circle one)

   If you have answered YES, please include the type and amount:

4. Have you participated in any exercise in past 24 hours?

   YES NO (circle one)

   If you have answered YES, please include the type and amount:

Appendix D

Waterloo Footedness Questionnaire

Instructions: Answer each of the following questions as best you can. If you *always* use one foot to perform the described activity, circle Ra or La (for **right always or left always**). If you **usually** use one foot circle Ru or Lu, as appropriate. If you use **both** feet **equally often, circle Eq.**

Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1. Which foot would you use to kick a stationary ball at a target straight in front of you?
   La Lu Eq Ru Ra

2. If you had to stand on one foot, which foot would it be?
   La Lu Eq Ru Ra

3. Which foot would you use to smooth sand at the beach?
   La Lu Eq Ru Ra

4. If you had to step up onto a chair, which foot would you place on the chair first?
   La Lu Eq Ru Ra

5. Which foot would you use to stomp on a fast-moving bug?
   La Lu Eq Ru Ra

6. If you were to balance on one foot on a railway track, which foot would you use?
   La Lu Eq Ru Ra

7. If you wanted to pick up a marble with your toes, which foot would you use?
   La Lu Eq Ru Ra

8. If you had to hop on one foot, which foot would you use?

La Lu Eq Ru Ra

9. Which foot would you use to help push a shovel into the ground?
   La Lu Eq Ru Ra

10. During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?
    La Lu Eq Ru Ra

11. Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?

    YES NO (circle one)

12. Have you ever been given special training or encouragement to use a particular foot for certain activities?

    YES NO (circle one)

If you have answered YES for either question 11 or 12, please explain:

Appendix E

Facebook Announcement

Study Title: "Validity and reliability of a novel alternative to force plate technology for position-specific isometric strength tests and their relationship to dynamic performance in collegiate athletes"

Hi everyone,

My name is Parker Scott, and I am a Graduate student from the College of Kinesiology at the University of Saskatchewan, currently working under the supervision of Dr. Jon Farthing. I am conducting a research project focused on investigating the differences in force-generating capacity through various joint angles and the impact on athletic performance. For this research study, we are looking to recruit 50-100 Huskie athletes.

We are hoping to begin data collection early in the summer (mid-July 2022). If you are eligible and consent to participate, you will be asked to attend two separate 1-hour testing sessions between the Sport Science and Health Centre at Merlis Belcher Place and the Saskatoon Field House. This study will require participants to complete multiple bouts of intense activity such as jumping, sprinting, and maximal isometric strength efforts.

If you are a current Huskie athlete, have at least one year of varsity experience, and do not have a history of major injury (e.g., major ligament tears, reconstruction surgery) then you may be eligible to participate. Please contact me if you are interested in participating in this study, and I will send you the participant consent form with further information.

Thank you!

Contact information:
Parker Scott (MSc. Candidate)
YTN237@usask.ca

Dr. Jon Farthing, Ph.D.
Jon.farthing@usask.ca

Appendix F

Study Announcement Script

Study title: “Validity and reliability of a novel alternative to force plate technology for Position-specific isometric strength tests and their relationship to dynamic performance in collegiate athletes”

Hello, my name is Parker Scott. I’m working with Dr. Jon Farthing from the College of Kinesiology to examine differences in force-generating capacity at various joint angles and those respective relationships with athletic performance. Moderate to large correlations have been previously shown between the amount of force an individual can generate and their respective ability to jump, accelerate and change direction. We have found a large gap in the available literature when comparing maximal isometric strength with maximal speed sprinting at distances larger than 30m. Therefore, our efforts are to understand this relationship further by conducting several strength, sprinting and jumping tests and correlating the performance metrics. These findings will have important implications in monitoring maximal strength and force-generating capacity across a variety of settings to guide training interventions, rehabilitation, and assistance in predicting readiness for sport and sports performance.

If you choose to participate in this study you will be asked to complete multiple bouts of intense activity such as jumping, sprinting, and maximal isometric strength efforts. The study will require participation in one 1.5-hour testing session.

If you would like more information or are interested in participating, please contact:

Contact information:
Parker Scott (MSc. Candidate)
YTN237@usask.ca

Dr. Jon Farthing, Ph.D.
Jon.farthing@usask.ca

Appendix G

Dynamic Warm-Up

Increase HR

Jog – 20 yds (backward run back)

Side Shuffle – 20 yards/

Karaoke – 20 yards/

Dynamic Stretching

SA/SL Quad stretch – 20 yards

Bowling Hamstring – 20 yards

Side Lunge/Side Lunge and Twist – 20 yards

Flying Hamstring – 20 yards

Clapping Hamstring – 20 yards

Cradle – 20 yards

Step overs/skip – 20 yards

Tendon/Activation:

Pogo out and in – 25s

Iso Extended Lunge – 25s/

Pogo with twist – 25s

Back Lunge to hip Lock – 4/

Split Lunge forefoot sticks x 10/ (Bigs 6/)

Calf Stretch – 8/

Split squat forefoot jumps x 10/ (Bigs 6/)

Neuromuscular Prep:

Acceleration's x 3 (70, 80, and 90 percent) (30yrds)

Appendix H

Randomization Legend

SUB_01

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_02

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_03

1. Calf (CB)
2. Calf (SSB)
3. CMJ
4. Squat (CB)
5. Squat (SSB)

SUB_04

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_05

1. Squat (CB)
2. Squat (SSB)
3. Calf (CB)
4. Calf (SSB)
5. CMJ

SUB_06

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_07

6. CMJ
7. Squat (SSB)
8. Squat (CB)
9. Calf (SSB)
10. Calf (CB)

SUB_08

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_09

6. Calf (CB)
7. Calf (SSB)
8. CMJ
9. Squat (CB)

SUB_10

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)

10. Squat (SSB)

5. Calf (CB)

SUB_11

6. Squat (CB)
7. Squat (SSB)
8. Calf (CB)
9. Calf (SSB)
10. CMJ

SUB_12

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_13

11. CMJ
12. Squat (SSB)
13. Squat (CB)
14. Calf (SSB)
15. Calf (CB)

SUB_14

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_15

11. Calf (CB)
12. Calf (SSB)
13. CMJ
14. Squat (CB)
15. Squat (SSB)

SUB_16

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_17

11. Squat (CB)
12. Squat (SSB)
13. Calf (CB)
14. Calf (SSB)
15. CMJ

SUB_18

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_19

16. CMJ
17. Squat (SSB)
18. Squat (CB)
19. Calf (SSB)
20. Calf (CB)

SUB_20

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_21

21. CMJ
22. Squat (SSB)
23. Squat (CB)
24. Calf (SSB)
25. Calf (CB)

SUB_22

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_23

16. Calf (CB)
17. Calf (SSB)
18. CMJ
19. Squat (CB)
20. Squat (SSB)

SUB_24

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_25

16. Squat (CB)
17. Squat (SSB)
18. Calf (CB)
19. Calf (SSB)
20. CMJ

SUB_26

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_27

26. CMJ
27. Squat (SSB)
28. Squat (CB)
29. Calf (SSB)
30. Calf (CB)

SUB_28

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_29

21. Calf (CB)
22. Calf (SSB)
23. CMJ
24. Squat (CB)
25. Squat (SSB)

SUB_30

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_31

21. Squat (CB)
22. Squat (SSB)
23. Calf (CB)
24. Calf (SSB)
25. CMJ

SUB_32

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_33

31. CMJ
32. Squat (SSB)
33. Squat (CB)
34. Calf (SSB)
35. Calf (CB)

SUB_34

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_35

26. Calf (CB)
27. Calf (SSB)
28. CMJ
29. Squat (CB)
30. Squat (SSB)

SUB_36

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)
5. Calf (CB)

SUB_37

26. Squat (CB)
27. Squat (SSB)
28. Calf (CB)
29. Calf (SSB)
30. CMJ

SUB_38

1. Calf (SSB)
2. Calf (CB)
3. CMJ
4. Squat (SSB)
5. Squat (CB)

SUB_39

36. CMJ
37. Squat (SSB)
38. Squat (CB)
39. Calf (SSB)
40. Calf (CB)

SUB_40

1. Squat (SSB)
2. Squat (CB)
3. Calf (SSB)
4. Calf (CB)
5. CMJ

SUB_41

1. CMJ
2. Squat (SSB)
3. Squat (CB)
4. Calf (SSB)

Appendix I

Sprint Station Testing Sheet

Subject ID	10m	20m	40m	Trial 2:	10m	20m	40m
SUB_01							
SUB_02							
SUB_03							
SUB_04							
SUB_05							
SUB_06							
SUB_07							
SUB_08							
SUB_09							
SUB_10							
SUB_11							
SUB_12							
SUB_13							
SUB_14							
SUB_15							
SUB_16							
SUB_17							
SUB_18							
SUB_20							

