An Exploration Into The Association Between Maximal Isometric Calf Strength And Sprinting And Jumping Performance In Male Rugby Union Athletes.

A dissertation submitted to Auckland University of Technology in fulfilment of the requirements for the degree of Master of Sport, Exercise and Health.

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Abstract

Rugby union is a field invasion sport that requires a variety of high-level physical qualities, in particular, ballistic qualities such as sprinting and jumping. A key physiological mechanism that contributes to ballistic performance in the stretch shortening cycle (SSC), as well as muscular strength. The isometric contraction of the plantar flexors provides tension for the series elastic component to absorb and reproduce energy effectively and contribute to SSC performance. Therefore, the aim of this dissertation was to review current literature exploring the relationship between isometric plantar flexor strength and ballistic performance as well as the underlying mechanisms, followed by an investigation into the relationship in plantar flexor isometric strength and ballistic performance in provincial level rugby union players. Twenty-nine men provincial rugby players (age: 19.3 – 34.1; weight: 82.3 – 124.4 kg) participated in this investigation. Maximal seated and standing isometric plantar flexor strength, countermovement jump (CMJ), pogo jump and 30m sprint were performed. Isometric seated and standing planter flexor metrics (peak force, impulse at 100ms, 150ms and 200ms, and peak vertical force) were analysed using a correlation analysis, along with CMJ (jump height, peak power, flight time/contraction time ratio and concentric peak force), pogo jump (contact time and reactive strength index) and sprint (F0, V0, Pmax, max speed, 10m, 20m and 30m splits) metrics. Standing isometric plantar flexor peak vertical force on the left and right leg were significantly correlated to CMJ jump height ($p < 0.03$; $r = 0.570$-0.551), standing isometric plantar flexor peak vertical force on the left leg was significantly correlated with CMJ peak power ($p < 0.05$; $r=0.501$), and seated isometric plantar flexor peak vertical force on the left leg had a significant correlation with flight time and contraction time ratio ($p \leq 0.05$, $r=0.514$). The findings of this investigation indicate that maximal isometric plantar flexor strength may provide insight into the overt execution of slow SSC actions, but not for fast SSC movements.

Ethical Approval

Ethical approval was granted by the Auckland University of Technology Ethical Committee (AUTEC) (AUTEC #21/109) on the 15th of September 2022 (Appendix 4).

Table of Contents

List of Tables

Attestation of Authorship

I hereby declare that this submission is entirely original work of mine, and that it does not, to the best of my knowledge and belief, contain any previously published or written works by others (aside from those expressly acknowledged), nor does it contain any materials that are substantially similar to those that have been submitted for the award of any other degree or diploma from a university or other higher education institution.

Two distinct chapters of this dissertation are nearing completion to be submitted to peer-reviewed journals for publication. In the following section, the contribution by myself and that of another is described. Joint work has been included in this master's dissertation with the consent the co-author.

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Candidate Contributions

The student was the main contributor to the research and development of this dissertation, to the minimum requirement of 80%. The student was also the main contributor to the ethics application submitted to the AUTEC, and other progress reports required for the university.

Chapter 2.

Kovacs, J., Uthoff, A. The Musculotendinous Unit, Stretch Shortening Cycle, And The Role Of Isometric Contraction: A Narrative Review

Kovacs, J. (80%), Uthoff, A. (20%).

Chapter 3.

Kovacs, J., Uthoff, A. An Exploration Into The Association Between Maximal Isometric Calf Strength And Sprinting And Jumping Performance In Male Rugby Union Athletes.

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Dr Aaron Uthoff

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Chapter 1: Introduction and Rationale

1.0 Introduction

Rugby Union is a field-based team invasion sport that requires athletes to utilise stretch-shortening cycle abilities (SSC) during jumping and running actions to maximise individual and team performance (Duthie, et al., 2003). Lower body maximal strength has been shown to be a key performance indicator for success in rugby union (Duthie, et al., 2003), and underpins the ability to apply large mass-specific forces during SSC actions (Miyaguchi & Demura, 2008). Therefore, identifying and developing lower body maximal strength, and understanding its association with athletic-based SSC actions is important when considering programme design for rugby athletes.

Contractile tissues are one of the main contributors to maximal strength and have different force capabilities depending on whether they are being lengthened (eccentric action), shortened (concentric action), or maintain the same length (isometric action) (Kuschel, et al., 2022). There has been a recent surge in the use of isometric testing with the increased availability of technology that enables the quantification of force (Hart, et al., 2012). Isometric strength tests are commonly done by performing a maximal voluntary contraction against an unyielding resistance (Juneja, et al., 2010). While isometric testing is seeing a renaissance, maximal isometric strength testing has been utilised for over 50 years, with key metrics such as rate of force development and maximal force investigated for both single and multijoint exercises (Murphy & Wilson, 1996). Isometric strength tests are favourable compared to ballistic tests due to their low fatiguing nature and relative safety (Juneja, et al., 2010). Moreover, many muscles work isometrically, or quasi-isometrically during ballistic activities (Nuebert, et al., 1998; Lai, et al., 2015). Therefore, measuring muscles in this distinct working state may provide sport-specific functioning of the tissues under similar environments that they will be exposed to on the field or court.

One of the most common tests to assess lower body maximal strength is via the isometric mid-thigh pull (IMTP). This test has been found to have large correlations with sprinting and jumping performance (Thomas, et al., 2015; West, et al., 2011; Thomas, et al., 2017; Townsend, et al., 2019; McGuigan & Winchester, 2008). During the IMTP testing protocol, maximal force is produced whilst in a biomechanically advantageous position to exert the maximal possible force, with aspects of the test, such as the knee and hip angle similar to that of the midstance during running, and the coupling of the eccentric and concentric phase similar to that of SSC jumps (Comfort, et al., 2015; Rodgers, 1988). However, the IMTP is a gross measure of total lower-body strength with the feet supported across the entire base of the foot. This testing protocol is dissimilar to the base of support the foot undergoes during many locomotive-based SSC actions (Comfort, et al., 2019). The dorsiflexed position of the ankle during the IMTP is unlike the positioning and demands the lower leg tissues are exposed to during ballistic exercises (Rodgers, 1988). This suggests that general measures of lower-body strength, like the IMTP test, do not provide a measure of force production capabilities of the triceps surae muscles. Given the importance of the lower-leg muscles' influence on SSC performance, particularly during fast contractions (<250ms) such as sprinting and jumping (Pruyn, et al., 2014), it is important to understand whether measuring strength in this anatomical region provides empirical or practical insights into SSC actions commonly performed on the rugby pitch.

1.1 Significance and Purpose

Interest in the relationship between plantar-flexion isometric strength and ballistic performance has increased with the availability of force plates as well as the role isometric contractions play in the utilisation of the SSC. Despite the practical interest in this area, there is a lack of scientific investigations quantifying the relationship between lower-leg isometric neuromuscular performance and SSC performance in field-sport athletes. This dissertation compiled and reviewed current literature examining the musculotendinous mechanisms underpinning SSC actions and the relationship between lower-leg isometric strength and SSC performance, and thereafter attempted to establish the relationship between lower-leg isometric strength and SSC performance in provincial rugby union athletes. The findings of this research will give greater insight into the role isometric contractions play during ballistic movements and inform practitioners about the necessary inclusion of assessments in their testing battery.

1.2 Dissertation Aims

The specific aims of this dissertation were to:

1) Collect and review current literature regarding the role of the musculotendinous tissues during SSC movements, as well as the relationship between isometric contractions of the lower-leg and SSC actions.
2) To identify the strength of the relationship between isometric plantarflexion strength and ballistic performance during sprinting and jumping in rugby union athletes.

1.3 Dissertation Framework and Methodology

To achieve the aims, this dissertation is structured in four chapters. Chapter 1 is the introduction, providing a brief background on the utility of maximum strength for SSC performance, developing a rationale and providing the specific aims of this dissertation. Chapter 2 is a narrative literature review examining the roles of the different components of the musculotendinous tissues during SSC actions and the current understanding of the relationship between lower-leg isometric strength and ballistic performance. Chapter 3 is an acute cross-sectional study exploring the relationship between isometric plantar flexor strength and SSC performance during sprinting and jumping. Chapter 4 summarises the dissertations findings, where practical applications, limitations, and future research directions are discussed.

Chapter 2: The Musculotendinous Unit, Stretch Shortening Cycle, And The Role Of Isometric Contraction: A Narrative Review

2.0 Prelude

Rugby-union is a field-based invasion sport that requires a variety of physical qualities to be successful (Duthie, et al., 2003). A key mechanism that contributes to these physical qualities is the SSC. Currently, there is limited research regarding the general mechanics of the musculotendinous unit and the role it plays during the SSC in provincial level rugby union athletes. Current research commonly investigates the relationship IMTP has with ballistic performance, however little research investigates the lower leg isometric strength and ballistic performance. The purpose of this literature review is to summarise the current literature which discusses the physiological mechanism of the SSC, the role of the isometric contraction during the SSC, and finally the relationship isometric strength has with ballistic performance. Methods to assess ballistic performance in the rugby union population is useful to practitioners as it allows them to assess and identify physical performance qualities, providing insight into an individual's physical qualities and implement programs to further improve physical performance.

2.1 Introduction

The ability to apply large mass-specific forces in short periods of time is known to underpin athletic performance in movements such as sprinting, changing directions, and jumping (Hewit, et al., 2011). This ability is determined by a complex sequencing of muscle-tendon complexes and neural pathways (Hoffer & Andreassen, 1981). The most recognized pathway of force transmission from muscle fibers to bone is via the specialized myotendinous junction and tendon, named myotendinous force transmission (Mass & Sandercock, 2010). When skeletal muscles contract they are attempting to shorten. Muscle contraction is also termed muscle action due to the actin-myosin system resembling the sliding filament model, where the actin and myosin filaments slide across one another (Plosney & Barr, 2000). According to the sliding filament model, three primary muscle actions can occur: concentric, eccentric, and isometric. Concentric actions refer to the shortening of the muscle as the actin and myosin filament pull the proximal and distal attachments of the muscle "closer" together. Eccentric muscle actions result in the lengthening of the actin and myosin filament, resulting in the proximal and distal muscle attachments moving "further away". Isometric muscle actions are where the actin and myosin filaments do not move, maintaining their position relative to each other, resulting in the muscle maintaining its length, and the external joint angle remaining relatively unchanged. The action of the muscle is predicated on the external force acting upon the contracting muscle relative to the amount of internal force applied (Siff, 2000). The interaction of these muscle actions can be used to produce greater maximal force during ballistic movements than can be achieved by concentric muscular actions alone (Bas Van Hooren & Julia Zolotarjova, 2017). The sequencing of an eccentric phase, followed by an isometric transition period (amortization), leading into an explosive concentric phase is known as the stretch-shortening cycle (SSC) (Norman & Komi, 1979; Komi, 1984). During athletic movements like countermovement jumping, sprinting and changing directions, the lower leg is crucial in absorbing and producing force by utilising the SSC.

