The stability reliability, and utilisation of the isometric belt when measuring changes in strength across a professional Rugby Union competition.

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Abstract

Many athletes target an increase in strength in order to improve sporting performance. Specific to Rugby Union, an increase in strength has shown to distinguish between levels of competition, and as such, measuring strength is required for the implementation and monitoring of effective training programs. Traditionally, one-repetition maximum (1-RM) testing has been implemented as it is a direct measure of dynamic strength that is commonly incorporated into training programs. However, 1-RM testing is not very practical in-season and research suggests it is less safe and produces more fatigue than alternate methods of testing. Isometric testing is an alternative to 1-RM testing that has been shown to be reliable and effective at reducing testing time and reducing fatigue, loading, and injury risk. Anecdotally, however, isometric testing such as the isometric mid-thigh pull, and isometric back squat are less feasible in season due to the injuries Rugby Union athletes obtain. An alternative isometric test is an isometric belt squat which is strictly a lower-body method of evaluating strength; however, to date, the reliability and effectiveness of the isometric belt squat is unknown.

This thesis is separated into four chapters. Chapter One is a review of literature that highlights the importance of strength in sport, the changes in strength athletes sustain throughout a season, how reliability can be measured, the traditional methods of strength testing, isometric testing, and the specific methods of isometric testing commonly used in Rugby Union. The literature shows the isometric mid-thigh pull, and isometric squat are reliable methods of measuring strength that have been shown to correlate to 1-RM testing. Previous research comparing the isometric belt squat to an isometric squat show a reduction in lower-back stress and an increase in peak vertical force in the isometric belt squat, suggesting it is a potentially safer and more accurate evaluation of lower-body strength for athletes. However, there is no research into the stability reliability of the isometric belt squat. Furthermore, the literature has shown that while in competition, an increase in skill training results in a decrease in resistance training to balance training load while maintaining concurrent training. Therefore, periodised training programs are required in-season to minimise the negative effects concurrent training has on the maintenance/development of strength. As concurrent training conflicts with an increase in strength within a season and the evaluation of the fluctuations of strength levels helps guide training programs, valid and reliable strength testing is required to inform effective exercise prescription.

Chapter Two investigated the reliability of the isometric belt squat. Both between- and within-session reliability were measured during a five-week investigation with each athlete completing the isometric belt squat four times.

Intraclass correlation coefficients (ICC), coefficient of variation (CV), typical error (TE), smallest worthwhile change (SWC), and p-values were calculated to assess the reliability between-sessions, whereas a CV was used to quantify within-session reliability. The between-session reliability indicated the isometric belt squat was a reliable measure of strength after each athlete had completed one familiarisation period with a range of measures deemed reliable between Trials 2 and 4 (TE= 504.56 N, CV = 8.7%, ICC = 0.86, p-value = 0.021, SWC0.5 = 647.39 N). The within-session data was also considered reliable which was conducted after the familiarisation period (CV = 7.2%). Overall, the between- and within-session data indicated the isometric belt squat test is a reliable measure once each athlete has completed one familiarisation trial.

Chapter Three investigated the change in strength that occurred in professional Rugby Union athletes across a competitive season. This study was conducted over a 15-week block (end of preseason to end of competition) whereby each athlete completed five trials of the isometric belt squat. Effect size (ES), probability statistics, and a percentage of change in strength were used to highlight the change in strength between the five trials. Overall, the change in strength from Trial 1 to 5 was 'trivial' (+0.44%, ES = 0.04, p value = 0.871). The 'trivial' increase in strength across the season indicates the maintenance of strength from the end of preseason to end of competition is feasible despite the interference concurrent training imposes.

Overall, as concluded in Chapter Four, the results from the two studies in this thesis show that the isometric belt squat is a reliable measure of strength both between- and within-sessions once each athlete has completed one familiarisation period, and that strength can be maintained across a professional rugby union season. The limited literature surrounding the isometric belt squats reliability when applied to Rugby Union, and the change in strength across a competitive Rugby Union season is an area that needed to be addressed. This thesis described the literature surrounding isometric testing, identified the stability reliability of a isometric belt squat, and assessed strength changes across a season in professional Rugby Union athletes. This information can be used to enhance strength monitoring in professional team sports such as Rugby Union, Rugby League, Football, and Netball that have access to force plates or strain gauges.

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List of Abbreviations

1-RM – One-repetition maximum

CI – Confidence interval

CV – Coefficient of variation

d = Cohen's d

ES – Effect size

ICC – Intra-class correlation coefficient

IMTP – Isometric mid-thigh pull

kg – Kilograms

N – Newtons

PF – Peak force

r = Pearson correlation

RFD – Rate of force development

SD – Standard deviation

SPSS - Statistical Product and Service Solutions

SWC – Smallest worthwhile change

SWC0.5 – Alternate SWC calculated by multiplying the between-session standard deviation by 0.5