Appendix J

PARTICIPANT INFORMATION AND CONSENT FORM

STUDY TITLE: Validity and reliability of a novel alternative to force plate technology for position specific isometric strength tests and their relationship with dynamic performance in collegiate athletes

PRINCIPAL INVESTIGATOR:
Dr. Jonathan Farthing
College of Kinesiology
University of Saskatchewan
87 Campus Drive
Saskatoon SK, S7N 5B2
Email: jon.farthing@usask.ca

SUB-INVESTIGATORS
Dr. Joel Lanovaz
Dr. Kenzie Friesen (Post-doctoral fellow, supervised by Dr. Joel Lanovaz)
Graham Black (Sub-Investigator)
Cam Skinner (Sub-Investigator)

STUDENT RESEARCHERS
Parker Scott (M.Sc. Student, supervised by Dr. Jon Farthing)
Brianna Andrews (Undergraduate student researcher, supervised by Dr. Jon Farthing)
Amr Almasri (Undergraduate student researcher, supervised by Dr. Jon Farthing)
Meagan Wong (Undergraduate student researcher, supervised by Dr. Jon Farthing)

CONTACT PHONE NUMBERS
306-966-1068 OR 306-290-5912 (JON FARTHING)
306-281-9299 (PARKER SCOTT)

INTRODUCTION

You are invited to take part in this research study because you are a Huskie athlete with at least six months of varsity experience, do not have a current injury restricting you from full sport participation, and have not had a major musculoskeletal injury in the last 6 months.

Your participation is voluntary. It is up to you to decide whether you wish to take part. If you wish to participate, you will be asked to sign this form. If you do decide to take part in this study, you are still free to withdraw at any time and without giving any reasons for your decision.

If you do not wish to participate, you will not lose the benefit of any athletic opportunities, medical care, employment, or academic standing to which you are entitled or are presently receiving. It will not affect your relationship with Dr. Farthing or any of the researchers. It will not affect your relationship with Huskie athletics, the coaches of your team, or your strength and conditioning coaches.

Please take time to read the following information carefully. You can ask the researcher to explain any words or information that you do not clearly understand. You may ask as many questions as you need. Please feel free to discuss this with your family, friends, coaches, or family physician before you decide.

WHO IS CONDUCTING THE STUDY?
This study is being funded by a MITACS Accelerate Grant awarded to Principal Investigator, Dr. Jonathan Farthing, University of Saskatchewan. MITACS Accelerate Grants involve an industry partner who is external to the University. The industry partner for this MITACS grant project is Ignite Athletics. Parker Scott is the graduate student researcher for this project and receives graduate student stipend funding from the MITACS grant, as administered by the University of Saskatchewan. This research study is not part of the strength and conditioning services provided to Huskie Athletics by Ignite Athletics. Neither the institution, Ignite Athletics, nor any of the investigators or staff will receive any direct financial benefit from conducting this study. The findings of this study may be used in future development and promotion of a novel device used to measure force-generating capacity in athletes, but this will not directly benefit the institution or the researchers.

WHY IS THIS STUDY BEING DONE?
This study is being done to determine the test-retest reliability and criterion validity of a new portable and low-cost device being developed called the "Force Finder". The secondary aim is to gain insight into maximal isometric force-generating capacity (i.e., pushing against a fixed device or apparatus) in athletes and how it relates to dynamic performance such as how fast an athlete can sprint or jump. We are interested in a deeper understanding of the relationship between top-speed sprinting and force-generating capacity. We are also interested in examining the relationship between force-generating capacity during unilateral (single-leg) stance and subsequent sprinting and jumping performance. We would like to understand if these isometric tests can be useful to predict future performance in athletes.

WHO CAN PARTICIPATE IN THE STUDY? (if applicable)
You are eligible to participate in this study if you are 18 to 30 years old and are a current Huskie varsity athlete. You are not eligible to participate if you have less than six months of varsity experience or have a current or recent (within the last 6 months) injury preventing you from full sport participation. Please note that visitors to the University of Saskatchewan campus must confirm that they are fully vaccinated. We expect to enroll 50-100 varsity athletes in this study.

WHAT DOES THE STUDY INVOLVE?
This study will require participation in two separate testing sessions involving multiple bouts of intense activity such as jumping, sprinting, and maximal isometric strength efforts while standing on force-plates and simultaneously pressing into a novel device called the Force-Finder. The study will require participation in two separate 1.5-hour testing sessions, scheduled 1 week apart. Each session will take place at the Sport Science and Health Centre at Merlis Belsher Place at the University of Saskatchewan. Both sessions will consist of the exact same testing conditions and order will be kept consistent between sessions.

If you choose to participate, you will be asked to complete all the procedures listed below.

Testing Session 1: When you first arrive, the study and procedures will be described in detail and the consent form will be reviewed. We will familiarize you with the testing environment and equipment, and allow time for any questions, and you will be asked to sign a consent form. A series of questionnaires will then be given to you to verify your eligibility for the study. These include a demographic questionnaire (i.e., age, biological sex), a university athlete training and injury history questionnaire, a Waterloo Footedness questionnaire, and a pre-testing questionnaire regarding caffeine, alcohol, and supplement intake in which we will ask you to "keep your caffeine and supplement intake consistent between sessions". Thereafter, height (cm) and weight (kg) will be measured and recorded. Next, you will be asked to complete a 15-minute standardized warm-up involving a series of movements designed to increase heart rate, general dynamic stretches, and concluding with a series of exercises designed to stimulate the central nervous system (e.g., repeat broad jump or repeat vertical jump). Following the standardized warm-up, you will complete six testing conditions. The order of conditions will be kept consistent for you on each test occasion. The conditions will be completed using three separate testing stations: 1) Unilateral isometric strength tests (four conditions); 2) Jumping tests (one condition); 3) Sprinting tests (one condition). This session is expected to take approximately 1.5 hours. The six conditions of the full testing protocol are as follows:

Condition 1: Unilateral ISqT conventional barbell (CB)
The unilateral (single-leg) ISqT position involves assuming a split stance with one foot on a force plate, and the other foot in a "kickstand" position which will involve the rear legs' toes touching the ground to be used for balance but not force generation, while the front foot is used for force-generation. You will be asked to assume a squatting position and hold a conventional barbell on the upper back and shoulders. The knee and hip angles will be similar to a sprinting position on the pushing leg. Knee and hip angles will be measured by the researchers. Two maximal effort attempts will be completed for each limb, separated by three minutes of rest. Further attempts may be requested by the researcher.

Condition 2: Unilateral ISqT safety squat bar (SSB)
The unilateral ISqT SSB position will be identical to the unilateral CB condition, with the exception that a different type of bar will be used for the test.

Condition 3: Unilateral Isometric Calf Raise Condition (ICR)
The unilateral ICR position will mirror the midstance or initial contact phase of sprinting. The participants will be positioned in an upright sprinting position with an SSB on their shoulders. They will be standing upon a box which is placed on the force-plate devices, the athlete will have the front half of their foot on the box allowing for a slight raise of the heel (5°), and the knee will be positioned at 150-180°. The participants will be instructed to "push the slack out of the bar" creating a small amount of pretension in both the force-finder and force-plate simultaneously, then to push the bar "as hard and as fast as possible" continuously for five seconds while being provided with strong verbal encouragement, as described in James et al. (2017).

Condition 4: Unilateral Isometric Calf Raise Condition (ICR)
The unilateral ICR SSB position will be identical to the unilateral CB condition, with the exception that a different type of bar will be used for the test.

Condition 5: Jumping
The jumping test involves standing on a force plate with feet at hip width apart. You will be given instructions on how to engage in a maximal effort vertical jump. You will be instructed to "Jump as high as possible" while being provided with strong verbal encouragement. Two maximal effort attempts will be completed and separated by three minutes of rest. Further attempts may be completed at the discretion of the researchers.

Condition 6: Sprinting

You will perform a 40m sprint and we will record split times at 10m, 30m, and 40m using specialized timing equipment. We will also video record each attempt to better assess the specific components (peak velocity and split time) of the sprinting trial. You will begin the sprint in a 3-point starting position known as a static start. The three-point position is characterized by assuming a crouched stance with forward lean and maintaining three points of contact with the ground, including one hand, and both feet. You will be instructed to sprint through the gates as fast as possible. Two sprint trials will be completed with a minimum of three minutes of rest. Each athlete's face and body will be recorded during the sprinting trial. Your individual video recordings will be de-identified using the participant ID number. The recordings will only be accessible to members of the research team. Further information can be found in the confidentiality section.

Testing Session 2: You will be asked to return to the facilities for an identical testing session approximately one week apart. The second testing session will take only about 45 minutes because some measurements do not need to be repeated (e.g., questionnaires, etc).