Understanding the behaviour of the muscle-tendon complex during locomotion is important, particularly when discussing movements that rely on the SSC, such as sprinting and jumping. During fast ballistic movements, much of the length change in the muscle-tendon complex occurs in the tendon, whereby the muscle maintains a relatively quasi-isometric state (Roberts, 2002). For example, shank and thigh muscles (i.e., medial gastrocnemius and vastus lateralis) have been shown to act near isometrically during sprinting (Ishikawa, et al., 2003; Fukunaga, et al., 2000). Harnessing elastic energy from passive components contributes to that of the active components during the SSC actions (Bas Van Hooren & Julia Zolotarjova, 2017). This muscle-tendon function serves to promote a metabolically cost-effective method of locomotion (Bobbert, M & Cassius, L, 2005; Bobbert, M, et al., 1996) and to enhance force production capabilities (Finni, 2006). For example, Verkhoshansky (1996) reported efficient usage of SSC can recover approximately 60% of the total mechanical energy during sprinting. The utilisation of elastic energy, the greater uptake of muscle slack, and prior muscle activation are key contributors to enhanced performance when utilising the SSC (Bas Van Hooren & Julia Zolotarjova, 2017). The ability to produce greater forces with less metabolic expenditure is critical for sports like rugby union, where success is determined by the ability to produce repeated explosive movements (Duthie, et al., 2003).

Given that ballistic movements involving the SSC are prolific in many sports and training programs, these actions are commonly used to assess athletic capabilities (Turner & Jefferys). However, while dynamic testing is often used to assess performance with athletes, performing maximal dynamic strength testing or maximal effort explosive SSC movements can be taxing on the central nervous system and require relatively complex and time-intensive testing procedures (Warneke, et al., 2023). Therefore, isometric strength testing has been suggested to quantify athletes' strength capabilities while inducing less neuromuscular stress on the athlete in a more time-efficient manner (McGuigan & Winchester, 2008). Isometric strength has been shown to be positively correlated with jump performance (Tsiokanos, et al., 2002; West, et al., 2011; McGuigan & Winchester, 2008), sprinting (Thomas, et al., 2017; West, et al., 2011; Finni, 2006), change of direction (COD) (Thomas, et al., 2017) and maximal dynamic strength tests (McGuigan & Winchester, 2008). Isometric strength is commonly measured using multi-joint movements such as the isometric mid-thigh pull (McGuigan, et al., 2008; Thomas, et al., 2017; West, et al., 2011), but can also measure isolated muscle groups (Tsiokanos, et al., 2002).

The relationship between isometric strength and performance in various dynamic tests has been extensively investigated in the literature. Whole body isometric strength, measured via an isometric mid-thigh pull (IMTP), and strength, speed, and agility in collegiate rugby players has been found to be strongly correlated. Several studies have reported a strong correlation between isometric strength and ballistic performance (McGuigan et al., 2008; Thomas et al., 2017; Tsiokanos et al., 2002; West et al., 2011) with late-stage rate of force development (>90ms) correlated with strength performance (r=0.656 – 0.748) (Wang, et al., 2016). Isometric strength is also correlated with sprint, jump and COD performance (Mock, et al., 2022; West, et al. 2011; Thomas, et al., 2017). Studies revealed that early-stage rate of force development (RFD) (30-50ms) was strongly associated with sprint and agility performance (r=-0.527 and r=0.518 respectively) (Wang, et al., 2016). These results are consistent among various studies (McGuigan et al., 2008; Thomas et al., 2017; Tsiokanos et al., 2002; West et al., 2011). Taken together, these studies reveal that isometric strength testing is a valuable tool for assessing key physical qualities in athletic populations. However, it should be noted that the relationship between isometric performance and physical performance has been primarily investigated using the whole-body isometric tests, like the IMTP. Therefore, further research is required to investigate the relationship between isometric performance and physical performance using other isometric testing methods.

The lower leg plays a crucial role in absorbing and producing force during certain ballistic movements, including selected jump tests, speed, and COD, through the utilization of the SSC (Turner & Jefferys, 2010). This is due to the viscoelastic characteristics of the musculotendinous unit, particularly the Achilles tendon, which is capable of absorbing energy when stretched and effectively utilising it to enhance external force production (Fukashiro et al., 2006). Ballistic movements that utilise the SSC and isometric strength has been shown to have significant relationships with movements such as CMJ concentric peak power having a moderate correlation to IMTP peak force (r=0.52) (West, et al., 2011) and isometric plantar flexor peak force having a significant correlation to 30m sprint time (r= -0.72) (Mock, et al., 2018).

The SSC is a sequence of muscle actions that involves an eccentric phase (lengthening of muscle fibres), an isometric phase (maintaining muscle length), and a concentric phase (shortening of muscle fibres). During fast ballistic movements that rely on the SSC, much of the length change in the muscle-tendon complex occurs in the tendon, whereby the muscle maintains a relatively quasi-isometric state. While whole-body isometric strength has been found to significantly correlate with SSC movements like sprinting, jumping, and change of direction performance (McGuigan et al., 2008; Thomas et al., 2017; Tsiokanos et al., 2002; West et al., 2011, Wang, et al., 2016), there is currently little research investigating the relationship between the isometric strength of the lower limb muscles and ballistic performance. This manuscript aims to provide an overview of the role the lower-leg muscle-tendon complex plays during SSC actions and review the relationship between lower-leg isometric strength and athletic performance tasks utilising the SSC.

2.2 Role of Lower-Leg Muscle-Tendon Complex During Stretch-Shortening Cycle Actions

The SSC is a complex muscle function that involves both eccentric and concentric actions, characterised by a brief period of eccentric stretching followed by a concentric action. This mechanism is underpinned by two important features: pre-activation and variable activation (Komi, 2003). The purpose of the SSC muscle function is to augment the concentric phase of a ballistic movement, thereby enhancing the force produced, as compared to an isolated concentric action (Komi, 2003). The SSC is commonly observed in various activities such as running, walking and jumping. Of particular interest to this review is the utilization of the SSC in the lower leg and the role played by the various components of the triceps surae (i.e., Gastrocnemius, Soleus, Tibialis anterior, Achilles tendon, and muscle fascia) in enhancing ballistic performance. The soleus, medial gastrocnemius, and lateral gastrocnemius are the three principal plantar flexor muscles that work in conjunction with the Achilles tendon to store and release energy during ballistic movement. These components are of paramount importance due to Hill's suggestion that force is the summation of three components, namely a contractile component, a series elastic component, and a parallel elastic component (Hill, 1938).

2.3 Function of contractile tissues

The force production by a muscle is explained by the cross-bridge theory, which posits that myosin cross-bridges connect with the binding sites on the actin filaments (Challis, 2000). It is observed that the maximal isometric force is generated when sarcomere lengths are at their mid-range, also referred to as their optimal length; which is attributed to the maximum number of cross-bridges connecting the actin and myosin filaments (Challis, 2000). Consequently, there exists an optimal range within which a muscle can exert its maximal force due to the maximal number of connected cross-bridges.

The activation of the triceps surae muscles varies depending on the joint angle of the knee and ankle due to differences in muscle insertion and origin (Bolsterlee et al., 2018; Bordoni & Varracallo, 2018; Signorile et al., 2002). The gastrocnemius and soleus muscles have separate origins; the gastrocnemius heads come from the posterior surfaces of the medial and lateral epicondyles, whereas the soleus muscle comes from the posterior surfaces of the tibia and fibula (Bolsterlee et al., 2018; Signorile et al., 2002). Both muscles contribute to plantar flexion despite having different points of origin because they insert into the calcaneus via the Achilles tendon. According to Bolsterlee et al. (2018), the soleus muscle, which lies below the gastrocnemius, is structurally made up of an anterior aponeurosis that runs the length of the muscle belly and divides it into posterior and anterior compartments. These compartments ultimately insert into the calcaneus through the common Achilles tendon after further dividing into medial and lateral sections (Hodgson et al., 2006; Bolsterlee et al., 2018). However, due to the biarticulate structure of the gastrocnemius, the joint angle and position of one joint can affect the action at the other (Signorile et al., 2002).

During plantar flexion, the medial gastrocnemius is more active at a 180° knee angle than both the lateral gastrocnemius and the soleus, whereas the lateral gastrocnemius shows no significant change in activation at different knee angles (Signorile et al., 2002). Herbert-Losier et al. (2012) also reported that the medial gastrocnemius contributes the most to plantar flexion at 0° knee flexion, while the soleus muscle contributes the most at 45° knee flexion. Both studies suggest that the change in force output with a change in knee angle is mainly due to the contribution of the medial head of the gastrocnemius, while the soleus muscle provides a significant contribution to both standing and seated plantar flexion (23.2% and 27.0%, respectively) (Herbert-Losier et al., 2012; Signorile et al., 2002). Despite the differences in the activation of the lateral head of the gastrocnemius with a change in knee angle, both studies identify that the decrease in muscle activation is not as great as that of the medial head, which may be attributed to differences in the muscles' anatomy and physiology. The findings of these studies provide insights into the complex interplay of the triceps surae muscles and highlight the importance of considering joint angle when evaluating muscle activation.

Furthermore, the muscle architecture of the triceps surae contributes to the overall muscle function, and changes in muscle length brought on by alterations in ankle joint angle can affect the thickness of the gastrocnemius medialis, gastrocnemius lateralis, and soleus at rest.