TE – Typical error

y – years

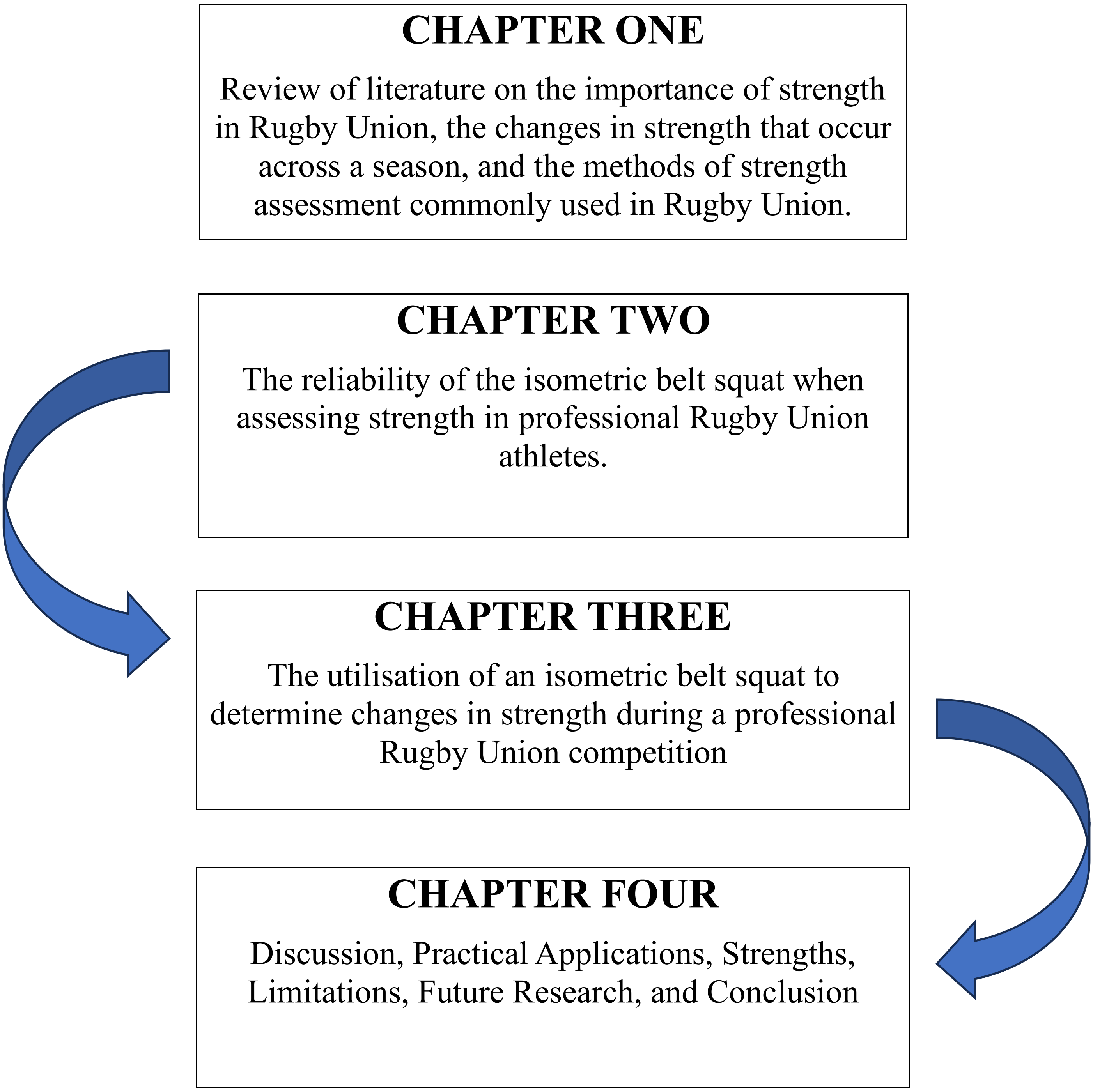


Figure 1: Thesis Outline.

Introduction to thesis

Maximal strength is important in a variety of sports due to the link it has between an improvement in sport specific performances, and decrease in injuries (Suchomel et al., 2016). Therefore, appropriately periodised training programs are used to elicit maximum strength gains and increase sporting performance (Baker & Nance et al., 1999). Rugby Union is an 80-minute-long game whereby athletes are required to be skilful, possess high levels of strength, and be physically conditioned to suit the fast-paced game (Lindsay et al., 2015; Hogarth et al., 2016). Scrummaging, tacking, and mauling are common occurrences during Rugby Union which involve high levels of physical contact; therefore, increased strength levels play a vital role in increasing sporting performance (Coughlan et al., 2011; Smart et al., 2013).

Argus et al. (2012) found that athletes who competed in higher levels of competition typically possessed greater levels of maximum strength and power levels. Greater levels of strength from academy level to professional athletes likely occurred due to the positive effect a greater resistance training age has. Therefore, professional Rugby Union athletes require greater maximum strength levels. However, due to the concurrent nature of Rugby Union, which requires a balance between the mode and quantity of individual training methods, improving strength throughout a competitive season can be difficult (Argus et al., 2012; McMaster et al., 2013). Therefore, "tactical periodisation" is crucial; whereby, training volume and intensity is fluctuated week to week to manage the overall stimulus of training (Crespo, 2011; Robertson et al., 2014). When investigating professional Rugby Union athletes, Gannon et al. (2016) found athletes maintained lower-body strength during competition (+1.3%), whereas Mitchell et al. (2016) found Rugby Sevens athletes decreased lower-body strength (-6.4%) across a competitive season; therefore, the various results found highlight the challenge in increasing strength throughout a competitive Rugby season.

Obtaining maximum strength values has traditionally been achieved via one-repetition maximum testing. A back squat is commonly utilised when measuring lower-body strength and bench press is often utilised when measuring upper-body strength (Argus et al., 2012). Measuring maximum strength allows coaches to appropriately prescribe training intensities and track performance (Comfort & McMahon., 2015). While 1-RM testing is a reliable and valid method of strength assessment, it requires a significant amount of time to complete which may not be practical in large squads of team sport athletes (Banyard et al., 2017). Additionally, this form of testing can be fatiguing due to the requirement of multiple sets of multi-joint resistance training exercises (Izquierdo et al., 2009).

One alternate method of testing is isometric strength testing which uses a force plate or strain gauge to assess the static phase of a dynamic movement; of which the strength qualities peak force (PF), mean force, and/or rate of force development (RFD) can be determined (McMaster et al., 2014). Isometric testing is easier to implement than traditional 1-RM testing due to isometric testing taking less time and requiring fewer coaching cues (Blakely et al., 1994). Additionally, isometric testing potentially reduces fatigue due to the fewer sets required (McMaster et al., 2014). One method of isometric strength testing commonly used in Rugby Union is an isometric mid-thigh pull (IMTP), which provides insight into an athlete's ability to generate full-body force (Wang et al, 2016). The IMTP has shown a high correlation to traditional testing (power-clean, r = 0.97; squat, r = 0.96; bench press, r = 0.73) and has shown high reliability between testing sessions (ICC = 0.97) (Dos'Santos et al., 2017; McGuigan & Winchester, 2006).