Secondary Sub-Study (Optional): In the future, we plan to conduct a secondary study. This study examines the validity and reliability of the force finder device with the force plate device using the isometric mid-thigh pull (IMTP). Please note that signing this consent form does not obligate you to participate in this secondary study. Your involvement in the current study will, however, make this available to you. If you volunteer for this secondary study, you will be contacted by the researchers to return to the lab to complete two additional 1 hour testing sessions, involving the following:

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
If you choose to participate in this study, there may or may not be direct benefits to you. It is hoped the information gained from this study can be used in the future to benefit other athletes, coaches and strength and conditioning experts who wish to assess athlete force generating capability and its relationship to sport performance. The study may lead to the development of commercial products but there are no plans to share with you any financial profits resulting from the use of your data.

ARE THERE POSSIBLE RISKS AND DISCOMFORTS?
If you choose to participate in this study, the following are possible:
Muscle soreness may result from the maximal effort isometric contractions, but any soreness or discomfort should subside within a day or two, and not last. Muscle injuries are also very rare with the maximal isometric tests. Muscle injuries are slightly more prevalent in the 40m sprint test but are still rare. The risk of injury will be offset by an extensive dynamic warm up. A trained strength and conditioning coach/researcher will oversee the procedures of this project, and you will be instructed on how to properly execute the maximal contractions and how to properly perform the dynamic tests in the safest possible manner.

It is possible that being asked to recall some information about prior or recent joint or muscle injuries during your athletic participation can be distressing. You do not have to answer any questions are you not comfortable with.

COVID-19 Information:

- The research site is located at the University of Saskatchewan, under the jurisdiction of Saskatoon public health. We are taking all safety precautions to reduce the risk of spread of COVID-19 and expect you to follow public health directives as well.
- If you feel that you are from a vulnerable group with respect to COVID-19 effects (e.g., immuno-compromised), please discuss your participation with the research team before consenting. You are

under no obligation to participate and nothing bad will happen if you change your mind about participating in the research.

- We will be collecting personal contact information that we must retain in order to follow up with you and/or conduct contact tracing if you may have been exposed to COVID-19 in coming to the research site.
- Contact information will be kept separate from data collected through the research study to allow for de-identification of the research data
- You maintain your right to withdraw from the study at any time, including research data (if applicable). If you do withdraw, we will continue to maintain your contact information and will only give it to the Saskatchewan Health Authority if required for contact tracing.
- We cannot guarantee anonymity as the personal contact information identifies you as a participant.

WHAT IF NEW INFORMATION BECOMES AVAILABLE THAT MAY AFFECT MY DECISION TO PARTICIPATE?
During this study, new information that may affect your willingness to continue to participate will be provided to you by the researcher.

WHAT HAPPENS IF I DECIDE TO WITHDRAW?
Your participation in this research is voluntary. You may withdraw from this study at any time. You do not have to provide a reason. There will be no penalty or loss of benefits if you choose to withdraw. Your future medical care, academic status, employment, or position on the Huskie varsity team will not be affected. Your relationship with Ignite Athletics or any of their strength and conditioning coaches will not be affected. Your access to strength and conditioning services as a Huskie athlete will not be affected.

If you choose to enter the study and then decide to withdraw later, all data collected about you during your enrolment will be retained for analysis.

WILL I BE INFORMED OF THE RESULTS OF THE STUDY?
A summary of findings using average data as well as an optional opportunity to receive individual data of test scores will be circulated to you via email 2-4 weeks after the study is complete. An opportunity to discuss the results will be provided to you through email. The researchers plan to publish the study in journals and as part of graduate student theses.

WHAT WILL THE STUDY COST ME?
You will not be charged for any research-related procedures. You will not be paid for participating in this study. You will not receive any compensation, or financial benefits for being in this study, or as a result of data obtained from research conducted under this study.

WHAT HAPPENS IF SOMETHING GOES WRONG?

In the unlikely event of an adverse effect related to the study procedures, necessary medical treatment will be made available at no additional cost to you. As soon as possible, notify the research team. By signing this document, you do not waive any of your legal rights.

WILL MY TAKING PART IN THIS STUDY BE KEPT CONFIDENTIAL?
In Saskatchewan, the *Health Information Protection Act (HIPA)* defines how the privacy of your personal health information must be maintained so that your privacy will be respected.

Your confidentiality will be respected. No information that discloses your identity will be released or published without your specific consent to the disclosure. It is possible that your participation in the study will be known to other Huskie athletes on your team, your coach, or other athletic teams and coaches. The testing will take place in a group cohort with back-to-back testing slots in an open lab space or on a field/track. Information collected about you will be labelled with a non-identifying study ID number instead of your name. While other participants may see you conducting the tests in an open lab or field, the scores on your tests will not be visible to them or shared with them. The results of your tests will be recorded and shared only among the researchers and will be kept confidential and shared with you upon request after the study. Each athlete's face and body will be recorded during the sprinting trial. The Kinovea software will be downloaded onto the computer that will be used for the study. After the testing sessions, video recordings will be temporarily stored on video card and then uploaded to a password-protected computer to be analyzed using the Kinovea software. The video recordings cannot be accessed by anyone outside the research team. After the necessary information is retrieved from the recordings, the recordings will be saved on a password-protected computer using only your participant ID, and permanently removed from the recording devices (e.g., video card) and from the Kinovea software. Your study records including your questionnaires, sprint trial video recordings (de-identified in the Kinovea software), and personal measurements will be kept for 5 years after publication of results, in a locked cabinet or password-protected computer in Dr. Farthing's office at the College of Kinesiology. Your information and the results of the study will also be recorded in a password-protected computer database. Only the investigators will have access to your study records. Your study records may be inspected in the presence of Dr. Farthing or his qualified designate by representatives of the University of Saskatchewan Research Ethics Board for quality assurance purposes. A spreadsheet linking your name to your specific study ID number will be kept in a separate locked cabinet in Dr. Farthing's office, separate from any of the results and will not be allowed to leave the Investigators' offices.

The results of this study may be presented in a scientific meeting or published, but your identity will not be disclosed.

WHO DO I CONTACT IF I HAVE QUESTIONS ABOUT THE STUDY?
If you have any questions or desire further information about this study before or during participation, you can contact Parker Scott 306-281-9299 OR Dr. Jon Farthing at 306-290-5912.

If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, contact the Chair of the University of Saskatchewan Biomedical Research Ethics Board, at 306-966-2975 (out of town calls 1-888-966-2975) or in writing at ethics.office@usask.ca. The Biomedical Research Ethics Board is a group of individuals (scientists, physicians, ethicists, lawyers, and members of the community) that provide an independent review of human research studies. This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Biomedical Research Ethics Board.

[Institutional logo/letterhead]

CONSENT TO PARTICIPATE

Study Title: Validity and reliability of a novel alternative to force plate technology for position specific isometric strength tests and their relationship with dynamic performance in collegiate athletes

- I have read (or someone has read to me) the information in this consent form.
- I understand the purpose and procedures and the possible risks and benefits of the study.
- I was given sufficient time to think about it.
- I had the opportunity to ask questions and have received satisfactory answers.
- I understand that I am free to withdraw from this study at any time for any reason and the decision to stop taking part will not affect my future relationships.
- I give permission to the use and disclosure of my de-identified information collected for the research purposes described in this form.
- I understand that by signing this document I do not waive any of my legal rights.
- I will be given a signed copy of this consent form.
- I agree to be contacted for future sub-studies (YES | NO)

I agree to participate in this study:

Printed name of participant:	Signature	Date
Printed name of person obtaining consent:	Signature	Date

Appendix K

UNIVERSITY OF SASKATCHEWAN

Biomedical Research Ethics Board (Bio-REB) 16-Aug-2022

Certificate of Approval Amendment

Application ID:	3487
Principal Investigator:	Jon Farthing
Department:	College of Kinesiology
Locations Where Research Activities are Conducted:	USask, College of Kinesiology, Sport Science and Health Centre (SSHC) at Merlis Belsher Place (MBP), Griffiths Stadium Field, Saskatoon Field House., Canada
Student(s):	Amr Almasri Brianna Andrews Meagan Wong Parker Scott
Funder(s):	Mitacs
Sponsor:	University of Saskatchewan
Title:	Validity and reliability of a novel alternative to force plate technology for position specific isometric strength tests and their relationship with dynamic performance in collegiate athletes
Protocol Number:	
Approved On:	16-Aug-2022
Expiry Date:	10-Jun-2023
Approval Of:	* Addition of Student InvestigatorsAmr Almasri & Meagan Wong * Farthing MITACS Participant_Info_Consent_form_V5_July 28 * Biomedical Application Form_Farthing MITACS_V5_July 28
Acknowledgment Of:	* TCPS2 Core Tutorial Certificates of Completion for Amr Almasri & Meagan Wong * Biomedical Amendment Form_ID 3487_July 28 2022
Review Type:	Delegated Review
IRB Registration Number:	Not Applicable