However, their thicknesses do not significantly vary, with measures of 17, 15, and 15 mm previously reported in physically active men, respectively (Maganaris et al., 1998). It is also important to consider that the maximum force-generating capacity of a muscle is proportional to its physiological cross-sectional area (Haxton, 1944, as cited by Albracht et al., 2008). It has been found that the physiological cross-sectional area (cm2) of the soleus muscle is the largest (131±31), followed by the Gastrocnemius medialis (51±10) and the Gastrocnemius lateralis (24±5) (Albracht et al., 2008). A positive correlation has been observed between Soleus physiological cross sectional area (r=0.77) and volume (r=0.55) and marathon runners performance (Kovacs, et al., 2020). Significantly differing pennation angles are exhibited between the posterior and anterior compartments, with the former exhibiting greater pennation angles than the latter (Bolsterlee et al., 2018; Sopher et al., 2016), whereas no noteworthy difference is reported between the medial and lateral compartments of the muscle (Bolsterlee et al., 2018).

Pennation angle and fibre length are subject to ankle angle dependence in all three muscles when they are at rest. Specifically, muscles with greater pennation angle are capable of producing greater force than muscles with less significant angle (to an upper limit of 45^{o}) or a non-pennate muscle (Aagaard, et al., 2001), whilst longer muscle fibres found in parallel fibred muscle have greater ability to produce higher velocity contractions (Charles, et al., 2022). The pennation angle has been shown to increase in all three muscles as the ankle angle increases from 15 degrees to +30 degrees: in the Gastrocnemius medialis from 17 degrees to 25 degrees (39%, P= 0.001), in the Gastrocnemius lateralis from 9 degrees to 15 degrees (67%, P= 0.005), and in the Soleus from 21 degrees to 33 degrees (57%, P= 0.001). As ankle angle increases from 15 degrees to +30 degrees, fibre length reduces in all three muscles: in the Gastrocnemius medialis from 53 mm to 36 mm (32%, P= 0.001), in the Gastrocnemius lateralis from 83 mm to 55 mm (34%, P= 0.001), and in the Soleus from 42 mm to 27 mm (33%, P= 0001) (Maganaris et al., 1998). The varying muscle architecture between the triceps surae muscles and the resulting implications on force output result in a change in muscular performance dependent on the joint angle and the movement pattern. This is evident during locomotion, with the medial gastrocnemius having greater contractile speed, particularly during the push off phase, but its contribution decreases as speed and exercise duration increases (Cronin, et al., 2012). Whilst the soleus maintains its contractile function behaviour regardless of the speed or duration, suggesting its potential greater impact on high speed and duration activities (Cronin, et al., 2012).

In recent research, it has been discovered that during a drop jump test, gastrocnemius activity experiences a decrease in activation approximately 20ms before ground contact and continues to be for more than 50% of the duration of ground contact, whilst the soleus maintains its activation during the movement, only increasing its activation during the initial ground contact to store elastic energy (Neubert, et al., 1998). This is accompanied by a higher activity of the rectus femoris (pre-tension before touchdown) at the same time as the gastrocnemius's lower activity. It has been observed that the gastrocnemius exerts the least amount of energy during the ground contact phase during a drop jump, while the rectus femoris exerts the most energy (Neubert, et al., 1998). Thus, the rectus femoris performs its function of knee extension at ground contact before the gastrocnemius begins to contract. However, to reduce the speed of knee extension and enable an impulse transfer from the knee joint to the ankle joint, significant gastrocnemius activity is required (Neubert, et al., 1998).

For short-range of motion actions like fast SSC movements such as running and hopping, the gastrocnemius and soleus experience greater muscle tension at maximal length of the muscle than during the eccentric phase of a drop jump (DJ) (124.9% and 79.4%, respectively) (Kooper et al., 2014). However, these differences are not observed in large range of motion actions at the ankle (Kooper et al., 2014). This suggests that over broad ranges of motion, the series elastic component's length change from the end of joint flexion (end of the eccentric phase) to the beginning of joint extension (beginning of the concentric phase) is small while the contractile component's length change is significant. On the other hand, over small ranges of motion, particularly in the plantar flexors, the length change in the series-elastic component is large while the length change of the contractile component is minimal. Furthermore, the contractile components are claimed to perform an isometric action when they are not extending or shortening, which is optimal for producing force during SSC exercises (Turner & Jeffreys, 2010). In the running gait's mid-stance phase, it has been suggested that the gastrocnemius works near isometrically (Lichtwark, et al., 2007), whilst the soleus works near isometrically throughout the whole phase

Prior to the transfer of force between the series elastic component (SEC) and the skeletal system, there is a period of inactivity. The delay in reactivity is referred to as the electromechanical delay and describes the period between the activation of the muscle and the eventual mechanical output from the muscle (Turner & Jeffreys, 2010). The negative effects of this time delay, which result from starting the movement from zero to low muscular tension, can be reduced by allowing the muscle to reach its maximal active state before the propulsive phase begins through either an isometric contraction (such as preloading) or an eccentric action (Turner & Jeffreys, 2010). Studies have indicated that isometric contractions can also produce a force output that is significantly greater than that of concentric contractions, making them an advantageous option (Turner & Jeffreys, 2010). For example, Finni et al. (2001) found that participants were able to jump higher while utilising a pre-stretch condition compared to a pre-isometric conditioning. This led them to conclude that additional elements, such as elastic energy, must be involved in the improved performance following a pre-stretch. It has also been noted that greater length change in the muscle tissue is not ideal for contractile forces at high-velocity SSC circumstances (Turner & Jeffreys, 2010). Therefore, discussing the function of elastic tissues during SSC movements is vital.

2.4 Function of Elastic Tissues

The muscle-tendon complex is a fundamental component in the production and absorption of kinetic energy during movement. As Challis (2000) notes, the force generated by contractile tissues is transmitted via fibrous connective tissue (i.e., tendons) and intramuscular connective tissue to the skeletal system. Indeed, the elastic properties of the musculotendinous unit have been linked to enhanced muscular performance, with studies showing a 20-30% increase in performance when comparing countermovement jump (CMJ) and squat jump (SJ) performance (Bosco, et al., 1981, as cited in Turner & Jefferys, 2010). Although there is an increase in non-metabolic energy use as velocity increases, there has also been observations of high correlations between a tendons' ability to store elastic energy and long-distance runners performance, highlighting the utilisation of the energy efficient system at various speeds (Verkhoshansky, 1996). Hence, understanding the function of the elastic properties of the muscle-tendon complex is crucial in explaining the mechanics of human SSC movement.

2.5 Musculotendinous Unit

In recent years, research has demonstrated that tendons play a crucial role in the storage and release of elastic energy within the musculoskeletal system (Turner and Jefferys, 2010). It is widely accepted that the amount of energy stored (Turner and Jefferys, 2010). The SEC is composed of the muscle-tendon, cross-bridges, and structural proteins (Hill, as cited by Turner and Jefferys, 2010). Tendons function as the primary transmission mechanism for the forces generated by muscle fibres to the skeletal system. The tendon is often referred to as a series elastic component because it is an elastic material which lies in series with the contractile component (Challis, 2000). When a tendon is initially loaded, it adopts a crimped, wave-like appearance that subsequently unfolds. Studies conducted by Rigby et al. (1959) and Bennett et al. (1986) indicate that tendons can stretch up to 8-10% beyond their resting length before breaking. Moreover, the energy loss associated with various mammalian tendons ranges from 6 to 11%, suggesting that tendons are highly efficient energy storage structures (Bennett et al., 1986). Due to the active contraction of the muscle resisting the stretching, the series elastic component exhibits significant storage of elastic energy. This effect is further amplified during rapid resisted stretching (Turner and Jefferys, 2010).

During fast SSC activities like running or pogo jumping, the entire musculotendinous unit undergoes minimal length change. This behaviour is akin to that of a spring, where the tendon extends upon landing and retracts during push-off, accounting for most of the ankle joint motion (Alexander, 1992). Notably, running only results in 6-7% length changes in the soleus and gastrocnemius muscle-tendon complex during the eccentric phase, indicating the potential for short-range elastic stiffness in skeletal muscles (Rack & Westbury, 1974). According to Ker et al. (1987), the elastic stretch and recoil of the Achilles tendon may account for up to 35% of the total energy storage and return during running, with soleus energy storage varying depending on whether the foot strikes with the forefoot or rearfoot (Young et al., 2020). In running and drop jumps, the length variations in the triceps surae-Achilles tendon complex range from 6 to 9% during the functional contact phase. Furthermore, compared to hopping, countermovement jumps rely substantially less on the triceps surae muscle's elastic recoil (Fukashiro et al., 1993; Finni et al., 1998). As a result of the slow stretch phase in the countermovement jump and the presumably lower reflex contribution to SSC potentiation than in hopping, this is to be expected.

Given the difficulties in measuring in vivo changes in muscle and tendon length, computer models have been developed to simulate motion and estimate muscle fibre and tendon behaviour. For example, Bobbert et al. (1986b) simulated the activity of the triceps surae during a maximal vertical jump and found that the tendon shortened more quickly than the muscle fibres in the soleus and gastrocnemius during the final 120ms of the jump. This allows the muscle fibres to shorten at a lower speed but with more force, as the tendon recoils from stretching during the countermovement phase (Komi, 2003). Experimental studies have also shed light on musculotendinous unit behaviour. For example, Kubo et al. investigated the musculotendinous unit of the human medial gastrocnemius during ankle dorsiflexion and plantarflexion. They found that tendon length increased more significantly in the fast-lengthening condition, while during plantarflexion, there was no discernible change in the fascicle's length, but the tendon rapidly shortened.

Notably, in isometric contractions, the total musculotendinous unit length does not change, but the muscle still contracts (shortens), resulting in tendon lengthening. The quasi-isometric action of the muscle, as well as the lengthening of the tendon closely replicates the muscle-tendon complex action which occurs during fast SSC actions (Warneke, et al., 2022). During SSC actions, the tendon’s ability to store and reproduce energy, due to the tendon’s elastic properties, is a significant contributor to SSC performance. Intramuscular tissue (PEC) may also contribute to slow SSC actions.