Anecdotally, although the IMTP is a valid and reliable measure of isometric strength it is not feasible during a competitive Rugby Union season due to the high number of upper-body injuries or "niggles" these athletes obtain. An alternative to the IMTP is the isometric belt squat, which is strictly a lower-body exercise that may allow more Rugby Union athletes to complete while in competition. Layer et al. (2018) reported the isometric belt squat reduced lower back moments and improved force-generating capacity when compared to an isometric squat. Therefore, with decreased lower-back moments, no upper-body involvement, and improved force-generating capacity, athletes may continue to build and test lower-body strength by performing an isometric belt squat (Layer et al., 2018).

The limited literature surrounding the isometric belt squats reliability when applied to Rugby Union, and the change in strength across a competitive Rugby Union season are both areas that needed to be addressed. This thesis aims to describe the literature surrounding isometric testing, identify the stability reliability of an isometric belt squat via peak force on force plates, and assess the strength changes professional Rugby Union athletes endure across a season.

CHAPTER ONE: Review of literature on the importance of strength in Rugby Union, the changes in strength that occur across a season, and the methods of strength assessment commonly used in Rugby Union.

Literature Review

Importance of strength in sport

Possessing a high level of maximal strength is important for athletes in many sports such as Track and Field, American Football, Rugby League, Wrestling, and Baseball due to the involvement of muscular force needed to shift one's own body mass or move an external force (Suchomel et al., 2016). The development and maintenance of strength in sports is an important factor as it has been linked to increasing sport-specific attributes and decreasing injuries (Suchomel et al., 2016). Furthermore, while the precise levels of strength required for optimal performance are unknown, greater levels of strength have shown to be indicative of increased levels of performance (Argus et al., 2012). Therefore, with the implementation of resistance training, an improvement in strength may contribute to an improvement in sporting performance (Baker & Nance et al., 1999; Suchomel et al., 2016).

Rugby Union is a dynamic contact sport where maximal strength is critical to successful performance (Smart et al., 2013; Duthie, 2006). Rugby Union is an 80-minute-long game compromised of two 40-minute halves, whereby two teams with 15 athletes in each team (eight forwards and seven backs) contest in the physically demanding sport (Nicolas, 1997) where players complete recurrent bursts of high-intensity running and collision based activity (Hogarth et al. 2016). Alongside repeated running ability, Lindsay et al. (2015) reported that all Rugby Union athletes require high amounts of strength, with previous analysis of the positional demands suggesting forwards require greater levels of strength than backs due to the higher amount of body contact and lesser running distances they complete. Indeed, forwards are heavier, complete more tackles, and tackle assists, and engage in more rucks on both offence and defence, when compared to backs. These positional requirements highlight the necessity for high degrees of strength. In contrast, backs are lighter and cover significantly more distance at a high speed than forwards; therefore, endurance, agility, and speed are of greater significance for training and performance (Lindsay et al., 2015). To fill these roles, each position trains specifically to the demands of the game to prepare for repeatable, enhanced performance in matches (Quarrie et al., 2013). Overall, as each position engages in a large number of tackles and physical contact, strength is an essential component in Rugby Union athletes (Coughlan et al., 2011). Moreover, strength forms the basis of power and strength endurance which alongside running ability, are crucial attributes in Rugby Union (Nicolas, 1997). However, as maintaining high levels of strength in-season can be difficult due to the concurrent nature of other modes of training (such as fitness, contact, skills, and speed), an emphasis on strength development in-season is required (McMaster et al., 2013).

Argus et al. (2012) characterised the differences in strength and power levels between different levels of Rugby Union athletes and concluded that greater absolute strength and power outputs were seen in those who competed in higher levels of competition as professional athletes had greater levels of strength in bench press and box squat performances respectively (141 ± 21 kg, 184 ± 32 kg), when compared to academy athletes (115 ± 16 kg, 151 ± 30 kg). An increase in training age and maturation as the level of competition increased likely contributed to the increases in strength observed due to the positive impact resistance training has on improving muscle mass, movement patterns, and neuromuscular activation (Argus et al., 2012). Smart et al. (2013) also investigated the difference between amateur and professional Rugby Union athletes. In this study, 1,161 athletes' performance test data was mined from the New Zealand Rugby Union database and analysed to determine differences in body composition, sprint performance, and strength (Smart et al. 2013). Analysing this data characterised Rugby Union athletes from amateur to professional level and demonstrated that, as the playing level increased, sprint performance increased, and athletes were heavier with greater fat-free mass while having increased strength and power levels (Smart et al., 2013). Therefore, the level of strength in Rugby Union athletes increases as the level of competition increases, and Rugby Union athletes competing, or wanting to compete at a high level of competition should aim to possess high levels of strength (Argus et al., 2012; Hamlin et al., 2021).

Changes in Strength

The high level of strength professional Rugby Union athletes possess decreases the scope for improvement. Additionally, conflicting variables cause difficulty in balancing the mode and quantity of training potentially saturating individual qualities (Argus et al., 2012; McMaster et al., 2013). As stated by Duthie et al. (2003) Rugby Union athletes in all positions need significant amounts of strength and power which requires athletes to develop and maintain these two attributes both in preseason and in competition. Alongside addressing these sometimes conflicting training requirements, programs should be periodised with fluctuating volume and intensity (McMaster et al., 2013). McMaster et al. (2013) stated that adaptation rates may drop as training experience increases due to the law of diminished returns; therefore, athletes completing long-term periodised strength and power programs may see minimal improvement.

Variations in strength during a season of Rugby Union are common due to varied periodisation models used to recover and peak athletes' performance for specific weeks of competition, which can be labelled "tactical periodisation" (Crespo, 2011; Robertson et al., 2014). Eliciting substantial increases in a professional athlete's strength is often difficult due to a large percentage of their strength already developed, creating limited space for increased growth; therefore, the structure of a training program for professional athletes becomes very important (Appleby et al., 2012). Argus et al. (2012) characterised the differences in strength and power between different levels of competition in Rugby Union athletes and found by the time a Rugby Union athlete is in an academy system and has 1.5 years training experience, they have developed approximately 81% of their strength. Consequently, by the time a Rugby Union athlete has spent several years in a structured training environment, the periodisation of a training program becomes very important when trying to elicit meaningful strength gains alongside other sport specific attributes (Appleby et al., 2012). The requirement for concurrent training, whereby Rugby Union athletes need to complete resistance training and conditioning to improve rugby performance (Baker, 2001) and the law of diminished returns, often means that developing strength is often a difficult task (Gannon et al., 2016).