Appendix L

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Position	Sphericity Assumed	23.959	1	23.959	81.171	<.001	.670
	Greenhouse-Geisser	23.959	1.000	23.959	81.171	<.001	.670
	Huynh-Feldt	23.959	1.000	23.959	81.171	<.001	.670
	Lower-bound	23.959	1.000	23.959	81.171	<.001	.670
Error(Position)	Sphericity Assumed	11.807	40	.295			
	Greenhouse-Geisser	11.807	40.000	.295			
	Huynh-Feldt	11.807	40.000	.295			
	Lower-bound	11.807	40.000	.295			
Bar	Sphericity Assumed	7.762	1	7.762	97.481	<.001	.709
	Greenhouse-Geisser	7.762	1.000	7.762	97.481	<.001	.709
	Huynh-Feldt	7.762	1.000	7.762	97.481	<.001	.709
	Lower-bound	7.762	1.000	7.762	97.481	<.001	.709
Error(Bar)	Sphericity Assumed	3.185	40	.080			
	Greenhouse-Geisser	3.185	40.000	.080			
	Huynh-Feldt	3.185	40.000	.080			
	Lower-bound	3.185	40.000	.080			
Side	Sphericity Assumed	.000	1	.000	.004	.950	.000
	Greenhouse-Geisser	.000	1.000	.000	.004	.950	.000
	Huynh-Feldt	.000	1.000	.000	.004	.950	.000
	Lower-bound	.000	1.000	.000	.004	.950	.000
Error(Side)	Sphericity Assumed	1.747	40	.044			
	Greenhouse-Geisser	1.747	40.000	.044			
	Huynh-Feldt	1.747	40.000	.044			
	Lower-bound	1.747	40.000	.044			
Position * Bar	Sphericity Assumed	.090	1	.090	1.758	.192	.042
	Greenhouse-Geisser	.090	1.000	.090	1.758	.192	.042
	Huynh-Feldt	.090	1.000	.090	1.758	.192	.042
	Lower-bound	.090	1.000	.090	1.758	.192	.042
Error(Position*Bar)	Sphericity Assumed	2.056	40	.051			
	Greenhouse-Geisser	2.056	40.000	.051			
	Huynh-Feldt	2.056	40.000	.051			
	Lower-bound	2.056	40.000	.051			
Position * Side	Sphericity Assumed	.039	1	.039	2.103	.155	.050
	Greenhouse-Geisser	.039	1.000	.039	2.103	.155	.050
	Huynh-Feldt	.039	1.000	.039	2.103	.155	.050
	Lower-bound	.039	1.000	.039	2.103	.155	.050
Error(Position*Side)	Sphericity Assumed	.746	40	.019			
	Greenhouse-Geisser	.746	40.000	.019			
	Huynh-Feldt	.746	40.000	.019			
	Lower-bound	.746	40.000	.019			
Bar * Side	Sphericity Assumed	.001	1	.001	.026	.872	.001
	Greenhouse-Geisser	.001	1.000	.001	.026	.872	.001
	Huynh-Feldt	.001	1.000	.001	.026	.872	.001
	Lower-bound	.001	1.000	.001	.026	.872	.001
Error(Bar*Side)	Sphericity Assumed	.954	40	.024			
	Greenhouse-Geisser	.954	40.000	.024			
	Huynh-Feldt	.954	40.000	.024			
	Lower-bound	.954	40.000	.024			
Position * Bar * Side	Sphericity Assumed	.004	1	.004	.330	.569	.008
	Greenhouse-Geisser	.004	1.000	.004	.330	.569	.008
	Huynh-Feldt	.004	1.000	.004	.330	.569	.008
	Lower-bound	.004	1.000	.004	.330	.569	.008
Error(Position*Bar*Side)	Sphericity Assumed	.459	40	.011			
	Greenhouse-Geisser	.459	40.000	.011			
	Huynh-Feldt	.459	40.000	.011			
	Lower-bound	.459	40.000	.011			

Appendix M

Correlations

		10 Yrds	20 Yrds	40 Yrds	Max Height	mRSI
10 Yrds	Pearson Correlation	1	.975**	.933**	-.579**	-.560**
	Sig. (2-tailed)		<.001	<.001	<.001	<.001
	N	41	41	41	41	41
20 Yrds	Pearson Correlation	.975**	1	.983**	-.616**	-.620**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001
	N	41	41	41	41	41
40 Yrds	Pearson Correlation	.933**	.983**	1	-.630**	-.628**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001
	N	41	41	41	41	41
Max Height	Pearson Correlation	-.579**	-.616**	-.630**	1	.843**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001
	N	41	41	41	41	41
mRSI	Pearson Correlation	-.560**	-.620**	-.628**	.843**	1
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	
	N	41	41	41	41	41
Age	Pearson Correlation	-.037	-.102	-.129	.281	.212
	Sig. (2-tailed)	.818	.526	.423	.075	.183
	N	41	41	41	41	41
Years Played (University level)	Pearson Correlation	.010	-.056	-.083	.191	.180
	Sig. (2-tailed)	.951	.730	.605	.231	.260
	N	41	41	41	41	41
Years Played (USport)	Pearson Correlation	-.063	-.141	-.170	.246	.188
	Sig. (2-tailed)	.696	.380	.289	.121	.239
	N	41	41	41	41	41

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix N

Literature Synopsis on Isometric Strength and Sprinting

Study	**Bilateral/ Unilateral**	**Primary outcomes**	**IV's**	**Correlations**
Brady et al. 2019	Bilateral IMTP/ISqT	5m Sprint time	IMTP PF vs 5m	r = -0.626
		PF	IMTP RFD (0-150ms) vs 5m	r = -0.550
		RFD (0-150 ms)	ISqT PF vs 5m	r = -0.714
			ISqT RFD (0-150ms) vs 5m	r = -0.521
Kuki et al. 2017	Unilateral IMTP	10 and 30m sprint time	D $_{uni}$IMTP aPF vs 30m	r = -0.456
		Absolute PF	N.D $_{uni}$IMTP aPF vs 30m	r = -0.452
		Relative PF	N.D $_{uni}$IMTP rPF vs 10m	r = -0.447
Lum and Joseph et al. 2019	Bilateral ISqT	5, 10, and 20m sprint time	ISqT PF vs 5 and 20m	r = -0.42
		PF	ISqT PF vs 5, 10, and 20m	(5/10/20) r = -0.52 to -0.62
		RFD 0-90ms	ISqT RFD vs 5, 10, and 20m	(5/10/20) r = -0.51 to -0.66
Thomas et al. 2015	Bilateral IMTP	5 and 20m sprint time	IMTP PF vs 5 and 20m	r = -0.57 to r = -0.69
		PF	IMTP RFD vs 5 and 20m	r = -0.58 to r = -0.71

		RFD		
Tillin et al. 2013	Bilateral ISqT	5 and 20m sprint time	ISqT F100 vs 5 and 20m	r = -0.42 to r = -0.54
		Force normalized at 100ms		
Townsend et al. 2017	Bilateral IMTP	sprint time	IMTP PF vs Sprint Time	r = -0.619 to r = -0.696
		PF	IMTP RFD vs Sprint Time	r = -0.432 to r = -0.472
		RFD		
West et al. 2016	Bilateral IMTP	5m sprint time	IMTP PF vs 5m Sprint Time	r = -0.527 to r = -0.570
		PF		
West et al. 2011	Bilateral IMTP	10m sprint time	IMTP PF vs 10m Sprint Time	r = -0.23
		PF	IMTP rPF vs 10m Sprint Time	r = -0.37
		rPF	IMTP RFD vs 10m Sprint Time	r = -0.66
		RFD		

Thomas et al. 2016	Unilateral IMTP	PF	IMTP PF (right leg) vs 5, 10, and 20m sprint IMTP PF (left leg) vs 20m sprint	r = -0.52, r = -0.49, r = -0.53 r = -0.50

Isometric Strength Relationship with Jumping

Study	**Bilateral / Unilateral**	**Primary outcomes**	**IV's**	**Correlations**
Bailey et al. 2013	Bilateral IMTP	SJ Height	IMTP PF SI vs SJ Height	r = 0.39 to 0.52
		CMJ Height	IMTP PF SI vs CMJ Height	r = 0.47 to 0.49
		IMTP PF Symmetry Index	IMTP PF SI vs SJ Peak Power	r = 0.34 to 0.43
		SJ/CMJ Peak Power	IMTP PF SI vs CMJ Peak Power	r = 0.28 to 0.34
Berger and Henderson et al. 1996	Bilateral ISqT	ISqT PF	ISqT PF vs Vertical Jump Power	r = 0.64
		Vertical Jump Power		
Dos' Santos et al. 2017	Bilateral IMTP	IMTP force at 250 ms	IMTP F250 vs CMJ Height	r = 0.346
		CMJ Height		