2.6 Connective Tissues

The PEC primarily contributes to the force produced by a passive muscle when it is stretched to its end range, with relatively little involvement in the storage of energy (Turner & Jefferys, 2010). The structure of the entire muscle reveals the presence of a significant amount of intramuscular connective tissue, including fascia, epimysium, perimysium, and endomysium. These connective tissues are made up of collagen and elastin, which possess considerable elastic properties (Challis, 2000). The connective tissues are stretched beyond their resting length at a specific point along the muscle's length-tension curve, generating force (Challis, 2000). They prevent overextension of the muscle fibres at extreme muscular lengths, thus inhibiting damage to the muscle. Furthermore, the amount of connective tissue present in each muscle influences the force that the PEC contributes to complete muscles; the more tissue present, the greater the forces (Challis, 2000). Tonic muscles contain more perimysium than phasic muscles. As they resist gravity, the plantar flexors are considered tonic muscles, while the anterior tibialis is phasic. Therefore, during SSC, especially from the perimysium, the connective tissue contribution is significantly greater for plantarflexion than dorsiflexion (Schleip, et al., 2005). The perimysium's collagen fibre form and arrangement differ from that of the epi- or endomysium, with collagen fibres with a large diameter constituting the majority of the perimysium (Borg & Caulfield, 1980). These fibres have a distinct crimp formation in the perimysium and are organised in a lattice-like pattern with parallel fibres pointing in two different directions. Muscle contraction or stretching alters the angles of this lattice with respect to the direction of the muscle fibres. The perimysium serves to prevent overstretching of the muscle fibre bundles and increase passive muscular stiffness, promoting efficient muscle function (Rowe, 1974; Purslow, 1989). The contribution of connective tissue (PEC) is relative to the activity level of the musculature, with the stiffness of tendon during running 100 times that of the PEC during rest (Wilson & Flanagan, 2008). During relaxed movements, the tendon goes through rather little deformation, with the majority of the deformation occurring in the PEC, whilst during active movements, the stiffness of the muscle tissue and the surrounding PEC exceeds that of the muscle tendon (Wilson & Flanagan, 2008). This highlights the utilisation of the PEC elastic properties during slower SSC movements, and the increase is PEC stiffness during faster SSC movements.

2.7 Relationship Between Lower Leg Isometric and Stretch-Shortening Cycle Actions

The relationship between isometric strength and dynamic performance remains indefinite, with mixed results reported in the literature. Isometric strength and its related metrics have been found to have a strong correlation with sprint performance. For instance, Brady et al. (2020) reported significant negative correlations between all isometric mid-thigh pull variables and 5m sprint times, with peak force showing a significant correlation with 0-30m time and 10-20m split time. Additionally, all variables of the isometric squat significantly correlated with 0-5m sprint time, supporting the findings of Dobbs, et al. (2020). While the multi-joint isometric mid-thigh pull is the most commonly used isometric test, other commonly used isometric tests are the isometric bench press and the isometric squat (Juneja, et al., 2010). A review by Lum, et al. (2020), highlights the inconsistency in correlation between isometric tests and ballistic performance. Among other areas, Lum, et al., discussed the relationship between isometric tests and sprinting and jumping performance. When investigating sprinting, Lum et al., (2020) concluded that isometric squat and isometric mid-thigh pull testing can quantify an individual's force generating capabilities that can relate to sprint performance. However noted that most research investigates this over a shorter, acceleration-based distance. When discussing jump performance, Lum et al., (2020) found that often the correlation between isometric test metrics and jump performance was the result of the testing method, suggesting that multi-joint isometric tests are not indicators of jump performance. Although these multi-joint isometric strength tests are sometimes applicable to ballistic movements such as sprinting and jumping (Mcguigan & Winchester, 2008; Thomas, et al., 2017; Dobbs, et al., 2018), it is unclear which muscle group is the primary contributor for this relationship.

The ability to perform high-intensity movements, such as the standing long jump, vertical jump, change-of-direction, and linear sprint, is highly dependent on the maximal strength of the lower limb muscles (Keiner, et al., 2021; Möck et al. 2018). To effectively amortize the load acting eccentrically upon ground contact during SSC actions, the lower leg musculature must possess ample maximal strength (Wirth et al., 2011). Lower-limb strength influences ballistic performance, with many studies investigating the relationship (Mock, et al., 2022; Keiner, et al., 2021; Avila-Carvalho, et al., 2022; Seitz, et al., 2014). A strong correlation has been found between maximal calf raise strength and squat jump and CMJ performance ($r = 0.659$, $p < 0.01$ and $r = 0.708$, $p < 0.01$ respectfully) as well as relative performance ($r = 0.575$, $p < 0.01$ and $r = 0.565$, $p < 0.01$ respectfully) (Mock, et al., 2022). Mock et al. (2018) discovered moderate to strong correlations between absolute and relative strength and performance in a 30-m sprint, with a tendency for larger coefficients in the second half of the running distance. However, Mock et al. (2022) found that the relative strength of the calf raise has a low correlation with SJ and CMJ performance, likely due to the primary propulsion being generated by the knee and hip extensors during these movements. Though, a high capacity for force generation in the plantar flexors may still be relevant for accelerating the centre of mass.

Although, research suggests that lower-leg strength is positively correlated with ballistic performance, due to the quasi-isometric nature of the plantar flexors during ballistic exercises such as sprinting, jumping, and hopping it has been hypothesised that isometric strength of the lower-leg may be significantly associated with SSC performance (Warneke, et al., 2022).

Research by Dobbs, et al., (2018) supports the relationship between isometric plantar flexor strength and SSC performance. Dobbs, et al., found that bilateral isometric plantar flexor strength had a significant correlation with 5m sprint splits (r=-0.582).

Lower limb strength has a direct influence on ballistic performance due to the relationship maximal strength has with power (Baker & Nance, 1999). The majority of previous research has investigated the relationship multi-joint isometric tests have with ballistic performance, with the use of the IMTP being of particular use. The limited studies available which explored the relationship between plantar flexor strength and ballistic performance suggest that the strength capabilities of the triceps surae complex carry over into fast SSC movements like changing directions and linear sprinting. However, this evidence is scarce due to a dearth of scientific investigations focusing on isolating muscle groups such as the triceps surae and their effects on dynamic performance. Therefore, further research is needed to elucidate the potential contribution of specific muscle groups to isometric strength and its relationship with dynamic performance.

2.8 Conclusion

The SSC is characterised by a brief period of eccentric stretching followed by a concentric action and is a key mechanism that influences physical performance due to the physiological properties of musculature and the musculotendinous unit. The purpose of the mechanism is to increase the concentric phase of a movement, resulting in an increase in force production, and as a result, physical performance (Komi, et al., 2003). Physiological properties such as contractile component, a parallel elastic component, and the series elastic component are key contributors to force production. The contractile component refers to the contractile tissue, made up of myosin cross bridges and actin binding sites which work together resulting in muscle contraction (Challis, 2000). The contractile component produces muscular force, with the greater number of cross bridges resulting in greater force production. The parallel elastic component refers to the connective tissue, composed of collagen and elastin, and have significant elastic properties (Challis, 2000). These elastic properties can generate force when stretched to beyond there resting length. Muscles include various forms of connective tissue, with the relative stiffness of the tissue varying dependent on the activity level of the musculature (Wilson & Flanagan, 2008). The series elastic component comprises of the cross bridges, the structural protein, and tendons (Turner & Jefferys, 2010).

Ballistic movements such as sprinting and jumping are directly influenced by the SSC mechanism. This is due the role the eccentric action which occurs, prior to the concentric action, and is identifiable in key ballistic movements, such as varying phases during locomotion and jumping. (Komi, 2003) As a result, the contractile component acts in an isometric manor, particularly in the lower-leg plantar flexors, which are partially responsible for the increase in tension which occurs in the Achilles tendon (Lichtwark, et al., 2007; Turner & Jefferys, 2010). Due to the physiological properties of the tendon, an increase in elastic energy storage, and the resulting energy release, increases (Turner & Jefferys, 2010). This directly influences physical performance, with an increase in energy storage and reproduction.

Isometric test are commonly used to asses maximal strength and as well as other metrics such as rate of force development (McGuigan & Winchester, 2008). The most common researched isometric test is the isometric mid-thigh pull, which is a multi-joint tests, and has frequently been shown to have a relationship with muscular strength and ballistic performance (McGuigan & Winchester, 2008; Thomas, et al., 2017; West, et al., 2011). Although the isometric mid-thigh pull test has shown to have a significant relationship with ballistic performance (Thomas, et al., 2017; West, et al., 2011), it can be argued that this is the result of the test having a significant relationship with muscular strength (McGuigan & Winchester, 2008), and is the result of interaction of force and time with power (Baker & Nance, 1999). Currently, there is limited research investigating the relationship the isometric strength has with ballistic performance due to the role the isometric contraction has during the SSC. Furthermore, there is even less research investigating this relationship amongst provincial level rugby union athletes.

Chapter 3: An Exploration Into The Association Between Maximal Isometric Calf Strength And Sprinting And Jumping Performance In Male Rugby Union Athletes.

3.0 Prelude

The previous chapter highlights some of the key contributors to physical success, the SSC and its underlying mechanisms as well as the role of the isometric contraction. A key gap in the literature was identified to be lower leg isometric strength and its relationship with ballistic performance. This chapter focuses on quantifying isometric plantar flexor strength in a seated and standing position, and ballistic performance exercises (CMJ, Pogo and Sprint) in provincial level rugby-union athletes, and a correlation analysis between isometric plantar flexor strength in a seated and standing position and ballistic performance. The objective of this chapter is to provide further understanding around how isometric plantar flexor strength relates to ballistic performance in provincial level rugby union athletes.

3.1 Introduction

Key qualities identified to be determinants of technical and tactical success in rugby union are strength, reactive strength, power, conditioning, and sprint performance (Cunningham, et al., 2018). A key mechanism that contributes to physical, and as a result, technical and tactical success, is the stretch shortening cycle (SSC) (Duthie, et al., 2003; Turner & Jefferys, 2010; Jefferys, et al., 2019, Cunningham, et al., 2018). The SSC is a physiological mechanism where an eccentric action is immediately followed by a concentric action, resulting in greater mechanical output (Turner & Jefferys, 2010; Jefferys, et al., 2019). In rugby union, where key physical qualities such as sprinting and jumping can contribute to technical and tactical success, the leg has a direct influence on the level of physical performance of these qualities, in particular the musculotendinous unit of the plantar flexors (Duthie, et al., 2003; Hewit, et al., 2011; Finni, 2006).