Similar to Rugby Union, Rugby League athletes require strength and power to be successful in competition (Baker, 2001). Baker (2001) investigated the change in upper body strength (bench press) in college-aged athletes and professional Rugby League athletes. Baker. (2001) found professional Rugby League athletes maintained upper-body strength throughout the season (-1.2%), whereas college-aged Rugby League athletes significantly increased upper-body strength throughout the season (3.4%). The increase in strength in college-aged athletes is believed to be due to professional athletes having a greater training age that limited their ability to gain strength. In Rugby Sevens, Mitchell et al. (2016) investigated the changes in body composition, strength, and lower-body power during an international season. Fourteen males with one to four years resistance training (seven backs and seven forwards) were included in this study whereby their upper- (bench press) and lower-body (back squat) strength were evaluated through one-repetition maximum testing. Strength levels were assessed at three different time points (start of preseason, start of competition, end of competition). While in competition the backs maintained lower-body strength, whereas the forwards had lost the lower-body strength gained in preseason (-7.9%). Both forwards and backs increased upper-body strength levels between start of competition and end of competition, with the forwards (3.6%) improving more than the backs who improved moderately (Mitchell et al., 2016). Therefore, this study has demonstrated Rugby Sevens athletes are capable of increasing lower-body strength Overall, these studies conclude that an increase in upper-body strength in-season is achievable for professional athletes; however, increases in lower-body strength across a competitive season do not consistently occur (Baker, 2001; Mitchell et al., 2016).

In Rugby Union, Argus et al. (2009) investigated the changes in strength, power, and steroid hormones during a professional Rugby Union season. Thirty-two athletes competing in a Super 14 professional Rugby Union team completed measurements of strength and power at the beginning of their gym session with each measure placed on separate days. This study measured upper body strength (bench press) and lower body strength (box squat) at various points during the season with each athlete completing a minimum of two and maximum of five assessments of strength throughout the testing period. Regardless of a reduction in resistance training, upper-body strength was maintained (-1.2%) while lower-body strength improved (8.5%) (Argus et al., 2009). These strength gains suggest that combining strength training with other training methods such as conditioning and skill training may not affect the gains imposed by strength training, at least for the lower-body; therefore, giving an opportunity for athletes to maintain or potentially increase strength levels throughout a competitive season when appropriate periodisation is incorporated (Argus et al., 2009). Similarly, in a professional English Rugby Union team, Gannon et al. (2016) investigated the strength and power characteristics throughout a 45-week period. Sixteen professional Rugby Union athletes were monitored at the beginning of preseason, the end of preseason, midway through their competition, and at the end of their competition. Lower-body power was measured in an explosive hack squat, and lower-body strength was measured in an isometric squat. Beneficial increases in strength were seen in preseason training, while power was maintained (2.7 ± 1.1%, 0.2±1.0%). Strength was maintained from preseason to midseason (1.9 ± 1.1%), while power had a beneficial increase (3.6 ± 1.1%) and strength and power were maintained/slightly decreased from midseason to the end of the season (-0.6 ± 1.0% and -0.8 ± 1.0%, respectively) (Gannon et al., 2016). Overall, this study observed a maintenance of lower-body strength during competition (+1.3%). An emphasis on strength development is therefore placed during preseason as it is a critical period for progression as indicated by this study; however, adapting training methods to enable athletes to continue to improve strength through until the end of season is a challenge and there may be potential to improve prescription in this area (Gannon et al., 2016). As shown in Table 1 which summarises the current literature available on changes that occur in strength over a Rugby Union and Rugby League/Football season, demonstrating that an increase in lower-body strength is not always feasible due to concurrent training (Baker, 2001). Rugby Sevens athletes were unable to maintain lower-body strength in competition (-6.4%), whereas an increase and maintenance in lower-body strength was observed in Rugby Union athletes (+8.5%, +1.3%) (Argus et al., 2009; Gannon et al., 2016).

Additionally, Hoffman and Kang (2003) investigated the changes in strength 53 NCAA division III Collegiate Football athletes across 12 week period. For these athletes, 1-RM strength testing in a concentric back squat and bench press was conducted on the first day of summer training and during the final week of the season. During this period, a maintenance of upper-body strength was observed (-1.2%), whereas an increase in lower-body strength occurred (+8.5%). Thus the results are similar to the investigation Baker (2001) whereby college-aged athletes increased upper-body strength by 4.9%, collegiate athletes increased lower-body strength by 8.5% (Hoffman & Kang, 2003) The increases observed could be due to the large scope for improvement in strength athletes with a younger training age have (Baker, 2001).

Table 1: Longitudinal changes in upper- and lower-body strength in the rugby codes.

Reference	**Athlete population**	**Training phase duration**	**Exercise**	**Changes in upper body strength during competition**	**Changes in lower body strength during competition**
Baker. (2001)	College-aged RL (n=15)	19 weeks (college-aged)	1-RM BP	3.4% (ES = 0.24)	-
	Professional RL (n=14)	29 weeks (professional)		-1.2% (ES = 0.13)	-
Mitchell et al. (2016)	Professional 7s (n=14)	40 weeks	1-RM BP 1-RM SQT	3.6% (ES = 0.37)	-6.4% (ES = 0.48)
Argus et al. (2009)	Professional RU (n=32)	13 weeks	1-RM BP 1-RM SQT	-1.2% (ES = 0-0.19*)	8.5% (ES = 0.2-0.59*)
Gannon et al. (2016)	Professional RU (n=16)	45 weeks	Isometric SQT	-	1.3% (ES = 0.12)
Hoffman and Kang (2003)	NCAA division III Football athletes (n=53)	12 weeks	1-RM BP 1-RM SQT	-0.6% (ES = 0.04)	5.4% (ES = 0.27)
Weakley et al. (2019)	Adolescent male RU (n=35)	12 weeks	3RM BP 3RM SQT	11.1% (ES = 0.57)	24% (ES = 0.63)
Hogben (2015)	Professional RU (n=19)	33 weeks	IMTP	-	4.5% (ES = 0.34)

IMTP: Isometric mid-thigh pull; 1-RM: one-repetition maximum; ES: Effect size; RU: Rugby Union; RL: Rugby League; 7s: Rugby Sevens; SQT: Back squat; BP: Bench press. *: Argus et al. (2009) did not report specific ES numbers but rather the range they were in, 0-0.19 = trivial, 0.2-0.59 = small.