Haff et al. 2005	Bilateral IMTP	IMTP PF	IMTP PF vs CMJ Peak Power	r = 0.88
		CMJ Peak Power	IMTP PF vs SJ Peak Power	r = 0.92
		SJ Peak Power		
Haff et al. 1997	Bilateral IMTP	IMTP PF/RFD	IMTP PF vs SJ Peak Force	r = 0.76
		SJ Peak Force	IMTP RFD vs SJ Peak Power	r = 0.76
		SJ Peak Power	IMTP RFD vs SJ Height	r = 0.80
		SJ Height		
Kawamori et al. 2006	Bilateral IMTP	IMTP PF	IMTP PF vs CMJ PF	r = 0.87
		CMJ PF, PP, Height	IMTP PF vs CMJ PP	r = 0.95
		SJ Height	IMTP PF vs CMJ Height	r = 0.82
			IMTP PF vs SJ Height	r = 0.87
Khamoui et al. 2011	Bilateral IMTP	IMTP rPF	IMTP rPF vs CMJ Height	r = 0.61
		CMJ Height		
Kraska et al. (2009)	Bilateral	IMTP PF	IMTP PF vs Weighted/Unweighted SJ Height	r = 0.55, 0.40, respectively

	IMTP			
		Weighted/Unweighted SJ and CMJ Height	IMTP PF vs Weighted/Unweighted CMJ height	r = 0.55, 0.36, respectively
Loturco et al. 2016	Bilateral ISqT	ISqT PF	ISqT PF vs SJ Height	r = 0.79
		ISqT RFD	ISqT PF vs CMJ Height	r = 0.79
		SJ Height	ISqT RFD vs SJ Height	r = 0.80
		CMJ Height	ISqT RFD vs CMJ Height	r = 0.76
Markovic & Jaric et al. 2007	Bilateral ISqT (120◦)	ISqT PF	ISqT PF vs SJ Power & Height	r = 0.35 & 0.54, respectively
		SJ Power & Height	ISqT PF vs CMJ Power & Height	r = 0.34 & 0.39, respectively
		CMJ Power & Height		
McGuigan et al. 2006	Bilateral IMTP	IMTP PF	IMTP PF vs CMJ Height	r = 0.72
		CMJ Height		
Nuzzo et al. 2008	Bilateral IMTP	IMTP rPF	IMTP rPF vs CMJ Height	r = 0.588
		CMJ Height		

Stone et al. 2004	Bilateral IMTP	IMTP PF	IMTP PF vs CMJ Height	r = 0.59 to 0.67
		CMJ Height	IMTP PF vs SJ Height	r = 0.51 to 0.66
		SJ Height		
Tillin et al. 2013	Bilateral ISqT	ISqT PF	ISqT PF vs CMJ Height	r = 0.48
		ISqT Force at 100,150, 200, 250ms	ISqT Force at 100,150, 200, 250ms vs CMJ Height	r = 0.51, 0.61, 0.57 and 0.51, respectively
		CMJ Height		
West et al. 2011	Bilateral IMTP	IMTP rPF	IMTP rPF vs CMJ Height	r = 0.45
		IMTP RFD	IMTP RFD vs CMJ Height	r = 0.39
		IMTP rPF at 100ms	IMTP rPF at 100ms vs CMJ Height	r = 0.43
		CMJ Height		

Appendix O

uniISqT SSB Dominant FT-Characteristics Correlations (First rep)

Correlations

		Squat_SSB_Dom_rfd0_50_rep1	Squat_SSB_Dom_rfd50_100_rep1	Squat_SSB_Dom_rfd100_150_rep1	Squat_SSB_Dom_rfd150_200_rep1	Squat_SSB_Dom_rfd200_250_rep1	Squat_SSB_Dom_rfd250_300_rep1	Squat_SSB_Dom_aveimpulse1_rep1	Squat_SSB_Dom_aveimpulse2_rep1	Squat_SSB_Dom_aveimpulse3_rep1	pF_SQUAT_SSB_Dominant_RELATIVE_rep1	10 Yrds	40 Yrds	rep1 Height	mRSI rep 1
Squat_SSB_Dom_rfd0_50_rep1	Pearson Correlation	1	-0.073	-0.019	-0.106	-0.165	-0.085	.479**	.471**	.418**	0.154	0.058	-0.030	-0.106	-0.079
	Sig. (2-tailed)		0.649	0.905	0.508	0.304	0.597	0.002	0.002	0.007	0.336	0.718	0.852	0.511	0.623
	N		41	41	41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_Dom_rfd50_100_rep1	Pearson Correlation		1	.919**	.736**	.499**	0.116	-0.206	0.096	.323*	0.293	0.044	0.050	-0.105	-0.030
	Sig. (2-tailed)			0.000	0.000	0.001	0.468	0.196	0.549	0.039	0.063	0.784	0.758	0.514	0.852
	N			41	41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_Dom_rfd100_150_rep1	Pearson Correlation			1	.900**	.665**	0.247	-0.190	0.119	.379*	0.249	0.120	0.116	-0.115	-0.061
	Sig. (2-tailed)				0.000	0.000	0.119	0.234	0.460	0.014	0.116	0.456	0.469	0.473	0.705
	N				41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_Dom_rfd150_200_rep1	Pearson Correlation				1	.886**	.450**	-0.256	0.014	0.297	0.211	0.114	0.117	-0.101	-0.063
	Sig. (2-tailed)					0.000	0.003	0.106	0.930	0.059	0.186	0.478	0.466	0.530	0.696
	N					41	41	41	41	41	41	41	41	41	41
Squat_SSB_Dom_rfd200_250_rep1	Pearson Correlation					1	.752**	-0.288	-0.091	0.172	0.179	0.084	0.097	-0.068	-0.038
	Sig. (2-tailed)						0.000	0.068	0.571	0.282	0.264	0.603	0.548	0.673	0.814
	N						41	41	41	41	41	41	41	41	41
Squat_SSB_Dom_rfd250_300_rep1	Pearson Correlation						1	-0.206	-0.140	0.015	0.052	0.137	0.175	-0.133	-0.138
	Sig. (2-tailed)							0.196	0.382	0.924	0.747	0.394	0.274	0.408	0.391
	N							41	41	41	41	41	41	41	41
Squat_SSB_Dom_aveimpulse1_rep1	Pearson Correlation							1	.951**	.829**	-.332*	.328*	.332*	-0.160	-0.175
	Sig. (2-tailed)								0.000	0.000	0.034	0.036	0.034	0.317	0.275
	N								41	41	41	41	41	41	41
Squat_SSB_Dom_aveimpulse2_rep1	Pearson Correlation								1	.958**	-0.251	.362*	.367*	-0.199	-0.194
	Sig. (2-tailed)									0.000	0.113	0.020	0.018	0.212	0.224
	N									41	41	41	41	41	41
Squat_SSB_Dom_aveimpulse3_rep1	Pearson Correlation									1	-0.171	.377*	.384*	-0.221	-0.203
	Sig. (2-tailed)										0.286	0.015	0.013	0.164	0.204
	N										41	41	41	41	41
pF_SQUAT_SSB_Dominant_RELATIVE_rep1	Pearson Correlation										1	-.493**	-.511**	0.292	.402**
	Sig. (2-tailed)											0.001	0.001	0.064	0.009
	N											41	41	41	41
10 Yrds	Pearson Correlation											1	.933**	-.700**	-.607**
	Sig. (2-tailed)												0.000	0.000	0.000
	N												41	41	41
40 Yrds	Pearson Correlation												1	-.765**	-.682**
	Sig. (2-tailed)													0.000	0.000
	N													41	41
rep1 Height	Pearson Correlation													1	.841**
	Sig. (2-tailed)														0.000
	N														41

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix P

uniISqT SSB Non-Dominant FT-Characteristics Correlations (First rep)