Isometric testing has been recommended for its ease and safety of testing (McGuigan & Winchester, 2008), but also because it tangentially resembles the contractile components function during fast SSC movements (Wareneke, 2022.). One of the most common methods of determining muscular strength is the isometric mid-thigh pull (IMTP), with various research highlighting the relationship that IMTP has with dynamic strength (r= 0.61to 0.72), speed and agility (r= -0.41 to -0.66) in athletic populations (McGuigan et al., 2008; Thomas et al., 2017; Tsiokanos et al., 2002; West et al., 2011). However, the IMTP is a multi-joint strength test. Therefore, it is impossible to decipher whether these relationships are due to the contribution of the upper or lower leg muscles.

During ballistic performance, is has been found that the plantar flexors work quasi-isometrically, applying tension primarily to the series elastic tissues, increasing their ability to absorb and reproduce elastic energy, increasing plantar flexor force output, and as a result, physical performance (Turner & Jefferys, 2010; Challis, 2000, Nuebert, et al., 1998). This highlights the important role the isometric contraction has during the SSC mechanism.

A variety of current research has highlighted the relationship plantar flexor strength (both isometric and dynamic) has with ballistic performance (Mock, et al., 2022; Keiner, et al., 2021; Avila-Carvalho, et al., 2022; Seitz, et al., 2014). Keiner et al. (2021) found that standing calf raise was significantly correlated to squat jump ($p= <0.05$ $r= 0.35$) and 20m sprint ($p= <0.05$ $r= -0.36$). Whilst the limited research investigating isometric plantar flexor strength and its relationship with dynamic performance, particularly in athletic populations, have not provided enough evidence to suggest either way (Tsiokanos, et al., 2002).

Due to the role isometric plantar flexor strength has in the SSC mechanism, as well as the current research demonstrating the relationship isometric strength has with ballistic performance, investigating the relationship isometric plantar flexor strength has with ballistic performance may provide further insight into the influence of this function on ballistic performance. Furthermore, exploring this relationship may provide support and recommendations around the practical application of not only isometric plantar flexor strength testing, but also the inclusion of isometric plantar flexor strength training in physical performance programming. Currently, research into isometric plantar flexor strength and ballistic performance has investigated other populations (physical education students) (Tsiokanos, et al., 2002). Therefore, the aim of this study was to investigate the relationship between isometric plantar flexor strength and ballistic jumping and sprinting performance in provincial level rugby union athletes.

3.2 Methods

3.2.1 Participants

29 provincial level rugby players playing in the National Provincial Championship competition volunteered to participate in this investigation (age: 24.08 ± 3.90 ; weight: 102.44 ± 9.34 kg). A convenience sampling method was used for participant selection. All participants were males between the ages of 18 and 33 years, and were healthy and injury free for the previous three months. Testing protocols were fully explained to each participant before obtaining their informed consent. The study was approved by the Auckland University of Technology ethical committee (22/216).

3.2.2 Test Procedures

Isometric plantar flexor testing was completed prior to gym sessions five days prior to a game day. All participants completed a standardised warm-up which targeted the lower-limb and included standing body weight calf raises. Standing isometric plantar flexion was test first prior to testing seated isometric plantar flexion. The individual rested for a minimum of 3 minutes between completing standing isometric plantar flexion and seated. All isometric plantar flexor testing was completed over a five week time frame.

Pogo jump test and CMJ test was completed prior to gym session, two days prior to game day. All participants completed a standardised warm-up which targeted the lower-limb. Pogo jump testing was completed over a two week time frame, whilst CMJ testing was completed over a four week time frame.

Speed testing was completed during one session, located on an outdoor artificial field. Testing was performed four days prior to a game day. All participants completed a standardised warm-up which was facilitated by the teams trainer.

3.2.2.1 Isometric Plantar Flexion

The AMTI Force Plates with ForceDecks Software (Newstead, Queensland, Australia) were used to measure the maximal isometric calf strength during the unilateral standing calf raise test. Prior to each test, the force plates were “zeroed” and participant body weight was measured. J hooks, located directly above the participants' shoulders, were used to secure a barbell into an immovable position while they were partially plantar-flexed with their knee and hip completely extended (180 degrees at the knee and hip). Individuals held a barbell across their upper back (similar to a back squat barbell position) while applying pressure to the J hook to administer the test. They were advised to push as hard and as quickly as they could for five seconds after being given a '3, 2, 1' countdown. A small four cm block was placed under the heel of the athlete. If the heel was lowered and made contact with the block, the test was ruled invalid, and a retrial was conducted.

Additionally, a unilateral seated calf raise was also performed. The height of the box on which the athletes were seated was adjustable with their hip and knees at 90 degrees, a 4cm block was placed under their heel. . A strap that was fastened to the squat rack was tightened just above the athlete's distal end of the femur. Using the same countdown technique employed for the standing plantar flexion task, the participant was told to push as forcefully and quickly as they could for five seconds, replicating the standing version of the test. Participants performed each version of the plantar flexion twice on each leg. The average of the two tests was used for further analysis. Between each test, there was a passive rest period of two minutes.

3.2.2.3 Pogo Jump

Participants performed one trial. Pogo Jump performance was assessed through the use of force plate technology (Pasco, Auckland, New Zealand). Prior to each test, the force plates were “zeroed” and body weight was recorded. Individuals performed 10 repeated pogo jumps, with hands located on their hips. Participants were cued to hop as high as they can, minimising their time spent on the ground. Simulating skip rope exercises was used as a que. The average of the five best jumps were used for further analysis.

3.2.2.4 Countermovement Jump

Participants performed a minimum of two trials of countermovement jumps. Participants were instructed to stand on the force plates and jump as high as possible while keeping their arms akimbo. Participants dropped to their preferred depth prior to the concentric phase of the jump. Countermovement jump performance was measured using force plater technology (Pasco, Auckland, New Zealand). Prior to each test, the force plates were “zeroed” and body weight was recorded. Participants held their hands on their hips. The best performance of the jumps were used for further analysis.

3.2.2.5 Sprint Performance

Participants each performed two 30-m sprint trials. Single beam timing lights (Fusion Sport, Colorado, USA) were located at 0, 10, 20, and 30 metre intervals. To avoid false triggers caused by participants' arms and legs moving and breaking the beams, the timing lights were set to a height of 100 cm, matching the relative centre of mass height of the participants. The 'Mysprint' mobile app was utilised to measure force-velocity profiles. The mobile device was set up following the protocol utilised in Romero-Franco, et al., (2016) research. Participants started each trial in a split stance with the toes of front foot on a line 30 cm behind the first timing light. They were told to start the sprint at their own discretion and continue sprinting through the last timing light. Two minutes of passive rest were provided between each sprint trial. The average of the two sprints were used for further analysis.

3.3 Data Analysis

The force plate variables obtained for the plantar flexion tasks were peak force, peak vertical force, and vertical impulse at 100, 150, and 200 ms. Peak force was considered the highest force recorded during the trial and has been considered highly reliable (CV= 3.5%) (Cormack, et al., 2008). Peak vertical force was considered the maximum total force produced during the trial, and has been found to be reliable (ICC= 0.94) (Cordova & Armstrong, 1996). Impulse was calculated as the total force produced over the 100, 150, and 200 ms timeframes and has been found to be a reliable statistic (ICC= 0.76, 0.83, 0.87 respectively) (Merrigan, et al., 2020).

Force plate variables obtained for the countermovement jump and pogo jump tests included jump height, peak power, flight time to contraction time ratio, concentric peak force, contact time and reactive strength index. Jump height was quantified via the force applied to the plates using impulse momentum method and has been observed to be a reliable variable (ICC= 0.87) (Merrigan, et al., 2020). Peak power was considered the highest power generated during the concentric phase of the jump, where power was calculated as force times centre of mass velocity and has been reported to be reliable (ICC=0.98) (Merrigan, et al., 2020). Jump flight time and contraction time were used to derive the flight time to contraction time ratio, whereby flight time was measured as the time the athlete spent during the aerial phase of the jump and the contraction time was measured as the time from the start of the 'unweighted phase' to the take-off phase of the jump (McMahon, et al., 2018). Concentric peak force was measured as the highest force generated during the concentric phase of the jump, with previous reports of intraclass correlation coefficients of 0.98 (Merrigan, et al., 2020). Contact time was measured as the time the athlete spent in contact with the force plate from toe-on to toe-off, with ICCs observed to be 0.83 (Feldmann, 2011). Reactive strength index was derived as the ratio of flight time and contact time and has previously been reported as highly reliable with ICCs of 0.99 (Flanagan, et al., 2008).

Force-velocity metrics obtained for sprint performance included F0, V0, Pmax, Max speed and distance splits. F0, V0, Pmax and max speed was quantified through the use of 'Mysprintapp'. F0 is the horizontal force output which directly influences individuals acceleration and has been shown to be highly reliable with an ICCs of 0.99 (Romero-Franco, et al., 2016). V0 is the maximal velocity recorded, and has shown to be highly relibable with an ICCs of 0.99 (Romero-Franco, et al., 2016). Pmax was the maximal power output of the individual in a horizontal direction, and has been shown to be highly reliable with a ICCs of 0.99 (Romero-Franco, et al., 2016). Max speed was the maximal speed reached in meters per second, and has shown to be highly reliable with an ICCs of 0.99 (Romero-Franco, et al., 2016). Distance split was the time taken for an individual to break the timing lights beam from the starting gate (measured in seconds), and has shown to be reliable with an ICCs of 0.89 (Altmanm, et al., 2018).

3.4 Statistical Analysis

Data from this study were reported as means ± standard deviations and analysed using JASP (University of Amsterdam, Amsterdam, Netherlands) with the alpha level set at $p<0.05$. A Shapiro-Wilk's test was conducted to check for normality of the performance variables. Homogeneity of variance was assessed using Leven's test. Pearson Product-Moment correlation coefficients was used to determine the strength of association between variables. Correlation coefficients will be considered as trivial ($r=< 0.001$), small ($r= 0.1 – 0.2$), moderate ($r= 0.3 – 0.4$), strong ($r= 0.5- 0.6$), very strong ($r= 0.7 – 0.8$) and nearly perfect ($r= 0.9$) and perfect ($r= 1.0$).
The criteria for statistical significance of these relationships were $P\leq0.05$.