In general, the changes in strength athletes go through is a topic that needs further understanding. The seven studies reported in Table 1 were discovered on Google Scholar using the search terms 'strength', 'rugby', 'competition', 'football', and 'season'. From these seven studies which investigated the changes in Rugby athletes endured during competition, one included adolescent athletes, one included college-aged athletes, one included college and professional athletes, and five included professional athletes. Four studies were conducted on Rugby Union athletes, one included Rugby League athletes, one included Division III American Football athletes, and one included Rugby Sevens athletes.

When exclusively including the competition period, Mitchell et al. (2016) observed the only increase in upper-body strength in professional athletes while Baker (2001) and Weakley et al. (2019) observed an increase in upper-body strength in college-aged athletes and adolescent athletes. Hoffman and Kang (2003), Argus et al. (2009), and the professional athletes in Baker. (2001) all observed a maintenance of upper-body strength. When assessing lower-body strength, Hoffman and Kang (2003), Argus et al. (2009), Weakley et al., (2019), and Hogben (2015) all observed an increase in lower-body strength, with Gannon et al. (2016), and Mitchell et al. (2016) observing a maintenance of lower-body strength.

Overall, the seven studies included in this review of longitudinal changes in upper- and lower-body strength in different rugby codes indicate increasing strength across a competitive season provide inconsistent evidence. The range of change in strength levels is often thought to be because of the fluctuating scope of strength improvement (adolescent to professional), the design of the training program, and how the concurrent nature changes across each sport (Robertson et al., 2014; Crespo, 2011; Appleby et al., 2012; Argus et al., 2012; McMaster et al., 2013). There are also a range of strength testing methodologies across the studies with both concentric and isometric testing being detailed in the literature. Therefore, incorporating valid and reliable strength testing during the season to measure changes in strength and evaluate the effectiveness of a training program becomes very important (Comfort & McMahon., 2015).

Reliability & Familiarisation

Before a strength test can be deemed worthwhile, it needs to show appropriate reliability between trials. Determining the reliability of a particular measure is important in determining the reproducibility of results between or within test occasions and inform meaningful changes. Obtaining reliability of a test measure informs practitioners how much variation lies in the process of test-retest. Two methods of evaluating the reliability of tests are an intraclass correlation coefficient (ICC) and a coefficient of variation (CV). An ICC identifies *relative* reliability and can be used to measure the systemic difference between or within trials (Liljequist et al., 2019). A "poor" ICC is considered <0.5, "moderate" 0.5-0.75, "good" 0.75-0.9, and "excellent" >0.9 (Liljequist et al., 2019). A second distinct measure that quantifies *absolute* reliability is a CV, which is typically used as a measure of precision for the scattering in data sets (Mahmoudvand et al., 2007). There are no universally accepted thresholds for quantifying CV values; however, a CV less than 10% is typically regarded as reliable (Currell & Jeukendrup, 2008). When reporting the reliability of isometric strength assessments, many studies only report the ICC without reporting a CV or confidence interval (CI) (Brady et al., 2018). However, reporting a second layer of reliability gives a better overall interpretation of reliability. Therefore, reporting both an ICC and CV can enhance the overall interpretation of reliability. Typical error (TE) and smallest worthwhile change (SWC) are also valuable measures of reliability. When the exercise has no movement, the typical error is the variability produced by the rater; however, if the exercise has movement the typical error is a combination of variability contributed by the athlete and rater (Hopkins, 2017). Additionally, the SWC is used to determine the smallest meaningful change or smallest clinically important difference in a measure (Ulupınar et al., 2023).

Before acceptable reliability can be produced, a familiarisation period is often required (Sampson et al., 2012). The familiarisation period requires the athlete to learn the movement and minimise the impact of any learning effect involved in the exercise (Sampson et al., 2012). Enabling each athlete to become familiar with the test will allow or better control any confounding variables that may impact the interpretation of strength evaluation (Sampson et al., 2012). Once the familiarisation period has occurred the reliability of the test can be considered. Familiarisation is typically assessed via the reliability. Once a test has acceptable reliability, the familiarisation period can be deemed completed and the test may be used to evaluate changes (Drake et al., 2018).

Strength Testing

Traditionally, concentric one-repetition maximum (1-RM) testing has been used to determine maximum strength in athletes (Buckner et al., 2017). Such 1-RM testing allows strength and conditioning coaches to prescribe training intensities and monitor the effectiveness of a training program through evaluating dynamic strength (Comfort & McMahon., 2015). Therefore, implementing regular strength assessment allows the prescription of optimal loading to be applied within an athlete's training program and can be used to gain an overall view of how an athlete is progressing in multiple areas of training (Suchomel et al., 2016). Assessing maximal upper- and lower-body strength in Rugby athletes has been previously attained via bench press and box squat exercises (Argus et al., 2012). According to the ACSM guidelines outlined in the investigation by Thompson et al. (2013), every athlete is advised to perform several submaximal warm-up sets, aiming to reach their 1-RM within four trials. These attempts should be spaced apart with rest intervals ranging from three to five minutes. Argus et al. (2012) implemented three sets of submaximal efforts in Rugby Union athletes (50, 70, 90%) of 4-6 repetitions, followed by one maximal set of 1-4 repetitions resulting in each athlete completing four sets ranging from 1-6 repetitions. The 1-RM was then predicted for each athlete through the maximal set which was inserted into an equation developed by Lander (1984) (1-RM = (100*weight)/(101.3-[2.67123*reps])) indicating the athlete's maximum 1-RM strength in a specific exercise (Argus et al., 2012). Lander's 1-RM predictor equation has been highly correlated to actual 1-RM values of bench press and squats in college American Football athletes, making it a valid method of predicting 1-RM (Ware et al., 1995). Furthermore, in a systemic review of 1-RM test-retest reliability, it was reported that 1-RM testing is reliable in single joint and multi joint exercises (median ICC = 0.97, median CV = 4.2 %) (Grgic et al., 2020).