Correlations

		Squat_SSB_nonDom_rfd0_50_rep1	Squat_SSB_nonDom_rfd50_100_rep1	Squat_SSB_nonDom_rfd100_150_rep1	Squat_SSB_nonDom_rfd150_200_rep1	Squat_SSB_nonDom_rfd200_250_rep1	Squat_SSB_nonDom_rfd250_300_rep1	Squat_SSB_nonDom_aveimpulse1_rep1	Squat_SSB_nonDom_aveimpulse2_rep1	Squat_SSB_nonDom_aveimpulse3_rep1	pF_Squat_SSB_NONDom_RELATIVE_rep1	10 Yrds	40 Yrds	rep1 Height	mRSI rep 1
Squat_SSB_nonDom_rfd0_50_rep1	Pearson Correlation	1	-.435**	-.356*	-.347*	-0.287	-0.074	.396*	0.282	0.124	-0.004	-0.143	-0.183	0.157	-0.015
	Sig. (2-tailed)		0.004	0.022	0.026	0.068	0.645	0.010	0.074	0.439	0.978	0.371	0.253	0.328	0.928
	N		41	41	41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_nonDom_rfd50_100_rep1	Pearson Correlation		1	.893**	.725**	.426**	-0.077	-.551**	-0.228	0.078	.415**	-0.086	-0.050	0.107	0.278
	Sig. (2-tailed)			0.000	0.000	0.005	0.632	0.000	0.151	0.629	0.007	0.593	0.755	0.505	0.078
	N			41	41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_nonDom_rfd100_150_rep1	Pearson Correlation			1	.922**	.605**	0.032	-.442**	-0.092	0.262	.543**	-0.090	-0.056	0.063	0.200
	Sig. (2-tailed)				0.000	0.000	0.844	0.004	0.569	0.098	0.000	0.577	0.730	0.698	0.210
	N				41	41	41	41	41	41	41	41	41	41	41
Squat_SSB_nonDom_rfd150_200_rep1	Pearson Correlation				1	.829**	0.262	-.351*	-0.031	.342*	.568**	-0.035	-0.004	0.011	0.130
	Sig. (2-tailed)					0.000	0.098	0.024	0.848	0.028	0.000	0.827	0.981	0.946	0.419
	N					41	41	41	41	41	41	41	41	41	41
Squat_SSB_nonDom_rfd200_250_rep1	Pearson Correlation					1	.699**	-0.182	0.035	.358*	.488**	0.025	0.065	-0.006	0.056
	Sig. (2-tailed)						0.000	0.255	0.830	0.022	0.001	0.876	0.686	0.972	0.730
	N						41	41	41	41	41	41	41	41	41
Squat_SSB_nonDom_rfd250_300_rep1	Pearson Correlation						1	0.107	0.127	0.251	0.214	0.125	0.177	-0.048	-0.115
	Sig. (2-tailed)							0.506	0.429	0.113	0.178	0.435	0.269	0.763	0.473
	N							41	41	41	41	41	41	41	41
Squat_SSB_nonDom_aveimpulse1_rep1	Pearson Correlation							1	.932**	.739**	-.448**	0.286	.350*	-0.123	-0.190
	Sig. (2-tailed)								0.000	0.000	0.003	0.070	0.025	0.444	0.233
	N								41	41	41	41	41	41	41
Squat_SSB_nonDom_aveimpulse2_rep1	Pearson Correlation								1	.926**	-0.297	0.291	.379*	-0.108	-0.120
	Sig. (2-tailed)									0.000	0.059	0.065	0.014	0.501	0.456
	N									41	41	41	41	41	41
Squat_SSB_nonDom_aveimpulse3_rep1	Pearson Correlation									1	-0.065	0.262	.361*	-0.090	-0.056
	Sig. (2-tailed)										0.685	0.098	0.021	0.574	0.730
	N										41	41	41	41	41
pF_Squat_SSB_NONDom_RELATIVE_rep1	Pearson Correlation										1	-.518**	-.478**	0.228	.341*
	Sig. (2-tailed)											0.001	0.002	0.152	0.029
	N											41	41	41	41
10 Yrds	Pearson Correlation											1	.933**	-.700**	-.607**
	Sig. (2-tailed)												0.000	0.000	0.000
	N												41	41	41
40 Yrds	Pearson Correlation												1	-.765**	-.682**
	Sig. (2-tailed)													0.000	0.000
	N													41	41
rep1 Height	Pearson Correlation													1	.841**
	Sig. (2-tailed)														0.000
	N														41

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Appendix Q

uniICalf SSB Dominant FT-Characteristics Correlations (First rep)

Correlations

		Calf_SSB_Dom_rfd0_50_rep1	Calf_SSB_Dom_rfd50_100_rep1	Calf_SSB_Dom_rfd100_150_rep1	Calf_SSB_Dom_rfd150_200_rep1	Calf_SSB_Dom_rfd200_250_rep1	Calf_SSB_Dom_rfd250_300_rep1	Calf_SSB_Dom_aveimpulse1_rep1	Calf_SSB_Dom_aveimpulse2_rep1	Calf_SSB_Dom_aveimpulse3_rep1	pF_CALF_SSB_DOM_RELATIVE_rep1	10 Yrds	40 Yrds	rep1 Height	mRSI rep 1
Calf_SSB_Dom_rfd0_50_rep1	Pearson Correlation	1	-0.125	-0.130	-0.194	-0.138	0.054	.568**	.536**	.465**	0.281	-0.282	-0.270	0.311	0.258
	Sig. (2-tailed)		0.443	0.425	0.230	0.395	0.740	0.000	0.000	0.003	0.080	0.078	0.092	0.051	0.109
	N		40	40	40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_Dom_rfd50_100_rep1	Pearson Correlation		1	.912**	.782**	.633**	.330*	-0.163	0.084	0.280	0.087	0.001	0.073	-0.003	-0.035
	Sig. (2-tailed)			0.000	0.000	0.000	0.038	0.315	0.607	0.080	0.593	0.997	0.655	0.987	0.830
	N			40	40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_Dom_rfd100_150_rep1	Pearson Correlation			1	.929**	.734**	.378*	-0.138	0.113	.330*	0.245	-0.007	0.057	0.016	-0.043
	Sig. (2-tailed)				0.000	0.000	0.016	0.396	0.486	0.038	0.128	0.964	0.728	0.924	0.793
	N				40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_Dom_rfd150_200_rep1	Pearson Correlation				1	.892**	.506**	-0.097	0.133	.359*	0.304	0.065	0.114	-0.049	-0.131
	Sig. (2-tailed)					0.000	0.001	0.552	0.412	0.023	0.056	0.692	0.482	0.762	0.421
	N					40	40	40	40	40	40	40	40	40	40
Calf_SSB_Dom_rfd200_250_rep1	Pearson Correlation					1	.784**	0.000	0.187	.394*	.350*	0.129	0.147	-0.033	-0.134
	Sig. (2-tailed)						0.000	1.000	0.248	0.012	0.027	0.427	0.364	0.838	0.409
	N						40	40	40	40	40	40	40	40	40
Calf_SSB_Dom_rfd250_300_rep1	Pearson Correlation						1	0.035	0.133	0.267	.445**	0.100	0.053	0.076	0.008
	Sig. (2-tailed)							0.829	0.412	0.096	0.004	0.541	0.747	0.642	0.960
	N							40	40	40	40	40	40	40	40
Calf_SSB_Dom_aveimpulse1_rep1	Pearson Correlation							1	.967**	.885**	0.021	0.151	0.213	-0.056	0.044
	Sig. (2-tailed)								0.000	0.000	0.898	0.351	0.186	0.730	0.785
	N								40	40	40	40	40	40	40
Calf_SSB_Dom_aveimpulse2_rep1	Pearson Correlation								1	.972**	0.068	0.153	0.233	-0.056	0.032
	Sig. (2-tailed)									0.000	0.675	0.345	0.148	0.731	0.844
	N									40	40	40	40	40	40
Calf_SSB_Dom_aveimpulse3_rep1	Pearson Correlation									1	0.136	0.159	0.245	-0.057	0.006
	Sig. (2-tailed)										0.401	0.328	0.128	0.726	0.970
	N										40	40	40	40	40
pF_CALF_SSB_DOM_RELATIVE_rep1	Pearson Correlation										1	-.327*	-.370*	0.228	0.177
	Sig. (2-tailed)											0.037	0.017	0.152	0.270
	N											41	41	41	41
10 Yrds	Pearson Correlation											1	.933**	-.700**	-.607**
	Sig. (2-tailed)												0.000	0.000	0.000
	N												41	41	41
40 Yrds	Pearson Correlation												1	-.765**	-.682**
	Sig. (2-tailed)													0.000	0.000
	N													41	41
rep1 Height	Pearson Correlation													1	.841**
	Sig. (2-tailed)														0.000
	N														41

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Appendix R

uniICalf SSB Non-Dominant FT-Characteristics Correlations (First rep)