3.5 Results

3.5.1 Seated vs Standing Plantarflexion

The relationship between seated and standing isometric plantar flexor strength are presented in table 1. The correlation analysis identified significant relationships between seated plantar flexor peak force on both the left (n=7) ($P=<0.05$, $r= 0.599, 0.496, 0.400, 0.453, 0.381, 0.493, 0.415$, respectively) and right (n=10) ($P= <0.05$, $r= 0.704, 0.690, 0.513, 0.553, 0.521, 0.561, 0.519, 0.554, 0.399, 0.381$ respectively) and standing plantar flexor variables. The only metrics not significantly correlated to seated isometric plantar flexor peak force were impulse at 100ms on the left leg, and peak vertical force on both legs. Both these metrics only lacked correlation with seated isometric plantar flexor peak force on the left.

3.5.2 Countermovement Jump

The relationships for standing and seated isometric plantar flexion strength and countermovement jump performance are presented in table 2. Regarding standing plantar flexor isometric strength, absolute peak vertical force on the left and right leg were found to significantly correlate with countermovement jump height ($p < 0.03$; $r = 0.570-0.551$) and peak vertical force on the left leg was observed to significantly correlate with countermovement jump peak power relative to body weight. For seated isometric plantar flexion, peak vertical force on the left leg showed a significant correlation with countermovement jump flight time and contraction time ratio ($p \leq 0.05$, $r=0.514$).

3.5.3 Pogo Jump

The relationships for standing and seated isometric plantar flexion strength and pogo jump performance are presented in table 3 No significant relationships were identified between standing or seated isometric plantar flexion variables and pogo jump performance variables.

3.5.4 Sprint

The relationships for standing and seated isometric plantar flexion strength and linear sprinting performance variables are presented in table 4. No significant relationships were identified between standing or seated isometric plantar flexion variables and linear sprint performance variables.

Table 1. Relationship between seated and standing isometric plantar flexor

Seated Plantar Flexion		Standing Plantar Flexion									
		Peak Force		Impulse 100		Impulse 150		Impulse 200		Peak Vertical Force	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Peak Force	**Left**	0.599***	0.496**	0.400*	0.336	0.453*	0.381*	0.493**	0.415*	0.297	0.192
	Right	0.704***	0.690***	0.513**	0.553**	0.521**	0.561**	0.519**	0.554**	0.399*	0.381*
Impulse 100	**Left**	-0.009	0.016	0.116	0.027	-0.050	-0.105	-0.140	-0.166	-0.176	-0.137
	Right	0.085	0.093	0.134	0.084	0.032	-0.012	-0.017	-0.033	-0.196	-0.174
Impulse 150	**Left**	0.003	0.029	0.133	0.047	-0.031	-0.085	-0.121	-0.148	-0.181	-0.141
	Right	0.101	0.113	0.15	0.105	0.052	0.009	0.004	-0.011	-0.203	-0.178
Impulse 200	**Left**	0.024	0.045	0.159	0.071	9.548×10^{-4}	-0.057	-0.089	-0.123	-0.177	-0.143
	Right	0.129	0.145	0.178	0.139	0.084	0.044	0.038	0.024	-0.203	-0.175
Peak Vertical Force	**Left**	0.181	0.073	-0.168	-0.125	-0.024	0.005	0.063	0.069	0.421*	0.307
	Right	0.501**	0.477*	0.163	0.289	0.239	0.364	0.270	0.376	0.600***	0.568**

* p < .05, ** p < .01, *** p < .001

Table 2. Relationship between CMJ and seated and standing isometric plantar flexor

Variable	Standing Plantar Flexion										Seated Plantar Flexion									
	Peak Force		Impulse 100		Impulse 150		Impulse 200		Peak Vertical Force		Peak Force		Impulse 200		Impulse 100		Impulse 150		Peak Vertical Force	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Jump Height	0.411	0.393	0.007	0.136	0.196	0.132	0.263	0.182	0.57*	0.551*	-0.02	-0.059	-0.263	0.047	-0.261	0.052	-0.262	0.049	0.242	0.107
Peak Power	0.468	0.452	0.073	0.207	0.213	0.149	0.256	0.177	0.501*	0.483	-0.035	0.107	-0.202	0.079	-0.19	0.099	-0.184	0.117	0.050	0.160
Flight time/ Contraction time Ratio	0.347	0.226	0.283	0.183	0.270	0.166	0.248	0.155	0.267	0.183	0.473	-0.155	-0.007	-0.281	-0.028	-0.351	-0.029	-0.422	0.514*	-0.209
Concentric Peak Force	-0.194	-0.206	0.108	-0.009	-0.100	0.002	-0.181	-0.044	-0.316	-0.333	0.127	0.154	0.341	-0.270	0.334	-0.283	0.329	-0.288	-0.073	0.046

Table 3. Relationship between Pogo jump and seated and standing isometric plantar flexor

Variable	Standing Plantar Flexion										Seated Plantar Flexion									
	Peak Force		Impulse 100		Impulse 150		Impulse 200		Peak Vertical Force		Peak Force		Impulse 200		Impulse 100		Impulse 150		Peak Vertical Force	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Contact Time	0.146	0.247	0.222	0.362	0.188	0.294	0.165	0.235	0.222	0.343	-0.267	0.001	0.464	0.231	0.458	0.212	0.450	0.190	-0.195	0.064
Reactive Strength Index	0.044	0.204	-0.339	-0.217	-0.273	-0.167	-0.187	-0.107	0.235	0.409	-0.139	-0.101	0.028	0.065	0.022	0.055	0.006	0.036	0.103	0.09

Table 4. Relationship between Sprint and seated and standing isometric plantar flexor

Variable	Standing Plantar Flexion										Seated Plantar Flexion									
	Peak Force		Impulse 100		Impulse 150		Impulse 200		Peak Vertical Force		Peak Force		Impulse 200		Impulse 100		Impulse 150		Peak Vertical Force	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
F0	-0.064	-0.134	0.029	-0.070	-0.004	-0.102	-0.002	-0.108	-0.171	-0.262	-0.262	-0.025	-0.207	0.087	-0.206	0.107	-0.208	0.133	-0.414	-0.147
V0	0.048	-0.013	-0.026	-0.046	-0.029	-0.037	-0.073	-0.036	0.347	0.289	-0.293	-0.197	0.383	0.156	0.366	0.116	0.343	0.066	0.152	0.107
Pmax	-0.067	-0.163	0.028	-0.092	-0.015	-0.129	-0.028	-0.140	-0.106	-0.224	-0.383	-0.09	-0.105	0.143	-0.109	0.153	-0.117	0.166	0.108	0.605
Max Speed	0.046	-0.039	0.033	-0.018	0.001	-0.039	-0.058	-0.053	0.319	0.232	-0.372	-0.214	0.418	0.205	0.402	0.164	0.381	0.114	0.922	0.843
10m	-0.281	-0.205	-0.252	-0.049	-0.251	-0.066	-0.229	-0.106	-0.297	-0.196	0.395	-0.111	-0.298	-0.467	-0.345	-0.507	-0.393	-0.556	0.254	0.782
20m	0.027	0.151	0.125	0.141	0.174	0.161	0.23	0.185	-0.197	-0.058	0.365	0.360	-0.276	0.05	-0.25	0.099	-0.217	0.155	0.891	0.577
30m	-0.081	0.003	0.055	0.069	0.044	0.159	0.055	0.177	-0.158	-0.069	0.274	0.290	0.196	-0.183	-0.194	-0.162	-0.188	-0.131	0.555	0.342

3.6 Discussion

The aim of this study was to explore the relationship between isometric plantar flexor strength and ballistic performance in provincial level male rugby union athletes. This is the first study to examine the association between isometric lower-leg strength and different SSC movements. The primary findings of this research were that relative seated and standing plantar flexor variables were significantly correlated and that isometric plantar flexion strength metrics were only significantly related to some of the slow SSC movement variables. These findings may have practical importance for strength and conditioning coaches and sports scientists as it highlights that seated and standing plantar flexor isometric strength are highly related, yet the current isometric calf strength testing protocol was not a viable test for determining ballistic performance.

3.6.1 Seated vs Standing

This study found that seated peak vertical force was significantly correlated with all but one standing metric. This result suggest that seated peak force may be a good indicator of standing isometric calf strength. This may be due to the bi-articulate nature of the gastrocnemius, and its level of activation being determined based on the angle of the knee, whilst the soleus being a monoarticulate muscle is able to function irrespective of the knee angle (Suzuki, et al., 2014). Since the gastrocnemius acts to both flex the knee and the foot (Herbert-Losier et al., 2012; Signorile et al., 2002), the isolated task of plantar flexion during a static state may not be the ideal test to measure the gastrocnemius function. Therefore, the seated plantar flexion task may be a better test for this type of contraction.