McMaster et al. (2014) reviewed 412 previous research articles surrounding strength and ballistic methodologies which found the methods applied to a training program need to match the demands of the athlete along with training age, experience, morphology, and anthropometry. Strength was most commonly measured using traditional concentric 1-RM testing through tests such as bench press, the back squat, and the power clean. When measuring 1-RM strength, the testing needs to be standardised to ensure consistency in methodology such as squat depth as shallower depths result in higher 1-RM scores (McMaster et al., 2014). Overall, concentric 1-RM testing is popular within a normal training environment and is often considered the gold standard for assessing maximal strength; however, the demands of the athlete need to be considered when implementing maximal strength testing (Levinger et al., 2009).

While concentric 1-RM testing is a reliable and valid method of strength assessment it requires a significant amount of time to complete which may not be practical in large squads of team sport athletes (Banyard et al., 2017). Additionally, this form of testing can be fatiguing due to the requirement of multiple sets of multi-joint resistance training exercises (Izquierdo et al., 2009). As frequent assessments of strength are desirable to inform prescription, alternate methods of testing could be implemented to avoid the additional fatigue thought to be associated with traditional concentric 1-RM testing. Isometric strength testing is one potential alternative method (Comfort et al., 2019).

Isometric Strength Testing

Isometric strength testing uses a force plate or strain gauge to assess the static phase of a dynamic movement and strength qualities such as peak force (PF), mean force, and/or rate of force development (RFD) can be determined (McMaster et al., 2014). Isometric strength testing utilises the measures RFD and PF which are used to evaluate neuromuscular function and determine which qualities each athlete possesses (Kawamori et al., 2006). Specifically, RFD examines how explosive an athlete is through the maximum force they produce over a short time period (derived from the force time curve) (Maffiuletti et al., 2016); whereas, PF is the maximal force an athlete is able to produce and is not time constrained (Peterson et al., 2006). Isometric strength testing is considered easier to implement into training and more reliable than concentric testing methods due to no movement being required, and in general has fewer coaching cues when completing (Blakely et al., 1994). Additionally, it has been suggested that isometric strength testing produces less fatigue than traditional concentric 1-RM testing due to fewer sets being required during testing; however, it is not commonly implemented due to the required equipment being expensive (McMaster et al., 2014). Regardless of it not being commonly implemented, isometric testing has shown be more reliable than both concentric and eccentric tests (Table 2), easier to implement, and a potentially less fatiguing measure of strength when compared to dynamic testing (Blakely et al., 1994; Comfort et al., 2019; McMaster et al., 2014).

Table 2: Reliability of isometric, concentric, and eccentric strength testing reported via ICC.

Reference	Isometric Peak Force ICC	Reference	1-RM Concentric ICC	Reference	1-RM Eccentric ICC
Blazevich et al. (2002)	0.97	Seo et al. (2012)	0.91	Lodge et al. 2020	0.91
Sheppard et al. (2011)	0.99	Ribeiro et al. (2014)	0.92	Johansson et al. (2015)	0.71
Thomas et al. (2017)	0.95	Callahan et al. (2007)	0.92	Gerodimos et al. (2015)	0.82
Suarez et al. (2022)	0.96	Schroeder et al. (2007)	0.88	Lee et al. (2017)	0.81

To ensure reliability in isometric testing occurs, the body positions are typically standardised in a controlled environment (Blakely et al., 1994). In general, McMaster et al. (2014) found measuring maximum strength in sports varies, as different sport-specific factors need to be considered when implementing tests. Specific to Rugby Union, isometric strength testing may be an ecologically valid way of testing forwards due to the ability to test at specific joint angles that relate directly to the sport-specific isometric strength needed in components of the game such as semi-static scrummaging and mauling situations (Nicolas, 1997). As such, this sport-specific testing may provide a better representation of a relevant physical capacity that will transfer into sports performance (Blazevich et al., 2002).

Regardless of the advantages isometric strength testing has over traditional concentric 1-RM testing, recent research has shown that isometric strength testing metrics are not necessarily associated with dynamic strength qualities and thus represent different physical capacities (James et al., 2023). Eleven articles were presented in this systemic review which show the relationship between isometric and dynamic strength following resistance training. Overall, this systemic review concluded that isometric and dynamic strength testing cannot be considered as interchangeable due to the separate neuromuscular domains they may represent. The concentric exercises described in this 2023 review included the 1-RM back squat, 1-RM deadlift, and the 1-RM power clean; whereas, the isometric testing methods included were the isometric mid-thigh pull and isometric squat. Implementing these methods has made it apparent that both isometric and dynamic strength qualities should be assessed before a training program to provide a complete neuromuscular profile (James et al., 2023). While aspects of isometric strength can be considered as distinct physiological characteristics, Wang et al. (2016) did report a positive correlation between peak force in an isometric mid-thigh pull and concentric 1-RM squat ($r = 0.87$) which demonstrates that isometric strength and concentric 1-RM do share some underlying physical commonalities.

Wang et al. (2016), evaluated fifteen collegiate Rugby Union athletes completing an IMTP. The IMTP was a 6-second maximum effort completed in the deadlift position where the bar was lifted until the barbell touched the athlete's thigh in which the knee and hip angles were self-selected. From this study they reported that the RFD in an IMTP significantly and positively correlated to a concentric 1-RM back squat at the time stamps of 90, 100, 150, 200, and 250 milliseconds ranging from ($r = 0.595$ to 0.748 $p = 0.003$ to 0.032) The concentric 1-RM squat also exhibited significant and positive relationships with force outputs at 90, 100, 150, 200, and 250 milliseconds ranging from ($r = 0.757$ to 0.816; $p = 0.001$ to 0.003); with PF also showing a positive and strong relationship strength with a 1-RM squat ($r = 0.866$, $p = 0.001$). It was noted that the peak RFD in an IMTP also had a moderate relationship with the sprint performance 0-5 m ($r = -0.539$, $p = 0.038$); whereas PF in an IMTP only had a weak relationship with sprint performances 0-5 m and 0-10 m ($r = 0.291$, $p > 0.05$, $r = 0.313$, $p > 0.05$). Overall, this study found the IMTP performance was positively correlated to a traditional concentric 1-RM squat performance showing an IMTP could be a valid method for measuring strength qualities with some relevance to sprint performance (Wang et al., 2016).