Correlations

		Calf_SSB_nonDom_rfd0_50_rep1	Calf_SSB_nonDom_rfd50_100_rep1	Calf_SSB_nonDom_rfd100_150_rep1	Calf_SSB_nonDom_rfd150_200_rep1	Calf_SSB_nonDom_rfd200_250_rep1	Calf_SSB_nonDom_rfd250_300_rep1	Calf_SSB_nonDom_aveimpulse1_rep1	Calf_SSB_nonDom_aveimpulse2_rep1	Calf_SSB_nonDom_aveimpulse3_rep1	pF_CALF_SSB_NON DOM_RELATIVE rep1	10 Yrds	40 Yrds	rep1 Height	mRSI rep 1
Calf_SSB_nonDom_rfd0_50_rep1	Pearson Correlation	1	-0.090	-0.114	-0.163	-0.220	-0.117	.530**	.512**	.444**	0.240	-0.150	-0.112	0.116	0.074
	Sig. (2-tailed)		0.583	0.485	0.316	0.173	0.470	0.000	0.001	0.004	0.135	0.356	0.492	0.476	0.652
	N		40	40	40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_nonDom_rfd50_100_rep1	Pearson Correlation		1	.925**	.824**	.679**	0.057	-0.186	0.066	0.278	.328*	-0.115	-0.055	0.115	0.148
	Sig. (2-tailed)			0.000	0.000	0.000	0.729	0.251	0.686	0.083	0.039	0.481	0.735	0.480	0.363
	N			40	40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_nonDom_rfd100_150_rep1	Pearson Correlation			1	.943**	.770**	0.087	-0.203	0.052	0.284	.415**	-0.107	-0.077	0.166	0.221
	Sig. (2-tailed)				0.000	0.000	0.593	0.208	0.751	0.076	0.008	0.511	0.638	0.307	0.171
	N				40	40	40	40	40	40	40	40	40	40	40
Calf_SSB_nonDom_rfd150_200_rep1	Pearson Correlation				1	.913**	0.244	-0.166	0.073	.314*	.465**	0.038	0.037	0.043	0.125
	Sig. (2-tailed)					0.000	0.130	0.305	0.653	0.048	0.003	0.815	0.822	0.790	0.444
	N					40	40	40	40	40	40	40	40	40	40
Calf_SSB_nonDom_rfd200_250_rep1	Pearson Correlation					1	.541**	-0.103	0.096	.322*	.416**	0.188	0.178	-0.093	-0.017
	Sig. (2-tailed)						0.000	0.526	0.554	0.043	0.008	0.245	0.272	0.569	0.917
	N						40	40	40	40	40	40	40	40	40
Calf_SSB_nonDom_rfd250_300_rep1	Pearson Correlation						1	0.086	0.113	0.186	0.179	0.229	0.279	-0.185	-0.138
	Sig. (2-tailed)							0.598	0.488	0.251	0.270	0.155	0.082	0.254	0.397
	N							40	40	40	40	40	40	40	40
Calf_SSB_nonDom_aveimpulse1_rep1	Pearson Correlation							1	.966**	.877**	0.115	0.165	0.230	-0.096	-0.060
	Sig. (2-tailed)								0.000	0.000	0.479	0.310	0.154	0.557	0.715
	N								40	40	40	40	40	40	40
Calf_SSB_nonDom_aveimpulse2_rep1	Pearson Correlation								1	.969**	0.221	0.143	0.220	-0.063	-0.013
	Sig. (2-tailed)									0.000	0.171	0.379	0.173	0.698	0.935
	N									40	40	40	40	40	40
Calf_SSB_nonDom_aveimpulse3_rep1	Pearson Correlation									1	.320*	0.145	0.221	-0.051	0.014
	Sig. (2-tailed)										0.044	0.373	0.170	0.754	0.930
	N										40	40	40	40	40
pF_CALF_SSB_NON DOM_RELATIVE_rep1	Pearson Correlation										1	-.339*	-.344*	0.231	0.170
	Sig. (2-tailed)											0.030	0.028	0.147	0.288
	N											41	41	41	41
10 Yrds	Pearson Correlation											1	.933**	-.700**	-.607**
	Sig. (2-tailed)												0.000	0.000	0.000
	N												41	41	41
40 Yrds	Pearson Correlation												1	-.765**	-.682**
	Sig. (2-tailed)													0.000	0.000
	N													41	41
rep1 Height	Pearson Correlation													1	.841**
	Sig. (2-tailed)														0.000
	N														41

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix S

Coefficient of Variation % Results – ISqT/ICalf

Reliability

		SSB SqT Dom			SSB SqT Non Dom			CB SqT Dom			CB SqT Non Dom		
sub #	**Sex**	**Time1**	**Time2**	**DIFF**	**Time1**	**Time2**	**DIFF**	**Time1**	**Time2**	**DIFF**	**Time1**	**Time2**	**DIFF**
2		3.170504	3.2484	-0.08	3.065247	3.237525	-0.17	2.882994	2.950255	-0.07	3.025198	2.671221	0.35
3		2.197398	1.801006	0.40	2.17142	2.014682	0.16	2.010895	1.761074	0.25	1.914745	2.080964	-0.17
4		2.929002	3.088587	-0.16	2.448716	2.536152	-0.09	2.293222	3.109453	-0.82	1.87429	2.310397	-0.44
5		2.200672	2.402515	-0.20	2.389107	2.427126	-0.04	2.281631	2.290142	-0.01	2.081114	2.226127	-0.15
6		3.373245	3.513349	-0.14	3.025744	3.057314	-0.03	3.006915	3.211284	-0.20	3.047386	3.276122	-0.23
7		3.369004	3.323532	0.05	3.370778	3.188873	0.18	3.051079	3.174176	-0.12	2.912663	3.4345	-0.52
8		2.736746	2.958524	-0.22	2.890926	3.283026	-0.39	2.417367	2.519921	-0.10	2.706456	2.940342	-0.23
9		2.35515	2.528058	-0.17	2.192128	2.401745	-0.21	2.190907	2.621624	-0.43	1.797253	2.392813	-0.60
10		2.487107	2.290713	0.20	2.003138	2.254317	-0.25	2.305453	2.193189	0.11	2.029733	2.504349	-0.47
11		1.591642	2.0763	-0.48	1.717926	1.688121	0.03	1.525488	1.884328	-0.36	1.488184	1.775884	-0.29
12		3.152176	3.303789	-0.15	3.388257	3.338926	0.05	2.919456	3.328650	-0.41	3.214607	3.266446	-0.05
13		3.259268	3.661396	-0.40	3.713836	3.936889	-0.22	3.524119	3.497032	0.03	3.556993	3.513125	0.04
14		2.8159	2.707444	0.11	2.598844	2.774245	-0.18	2.666366	2.416303	0.25	2.60211	2.722706	-0.12
17		2.342428	2.470405	-0.13	2.583559	2.511557	0.07	2.667618	2.596127	0.07	2.727296	2.939544	-0.21
Mean		2.71	2.81	-0.10	2.68	2.76	-0.08	2.55	2.68	-0.13	2.50	2.72	-0.22
SD		0.54	0.57	0.23	0.58	0.61	0.17	0.51	0.54	0.29	0.63	0.53	0.25
CV(%)				**5.84**			**4.34**			**7.96**			**6.70**

Reproducibility

Coefficient of Variation (CV)

CV = method error(ME)/ [(mean1 +mean2)/2]

ME (sd)= sd/root2

Reliability

sub #	Sex	SSB Calf Dom			SSB Calf Non Dom			CB Calf Dom			CB Calf Non Dom		
		Time1	Time2	DIFF	Time1	Time2	DIFF	Time1	Time2	DIFF	Time1	Time2	DIFF
2		1.976229	2.816042	-0.84	2.131278	2.663211	-0.53	1.721228	2.053856	-0.33	2.034447	2.166625	-0.13
3		1.382357	1.383842	0.00	1.648726	1.794049	-0.15	1.471106	1.380153	0.09	1.446346	1.597269	-0.15
4		1.950916	2.354174	-0.40	1.802035	1.753669	0.05	1.817559	1.63918	0.18	1.30126	1.168967	0.13
5		1.492035	1.468127	0.02	1.397209	1.472112	-0.07	1.151758	1.418427	-0.27	0.936178	1.300889	-0.36
6		2.192693	2.353074	-0.16	1.981206	2.395382	-0.41	1.879642	2.516871	-0.64	2.065094	2.477928	-0.41
7		2.128205	2.480461	-0.35	2.092038	2.590495	-0.50	2.250479	2.436676	-0.19	2.185458	2.549135	-0.36
8		2.558251	2.333361	0.22	2.372991	2.387872	-0.01	2.142313	1.801292	0.34	2.408261	1.802651	0.61
9		2.149374	2.477314	-0.33	2.111663	2.782961	-0.67	1.85376	2.102473	-0.25	1.619242	1.967227	-0.35
10		2.150862	1.894883	0.26	2.056916	1.934908	0.12	1.85961	1.893518	-0.03	1.861566	1.868895	-0.01
11		1.329955	1.340232	-0.01	1.358245	1.303142	0.06	1.132858	1.286215	-0.15	1.33237	1.233514	0.10
12		2.53483	2.57793	-0.04	2.306238	2.853317	-0.55	2.047635	2.325381	-0.28	2.00249	2.117549	-0.12
13		2.476227	3.059166	-0.58	3.035519	3.12454	-0.09	2.897934	2.601202	0.30	2.701149	2.854483	-0.15
14		2.953015	3.10783	-0.15	2.715647	2.961362	-0.25	2.156096	2.389474	-0.23	2.280044	2.554242	-0.27
17		2.183831	1.778754	0.41	2.479741	2.111607	0.37	1.616651	1.869516	-0.25	1.650888	2.232748	-0.58
Mean		2.10	2.24	-0.14	2.11	2.29	-0.19	1.86	1.98	-0.12	1.84	1.99	-0.15
SD		0.46	0.59	0.34	0.47	0.57	0.30	0.46	0.44	0.27	0.49	0.53	0.30
CV(%)				**11.03**			**9.79**			**9.91**			**10.90**