3.6.2 Countermovement Jump

The CMJ provides an effective method to quantify lower body power and ballistic performance (Klavora, 2000). CMJ performance was found to be the only ballistic test that resulted in a significant correlation with either seated or standing isometric plantar flexion strength. During the standing plantar flexor task, peak vertical force on the left and right legs were significantly related to CMJ height ($r = 0.55-0.57$; $p<0.03$) and peak vertical force on the left leg was associated with CMJ peak power relative to body weight. Meanwhile, for the seated plantar flexor task, the vertical force on the left leg was found to significantly correlate with CMJ flight time and contact time ratio. The distinctive associations between standing and seated plantar flexor isometric strength and CMJ performance can be expected due to the anatomical and functional nature of the different lower-leg muscles. Since the proximal origin of the gastrocnemius is above the knee and the proximal origin of the soleus is below the knee, this means that each muscle group is functionally unique. For example, the soleus achieves the greatest activation during the mid-stance phase of running and jumping, where knee flexion is greatest, whereas gastrocnemius activity is highest during the pre-impact, late-stance and toe-off phases because the muscles act to initially stabilise the knee and then subsequently slow down the velocity of knee extension to help transfer impulse from the knee joint to the ankle joint (Neubert et al., 1998; Reber, et al., 1993). Given the importance of take-off velocity for CMJ height (Zhou, et al., 2020), the extension-flexion coupling of the knee transferring to the ankle helps explain why standing isometric plantar flexion strength was observed to correlate with jump height. The current association between standing isometric plantar flexion strength and CMJ jump height are like the findings of Koznic and Sarabon (2022) and Warneke et al., (2022) who observed low to moderate correlations between isometric seated ankle plantar flexion and CMJ performance in young male soccer players and elite youth basketball players respectively**.** Poignantly, the correlations between seated isometric plantar flexion strength and CMJ height agree with the work by Warneke et al. work (2022), who observed that seated isometric plantarflexion strength does influence CMJ height. These findings may be partially explained by the relationship that ankle peak power has with CMJ performance. McErlain-Naylor et al., (2014) found that take-off shoulder angle and peak knee power are responsible for up to 74% of the performance variation observed in CMJ performance. The authors suggest that ankle peak power likely contributes the additional 26% of CMJ performance if the arms are kept akimbo. However, it is unclear what tissues are contributing the most to create peak ankle power during the CMJ.

The CMJ is categorised as a slow SSC movement due to the ground contact time being greater than 0.250 seconds (Turner & Jefferies, 2010). Loading times during slow SSC movements enable contractile tissues to reach a near-maximally active states (Turner & Jefferies, 2010), potentially further explaining why a significant correlation was observed between standing plantar flexion isometric strength and CMJ height. Furthermore, during the downward portion of the CMJ, the angular velocity of the ankle joint (0°) (Bobbert, et al., 1996) is less than the angular velocity at which the stretch reflex is evoked during passive ankle dorsiflexion (69°), suggesting that the stretch reflex in the plantar flexors may not be optimal during a CMJ (Van Hooren & Zolotarjova, et al, 2017). This may also help elucidate why seated isometric Impulse$_{200}$ was found to significantly correlate with the CT/FT ratio. This intuitively makes sense since the point at which the braking and propulsive phases of the CMJ coupling align with maximal knee flexion (McMahon, et al., 2018; McErlain-Naylor, et al., 2014). Ultimately, this means that athletes who can express greater average isometric plantar flexion force over the first 200ms are able to achieve relatively shorter times during the onset of CMJ movement and take-off compared to FT.

3.6.3 Pogo Jump

Unlike the CMJ, no significant relationships were observed between isometric plantar flexion strength and pogo jump performance. This may be due to the differences in the neuromuscular demands between the types of jumps. For example, while the CMJ is characterised by a slow SSC, the pogo jump is a fast SSC, whereby ground contact times are less than 250ms (Turner & Jefferies, 2010). The lack of significant relationships between isometric plantar flexor strength and pogo jump performance were unexpected given that the triceps surea has been reported to act quasi-isometrically, thereby allowing the Achilles tendon to store and release elastic energy during fast SSC actions (Turner & Jefferys, 2010; Challis, 2000, Nuebert, et al., 1998). As rugby is a field-based sport, athletes are adept to performing physical tasks on grass. Grass has relatively high compliance compared to the metal force plates used in this study (Wright & Illius, 1995). Variance in lower limb plantar pressure has been observed when comparing running on natural grass and concrete (Wang, et al., 2012). Greater contact time and lower maximal plantar pressure has been observed when running on natural grass compared to running on concrete (Wang, et al., 2012). Moreover, gastrocnemius activation has been reported to be higher while running on asphalt when compared to running on grass (Dolenec, et al., 2015). Therefore, it is possible that the chronic adaptations to training on grass result in unique adaptations to the musculotendinous tissues, altering the relationship between isometric plantar flexor strength and fast SSC performance. However, research is required to understand whether athletes who are habituated to surfaces with different compliance see distinct relationships between isometric plantar flexor strength and vertical fast SSC jumping capabilities.

3.6.4 Sprinting

Linear sprinting ability has been identified as a key performance indicator distinguishing elite professional rugby players from sub-elite professional players (Marshall, 2022). Therefore, it was of interest to understand whether isometric plantar flexion strength was related to this physical performance characteristic. No significant correlations were found between sprint performance and any isometric plantar flexion strength variable. This was surprising since research has found that the ankle contributes a relatively large amount of energy during sprinting (Novacheck, 1998) and ankle stiffness has been found to significantly relate to sprinting performance (Stefanyshyn & Nigg, 1998)). Given that stiffness is a measure of elastic energy utilisation from the SSC, intramuscular and intermuscular components, such as the titin molecule and tendon, respectively, contribute to this measure (Serpell, et al., 2012). Some authors have proposed that muscle stiffness may be a greater contributor to sprint performance than tendon stiffness (Takahasi et al., (2018); Kubo et al., 2011), leading to the idea that isometric strength of the contractile tissues are important for allowing energy to be transported via the stretching and shortening of the tendon during sprinting. However, Takahashi et al., (2018) found a correlation between plantar flexor stiffness and sprint performance (P=0.018), however they posit that many other factors contribute to sprint performance. One such factor is ankle range of motion. For example, this study measured plantar flexor force at 10^{o} of flexion, though ankle flexion during the mid-stance phase of sprinting, where the maximal ground reaction forces are experienced, has been reported to be slightly dorsiflexed, however this varies dependent on speed (Novacheck, 1998; De Wit, et al., 2000). Given the length-tension properties of contractile tissues (Challis, 2000), measuring plantar flexor strength at different angles may elucidate different degrees of association with sprinting performance.

3.7 Limitations

Readers should be cognisant that these findings are limited to provincial rugby union male athletes and that these findings are somewhat underpowered due to the relatively small sample size. Due to the limitations of squad numbers during the competitive season, the number of participants were limited. Having greater participant numbers may have resulted in greater accuracy and further findings. The second limiting factor was the timing of the study. Since the research took place during competition season, there was potential for the presence of fatigue during testing. Another limitation faced was the use of a singular plantar flexor angle, influencing the length of the musculotendinous unit. During running, foot contact occurs in a more neutral/dorsiflexed position, and transitions to a more plantarflexed positioning further into the stride (Rodgers, 1988). Testing the isometric plantar flexors in a more neutral position may be a more accurate representation of the lower limb during running and jumping. A final limitation faced was that this investigation only sampled rugby union athletes. Sampling only rugby union athletes resulted in findings that may only be applicable to athletes that train in a similar manner. Including individuals from a various athletic background may give a better insight into how isometric plantar flexor strength relates to ballistic performance.

3.8 Conclusion and Practical Application

Seated plantar flexion peak force appears to associate highly with nearly all standing plantar flexion metrics. Therefore, this metric may be used in place of the standing test to minimise the burden on the athletes and training staff. Isometric plantar flexor strength may provide insights into overt slow SSC capabilities (i.e., jump height). Fast SSC exercises, such as sprinting and pogo jumps, had no significant correlation with isometric plantar flexor strength. Therefore, it is determined that isometric plantar flexor strength and fast SSC are independent qualities in male professional and semi-professional rugby union athletes, and practitioners should measure both athletic qualities separately. The ankle angle used in this dissertation may not be beneficial for understanding ballistic performance due to the variance of ankle angle in different ballistic exercises. Changes in ankle angle may provide greater insight into how isometric plantar flexor strength correlates with specific ballistic exercises. Further research is needed to understand if and how the demographic of the sample population influenced these findings. Although these findings suggest there may be limited relationship between isometric plantar flexor strength and ballistic performance, the relationship between standing isometric plantar flexor strength and CMJ performance may suggest that the use of the CMJ test may be used in place of the standing isometric test.

Chapter 4: Summary, Practical Applications, Limitations and Future Research

4.0 Summary

This dissertation aimed to provide insights into the relationship between isometric plantarflexion strength and ballistic movements in provincial level rugby union athletes. Until now, few studies have explored this association in athletes or using varying SSC movements. Existing evidence suggests that the unique functioning of the lower-leg muscles contributes to ballistic actions utilising the SSC (Turner & Jefferys, 2010; Ishikawa, et al., 2003). Due to the role isometric contractions play during the SSC, quantifying maximal strength in this muscle group may allow insight into an individual's ability to perform exercises which incorporate the SSC. The findings of this dissertation highlight the roll and application of isometric plantar flexor testing in specific high-performance environments.

A large proportion of previous research into isometric performance has been limited to multi-joint isometric tests that did not evaluate how isometric performance related to ballistic movements, more so in a rugby union population. A narrative review was completed to analyse current research in the area of isometric contractions, the SSC and the role of the musculotendinous unit during ballistic exercises. To our knowledge, there is limited research into isometric plantar flexion strength and ballistic performance in rugby union athletes, and as a result, adjacent research was collated. The review focuses on key themes, the SSC and its role in athletic performance as well as the underlying mechanics, the lower limb musculotendinous unit and its function, and finally, the relationship between lower limb isometric strength and ballistic performance. The review concluded that the SSC is a key function, and the role the musculotendinous unit plays is significant, as well as there being a relationship between lower limb isometric strength and ballistic performance.

In an attempt to expand on the available literature exploring the relationship of lower-leg functioning with SSC activities, Chapter 3 aimed to investigate this association with a group of competitive athletes. This cross-sectional study elucidated novel findings which suggest that lower-leg maximal strength and SSC performance are mostly unique qualities. The limited number of significant relationships observed was somewhat unexpected given the functional role of the musculotendinous tissues during running and jumping (Bobbert, et al., 1986; Challis, 2000). However, these findings provide a unique understanding of what tests can be included in the testing battery of provincial male rugby players during their competitive season.

4.1 Limitations

It is important to consider the limitations of this study when interpreting the results of this dissertation.

1) Due the specificity of the population selected, the use of a single competition squad of athletes resulted in a relatively small sample size, which may underpower these findings. The inclusion of only professional and semi-professional rugby players means these findings can only be considered for this population.
2) Since testing was completed during the competitive phase of the season, the participants may have experienced the potential presence of fatigue, which can influence the testing results for specific individuals dependent on factors such as playing load and individual recovery strategies.
3) Due to time constraints, isometric plantar flexor testing strength was only assessed at a single joint angle for both seated and standing protocols. The joint angle assessed was greater than those typically observed during SSC actions. Given the length-tension relationship of muscles, this could have influenced the force output, and therefore correlation statistics with the ballistic movements used in this dissertation.