Isometric mid-thigh pull

A common method of assessing isometric strength in Rugby Union athletes is the isometric mid-thigh pull (IMTP), which is a full-body analysis of an athlete's ability to generate force (Wang et al., 2016). According to Comfort et al. (2019), an IMTP provides a safer, less fatiguing measure of strength when compared to traditional concentric 1-RM testing. The IMTP provides outcome measures such as PF and RFD which can be used to describe how quickly an athletes can produce force, along with their maximal force generating capacity. When assessing colligate wrestlers, the PF in an IMTP has been shown to have a very strong relationship with traditional concentric 1-RM testing (power-clean, $r = 0.97$; squat, $r = 0.96$; bench press, $r = 0.73$) (McGuigan & Winchester, 2006). The IMTP utilises the approximate position of the second pull of the snatch and clean and has been reported to be a reliable method to assess full body maximal strength (Beckham et al., 2013; De Witt et al., 2018). According to Martin et al. (2020), when compared to traditional concentric 1-RM testing, the IMTP is time efficient and reduces the time taken from training thus allowing more time to be dedicated into important aspects such as sport-specific lifts. The 'shortened' (one second) IMTP has also been shown to be closely linked to traditional outcome measures during a several second hold as the results were not statistically different and showed trivial difference ($p = 0.345$, $g = -0.07$), furthermore reducing the time taken to complete than traditional IMTP testing (Suarez et al., 2022).

The IMTP also requires less technical instruction when compared to dynamic movements such as the concentric back squat, power clean, and bench press which are the commonly used traditional concentric strength testing methods (Martin et al., 2020). The lack of a skill component required to complete the IMTP creates less-technical instruction and allows the IMTP to be administered frequently to collect quality data (Giles et al., 2022). The IMTP is an isolated movement which may better represent the force-generating capacity of an athlete that is not limited by technique or injury.

Additionally, the IMTP has been used to evaluate fatigue and recovery (Grgic et al., 2022). Monitoring fatigue is a crucial element of measuring performance and recovery from exercise, while measuring elements of recovery such as obtaining serum markers of muscle damage provides data-rich information, these tests are not feasible in training due to being costly and time inefficient. However, the IMTP is a single measure capable of showing recovery from exercise, which is highlighted by the drop in PF weightlifters achieved post high intensity weight training and the return to baseline PF following 24 hours of recovery (Stone et al., 2019). Similarly, Aben et al. (2020) found a large effect size (d =0.95) between baseline measures of PF in an IMTP and 24 hours post-match, indicating the IMTP can be used to evaluate neuromuscular fatigue after Rugby League competition.

Previous recommendations for the exercise testing protocol in an IMTP suggest each athlete should be familiarised with the test; however, a systematic review noted that a familiarisation period may not need to be included if the athlete has previous resistance training experience (Grgic et al., 2022). Being familiarised with the protocol signifies the athlete is accustomed to the test such that any learning effect involved in an exercise is minimised and the outcome represents the true measure of strength (Roschel et al., 2011). Of the sixteen studies included in the review by Grgic et al. (2022) on the IMTP, ten included a minimum of one familiarisation session (Aben et al., 2020; Comfort et al., 2020; De Witt et al., 2018; Guppy et al., 2018; Haines et al., 2016; Moeskops et al., 2018; Sheppard et al., 2011; Suarez et al., 2020; Thomas et al., 2015; Thomas et al., 2017), five only included athletes who were already familiar with the test (Comfort et al., 2020; Dos'Santos et al., 2017; Dos'Santos et al., 2018; Sawczuk et al., 2018; Thomas et al., 2017), and one did not include a familiarisation period (James et al., 2017). Regardless of whether a familiarisation period was included or not, this study reported that peak force derived from the IMTP had a median ICC of 0.96 (ranging from 0.73 to 0.99; see Table 3) and a CV of 3.1%. In this review, each athlete was given two practice attempts in the warmup and regardless of familiarisation, produced reliable test-retest results. While this data suggests a familiarisation period is not needed but rather that reliable peak force measures can be collected with an appropriate warmup (familiarisation in warm up: ICC = 0.96, CV = 3.1% (James et al., 2017), 1 familiarisation session: ICC = 0.99, CV = 2.0% (Sheppard et al., 2011), 2 familiarisation sessions: ICC = 0.95, CV = 3.8% (Thomas et al., 2015)), the authors suggested that best practice should be to include at least one familiarisation session. One study not included in this review evaluated the difference between a bent IMTP (knee and hip angle 125 degrees) and upright IMTP (knee angle 125°, hip angle 145°) and found peak force was considerably higher in the upright method of completing an IMTP (Beckham et al., 2018). Furthermore, one study evaluated the reliability of single leg peak force, with the right leg (ICC = 0.97) showing higher reliability than the left leg (ICC = 0.95) (Thomas et al., 2017). Overall, Grgic et al. (2022) found the IMTP has good to excellent peak force test-retest reliability and is effective at measuring strength.

Table 3: Table summarising the studies included in systemic review by Grgic et al. (2022) research on IMTP test-retest reliability.