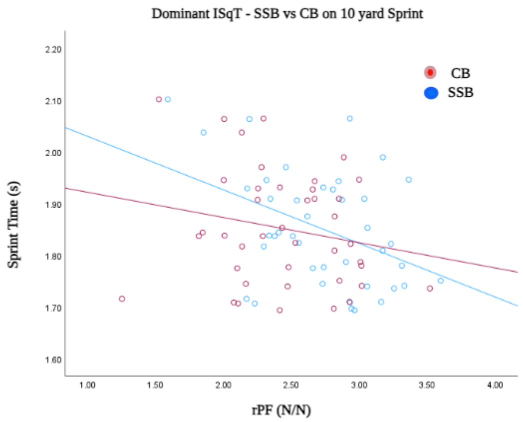
Appendix T

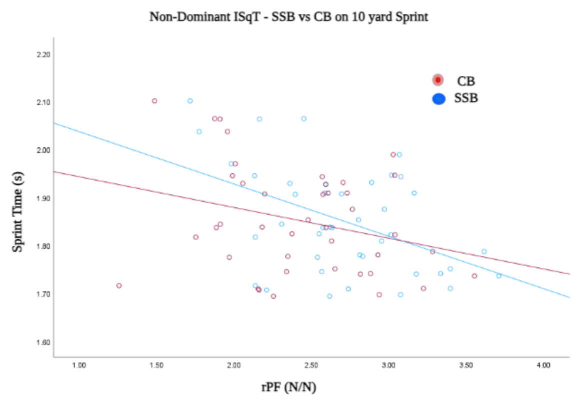
BW and Data Organization Procedure

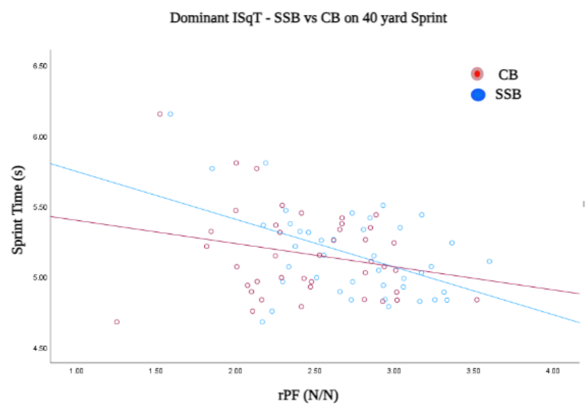
Subject ID	BW (N) + Bar	Day	BW (N) - Bar	ISqT_SSB_DOM_aPF	rPF
SUB_01	1065.3645	1	867.8645	2369.448245	2.730205286
SUB_02	924.9657	1	727.4657	2306.432664	3.170503659
SUB_03	1488.5151	1	1291.0151	2836.874617	2.197398479
SUB_04	1504.6271	1	1307.1271	3828.577782	2.929001918
SUB_05	1255.1485	1	1057.6485	2327.537371	2.200671935
SUB_06	1011.096	1	813.596	2744.458274	3.373244551
SUB_07	1053.1617	1	855.6617	2882.727528	3.369003811
SUB_08	1214.3964	1	1016.8964	2782.987648	2.736746485
SUB_09	1120.9806	1	923.4806	2174.935689	2.355150383
SUB_10	1191.7874	1	994.2874	2472.899466	2.487107315
SUB_11	1560.4367	1	1362.9367	2169.307913	1.591642453
SUB_12	1094.0397	1	896.5397	2826.05134	3.152176463
SUB_13	1131.414	1	933.914	3043.875625	3.259267582
SUB_14	937.6052	1	740.1052	2084.062361	2.815900174
SUB_15	1026.2069	1	828.7069	1797.28145	2.168778189
SUB_16	1255.4794	1	1057.9794	3507.98087	3.315736459
SUB_17	1223.8918	1	1026.3918	2404.248498	2.342427616
SUB_18	1559.9356	1	1362.4356	2529.796721	1.856819303
SUB_19	1039.9387	1	842.4387	2374.302264	2.818367988
SUB_20	942.2629	1	744.7629	2302.287272	3.091302309
SUB_21	1013.8825	1	816.3825	2496.374285	3.057848845
SUB_22	1099.416	1	901.916	2413.269501	2.675714258
SUB_23	1183.0877	1	985.5877	2831.585718	2.872992142
SUB_24	1074.6303	1	877.1303	2106.678475	2.401785088
SUB_25	1071.1752	1	873.6752	2867.290656	3.281872549
SUB_26	1097.814	1	900.314	2004.435122	2.226373379
SUB_27	1053.0201	1	855.5201	2534.582197	2.962621447
SUB_28	1168.4468	1	970.9468	2955.298777	3.04372884
SUB_29	1022.1535	1	824.6535	2442.356977	2.961676604
SUB_30	1200.432	1	1002.932	2354.170438	2.347288189
SUB_31	1158.2812	1	960.7812	2528.84774	2.632074546
SUB_32	1053.6089	1	856.1089	3090.033425	3.609392947
SUB_33	1207.8334	1	1010.3334	2342.060062	2.318106144
SUB_34	1354.2963	1	1156.7963	3300.25618	2.852927676
SUB_35	1165.1727	1	967.6727	2500.239339	2.583765501
SUB_36	1032.2852	1	834.7852	2558.919106	3.06536233
SUB_37	996.9298	1	799.4298	2321.785577	2.904302013
SUB_38	1195.7345	1	998.2345	2463.287243	2.467643868
SUB_39	1134.8467	1	937.3467	2203.763187	2.351065179
SUB_40	1073.5754	1	876.0754	2206.076025	2.518134883
SUB_41	1081.0281	1	883.5281	2803.830835	3.1734484
SUB_10	1201.4582	2	1003.9582	2306.432664	3.170503659
SUB_08	1218.4104	2	1020.9104	2836.874617	2.197398479
SUB_05	1277.3438	2	1079.8438	3828.577782	2.929001918
SUB_06	1017.0978	2	819.5978	2327.537371	2.200671935
SUB_09	1112.6357	2	915.1357	2744.458274	3.373244551
SUB_07	1045.6267	2	848.1267	2882.727528	3.369003811
SUB_14	935.0053	2	737.5053	2782.987648	2.736746485
SUB_02	902.4442	2	704.9442	2174.935689	2.355150383
SUB_11	1503.8533	2	1306.3533	2472.899466	2.487107315
SUB_17	1226.4458	2	1028.9458	2169.307913	1.591642453
SUB_04	1502.6369	2	1305.1369	2826.05134	3.152176463
SUB_12	1068.0869	2	870.5869	3043.875625	3.259267582
SUB_03	1489.4346	2	1291.9346	2084.062361	2.815900174
SUB_13	1139.7733	2	942.2733	2404.248498	2.342427616

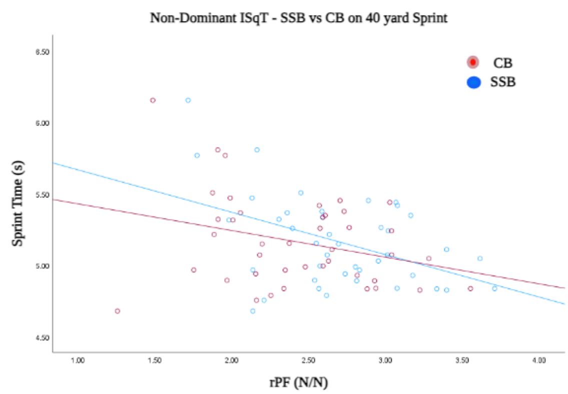
Appendix U

Objective One Scatter Plots









Appendix V

Objective Two Scatter Plots