4.2 Practical Application

It has been reported that the musculotendinous functioning of the lower-leg is critical for performance during SSC actions, with neuromuscular capabilities of the plantar flexor muscle group relating to ballistic movements. The findings of this dissertation somewhat contradict previous literature. These findings have practical implications for strength and conditioning coaches or sports scientists. The following points present the applicability of these finding for practitioners.

1) The seated and standing isometric plantar flexor tests are significantly correlated, suggesting the use of only the seated isometric plantar flexor test may be suitable to lighten practitioners load.
2) The use of the Isometric plantar flexor test may be useful to predict CMJ performance, however, is not effective in predicting fast SSC movements such as sprinting and pogo jumps, suggesting that contraction type (Isometric) and velocity and separate qualities. Testing battery should incorporate some form of fast SSC test along with isometric plantar flexor tests to develop a broader understanding of the individual in question.
3) Measuring isometric plantar flexor strength at the angle used in this investigation is not beneficial for predicting ballistic performance. Utilising various joint angles will give the practitioner better insight into how the lower limb may respond during various ballistic exercises.

4.3 Future Research

This dissertation aimed to investigate the relationship between isometric plantar flexor strength in rugby union athletes and ballistic performance, to provide greater insight into the role isometric contractions play during ballistic exercises as well as highlighting the importance of isometric strength. Considering the findings and limitations of this study, for a greater understanding, future research is needed. Beneficial areas of research may be:

1) Due to the different ballistic exercises having different mechanics, resulting in various movement patterns, an investigation into the relationship between isometric planter flexor strength at various ankle angels may provide further understanding into how the plantar flexor muscles respond during various exercise.
2) Investigating a wider variety of athletes with differing athletic backgrounds may provide insight into how the specific physical traits and adaptions of different athletic populations influence isometric plantar flexor strength.

4.4 Conclusion

This dissertation adds more insight into the relationship isometric plantar flexor strength has with ballistic performance in professional and semi-professional rugby union athletes. Current isometric plantar flexor test may not be effective in predicting ballistic performance in professional and semi-professional rugby union athletes. However, the data in this study showed that although the isometric contraction which occurs in the planter flexing muscle has been identified as crucial during the SSC.

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Appendices

Appendix 1:

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Consent Form

For use when laboratory or field testing is involved.

Project title:

An exploration into the association between maximal isometric calf strength and sprinting and jumping performance in male rugby union athletes.

Project Supervisors: *Dr Aaron Uthoff*

Researcher: *Jack Kovacs*

By signing this form, you agree to the following statements:

○ I have read and understood the information provided about this research project in the Information Sheet dated 1st September2022.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw myself or any information I have provided for this project at any time without being disadvantaged in any way.

○ I am not suffering from any current injury, illness, or disorder that may impair my ability to perform the required tasks nor am I outside the limits of the required age range of 18 to 35 years.

○ I agree to answer questions and provide physical effort to the best of my ability throughout testing.

○ I agree to take part in this research.

○ I consent to the indefinite storage of my de-identified data for re-analysis, should future similar uses arise (please tick one): Yes○ No○

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

○ I wish to have my performance information accessible to my coach (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

14 September 2022 page 1 of 1 This version was last edited in January 2020

Appendix 2:

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Participant Sheet

Date Information Sheet Produced:

28th of July 2022

Project Title

An exploration into the association between maximal isometric calf strength and sprinting and jumping performance in male rugby union athletes.

An Invitation

Kia Ora, my name is Jack Kovacs, and I am a master's student at the Auckland University of technology. You have received this information sheet as part of an invitation to participate in my master's research. My research aims to look at the relationship between Isometric calf strength and sprinting and jumping performance.

Your participation in this research will be indicated by your completion of the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

What is the purpose of this research?

The purpose of this study is to develop a better understanding of the relationship between isometric calf strength and the fast stretch shortening cycle, measured through sprint, and jumping performance. The aim of this study is to collect isometric strength, sprint, and jumping data from individuals and identify if there is a correlation between their isometric calf strength and sprint and jump performance.

Collecting and analysing this data will give strength and conditioning coaches a better idea of the influence isometric calf strength has on these skills, and the value they may add if integrated into their program, with the overall goal of increased athletic performance.

The findings of this research may be published in accredited academic publication and presentations.

How was I identified and why am I being invited to participate in this research?

You were identified for this project because you are (1) a male between the ages of 18 and 35 years, (2) are free from disorder, or acute/chronic injury at the time of testing occasion (>3 months injury free, and (3) are a member of the Wellington Rugby Unions National Provincial Competition team.

How do I agree to participate in this research?

If you are interested in participating in this study, you are required to contact primary researcher Jack Kovacs via email or phone. You will then be required to complete a consent form, indicating you are informed of the study and are happy to have your tests results used in the study. Tests will then be completed in line with the Wellington Rugby Unions training schedule.

Participation and consent is completely voluntary, and you will have freedom to withdraw from the study at any time.

What will happen in this research?

Once you have decided to participate in the study you will participate in four testing's, completed over three sessions, totalling 40 minutes. Testing times and date will be aligned to ensure they are not affecting or affected by your training schedule.

The study procedures are as follows:

Participants will complete four tests. One maximal isometric single leg standing calf raise (two reps each leg), one maximal isometric single leg seated calf raise (two reps each leg), one drop jump test (three reps), and a 30m sprint test (three reps). Prior to all tests participants will complete a 10min warm-up instructed by the primary researcher. In-between all tests a suitable rest period will be allowed to ensure a high level of performance for each test.

The data collected will only be used for the purpose of this research.

Testing will take place at the Wellington Rugby Union training facility.

What are the discomforts and risks?

There is little to no discomfort as a result of these test. Each tests requires no more effort than what would normall be exerted during a gym or rugby training. Potential discomforts are low level musslce soreness post testing.

How will these discomforts and risks be alleviated?

As a high-level athlete who regularly trains, the tests are designed to be similar to tasks which will be completed in a standard rugby session. If a high level of discomfort is experienced during the testing process, it is required that you inform the researcher as soon as possible. The primary research aims to ensure participants are as comfortable as possible through-out the research process.

If you have any questions regarding and risk or comfort that you anticipate, please feel free to address these concerns to the researcher so that you feel comfortable at all times throughout the process.

What are the benefits?

Each participant will receive a detailed performance assesment regarding their physical qualities tested. These individual results will allow the participant an indepth look at their qualities tested, and can contribute to the development of their own training program if weakness is identified.

Participants will also be taking part in research may influence their future performance, with the aim of understanding the influence of isometric calf strength, and the value of isometric training in high-performance environment. These findings may have significant influence on exercise prescription.

The results of this research are intended for publication and will contribute to part of my masters dissertation and will also be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Testing will occur in groups so participation privacy during testing will be limited, however, no results or data will be shared with individuals during the testing times to ensure individuals results are kept confidential. No names or images will be used in reporting (unless the participant gives explicit additional written consent for media purposes following AUT protocols and organised via the AUT university relations team). During the project, only the applicant and named investigators will have access to the data collected. The results of the study may be used for further analysis and submission to peer-reviewed journals or submitted at conferences.

To maintain confidentiality, in all publications resulting from this research participants' data will be averaged and represented as group means.

All data will be stored on password protected computers or in locked files. Following completion of data analysis your data will be stored by the AUT University SPRINZ research officer in the AUT University SPRINZ secure Ethics and Data facility at AUT Millennium campus. Given the progressive nature of research in this field, data will be kept indefinitely for the purposes of reanalysis (should future analysis methods arise) for purposes similar to that collected; however (as per above) all forms of data will be de-identified and kept secure for the entirety of the data's storage lifetime.

What are the costs of participating in this research?

Other than your time and effort, there will be no financial cost for you being involved with this study.

What opportunity do I have to consider this invitation?

Potential participants will be given two weeks to consider and respond to the initiation. consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, upon completion each participant will receive their performance profile. It is up to the individual whether they share this information with your coach or other people.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Jack Kovacs, jkskovacs@gmail.com, 0211787888.

Concerns regarding the conduct of the research should be notified to the AUT ethics comity, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Jack Kovacs, jkskovacs@gmail.com**,** 0211787888.

Project Supervisor Contact Details:

Dr. Aaron Uthoff, aaron.uthoff@aut.ac.nz, 027 231 9585.

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*,
AUTEC Reference number *type the reference number*.

Appendix 3:

Auckland University of Technology Research Proposal

An exploration into the association between maximal isometric calf strength and sprinting and jumping performance in male rugby union athletes.

What is the research?

The purpose of this study is to develop a better understanding of how isometric training may influence the fast stretch shortening cycle. The aim of this study is to investigate the relationship between isometric calf strength and sprinting and jumping performance.

What is required?

The potential participants will take place in four key test, an isometric max calf raise (seated and standing), a drop jump test, and a 30m speed test. Testing will be completed in approximately 40 mins.

Benefits of participation?

By participating in this study you are contributing to research which may help influence and shape the way individuals train to perform. Individuals will also be given the opportunity to analyse their performance in a variety of test not often used.

Participation Criteria?

Potential Participants must be:
- Male rugby players who are a part of a NPC squad in 2022.
- Between the age of 18-35
- Lower body injury free over the last 3 months
- No histroy of Achilles tendon injury

If you're interested please contact Jack!

Contact Information
Jack Kovacs
Phone- 0211787888
Email- jkskovacs@gmail.com

Appendix 4:

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

15 September 2022

Aaron Uthoff
Faculty of Health and Environmental Sciences

Dear Aaron

Re Ethics Application: **22/216 An exploration into the association between maximal isometric calf strength and sprinting and jumping performance in male rugby union athletes.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 15 September 2025.

Non-Standard Conditions of Approval

1. Assurance that athletes will not directly be sent an Information Sheet until they have given the researcher their contact details (as C.3.5.3 differs between the rebuttal and the revised EA1);
2. Proofread of poster "four key test" should be 'four key tests";
3. Revision of the concerns section to be the student's supervisor who is the contact, not the student researcher

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: jkskovacs@gmail.com