Author	Training experience/population	Exercise	Peak force ICC	Peak force CV	Familiarisation
Aben et al. (2020)	Male RL athletes	BL IMTP	0.92	4.9%	3 practice sessions
Comfort et al. (2020)	Male college athletes	BL IMTP	0.99	Not reported	1 practice session
Comfort et al. (2020)	Male collegiate athletes	BL IMTP	0.98	0.7%	Prior experience with exercise
De Witt et al. (2018)	Resistance trained athletes	BL IMTP	0.89	Not reported	1 practice session
Dos'Santos et al. (2018)	Youth soccer athletes	BL IMTP	0.96	4.6%	Prior experience with exercise
Dos'Santos et al. (2017)	Collegiate athletes	BL IMTP	0.97	5.3%	Prior experience with exercise
Guppy et al. (2018)	Strength and power athletes	BL IMTP (120° knee 145° hip)	0.92	8.0	1 practice session
Haines et al. (2016)	Adolescent male athletes	BL IMTP	0.87	6.4%	8 practice sessions
James et al. (2017)	Recreationally active males	BL IMTP	0.96	3.1%	Practice before main attempts
Moeskops et al. (2018)	Recreationally active females	BL IMTP	0.94	8.4%	1 practice session
Sawczuk et al. (2018)	Youth sport male and female athletes	BL IMTP	Not reported	5.5%	Prior experience with exercise
Sheppard et al. (2011)	athletes	BL IMTP	0.99	2.0%	1 practice session
Suarez et al. (2020)	Resistance trained men	BL IMTP	0.95	4.6%	Prior experience and 1 practice session
Thomas et al. (2015)	Male college athletes	BL IMTP	0.95	3.8%	2 practice sessions
Thomas et al. (2017)	Adolescent athletes	BL IMTP	0.86	6.8%	1 practice session
Thomas et al. (2017)	Female netball athletes	SL IMTP	Left leg: 0.95 Right leg: 0.97	Left leg: 4.9% Right leg: 4.2%	Prior experience with exercise

RL: Rugby League; BL: Bilateral; IMTP: Isometric mid-thigh pull; SL: Single leg

Isometric squat

Along with the isometric mid-thigh pull, another method of isometric testing is an isometric squat. Blazevich et al. (2002) analysed 14 athletic males with a minimum of six months of experience with free-weight squat variations and found the isometric squat had a high test-retest reliability (ICC=0.97). Additionally, Blazevich et al. (2002) reported that 1-RM testing in a concentric back squat demonstrated a strong, significant relationship with the isometric squat (r=0.77), Further, Drake et al. (2018) assessed the reliability and stability reliability of an isometric squat while including familiarisation in 18 athletes. Overall, Drake et al. (2018) found an isometric squats peak force to be reliable in experienced lifters after three familiarisation trials had occurred (ICC = 0.885, CV = 3.9%); however, peak force was the only metric that showed a moderate correlation to 1-RM load lifted in a concentric back squat (r =0.688). Overall, the minimal information currently available suggests that an isometric squat can be considered a reliable method of isometric strength (Blazevich et al., 2002; Drake et al., 2018).

Isometric belt squat

Anecdotally, because the IMTP is a full body analysis of strength that requires healthy athletes, it is not always appropriate in-season due to the high number of "niggles" or injuries obtained by Rugby Union athletes. In an epidemiological review by Kaux et al. (2015) 10-14% of injuries obtained during a Rugby Union match occurred in the torso. Additionally, Garraway (1995) reported injuries from 26 Rugby Union clubs competing in Scotland during 1993-1994 and found 10% of total injuries were back sprains and strains. Similarly, the prevalence of back strains would likely limit the applicability of the isometric back squat as many athletes may struggle to complete strength testing regularly in-season, thus reducing how informative the IMTP or isometric squat can be as a measure of strength. As well as not being appropriate due to the prevalence and location of injuries that Rugby Union athletes obtain, grip strength has been reported to be a limiting factor in an IMTP, thus effecting how accurate this strength test is at reflecting true lower-body strength levels (Layer et al., 2018).

An alternative to the IMTP is the isometric belt squat, which is strictly a lower-body exercise. As reported by Layer et al. (2018), the isometric belt squat reduced lower back moments when compared to an isometric back squat as the external load is shifted from the lower back to the hips ($p<0.001$). As such, the isometric back squat may be a better alternative to the IMTP as athletes with upper-body injuries would still be able to complete it. As shown in previous research into ten athletes with a minimum of six months of resistance training experience, the belt squat shifts the external weight being placed on the shoulder to the pelvis (Joseph et al., 2019). Loading placed on the lumbar erectors decreased by 45.4% during the complete movement and 52% at peak muscle activity (Joseph et al., 2019). Therefore, athletes with previous or current upper-body injuries that reduce the range of motion of the spine may continue to build and test lower-body strength by performing an isometric belt squat (Layer et al., 2018).

When comparing the isometric squat and isometric belt squat, Layer et al. (2018) found males and females completing both movements produced greater peak vertical ground force in an isometric belt squat compared to an isometric back squat; however, was not statistically different (243 vs 206 N, $p = 0.308$), potentially suggesting that the isometric belt squat provides a better representation of strength capability. The lower Newtons produced in an isometric squat suggest the presence of limiting factors affecting force output. In general, an isometric belt squat is a lower-body exercise that may better accurately represent an athlete's ability to produce force. Overall, limiting factors such as lower back strength and grip strength may not apply in an isometric belt squat; therefore, an isometric belt squat may be a better, practical method of strength assessment when compared to an isometric squat and IMTP (Layer et al., 2018).

The isometric belt squat measures a similar component of strength to the IMTP but has received limited research attention. Currently, standardisation and methodological considerations are only available from data obtained in a single IMTP study. Comfort et al. (2019) found the optimal knee angle of an IMTP to be between 125-145°, while the hip angle should be between 140-150°. No precise measurements in these ranges were suggested as previous research has shown no significant difference between PF and RFD in precise knee angles of 120°, 130°, 140°, 150°, and hip angles 125°, 145° (Comfort et al., 2015). However, Beckham et al. (2012), reported that powerlifters produced greater PF with a vertical torso when compared to being slightly lent over the bar (5829 N vs 4910 N, $p < 0.001$). In general, achieving a similar position to the second phase of the clean with an upright position of the torso and slight flexion of the knee (knee angle: 125-145°, hip angle: 140-150°), should provide the athlete with an adequate position to produce maximum ground reaction forces (Comfort et al., 2019). Additionally, Beckham et al. (2018) evaluated the difference between a bent IMTP (knee and hip angle 125 degrees) and upright IMTP (knee angle 125°, hip angle 145°) and found participants experienced in weightlifting had greater peak force in the upright method of the IMTP (3661 N vs 4587 N, $p = 0.01$). Therefore, available research is suggestive that athletes completing the isometric belt squat should complete it with a knees angle of between 125-145°, and a hip angle of between140-150° to maximise force production (see Figure 2).

Gaining an accurate measure of an athlete's strength through an isometric belt squat would help determine an athlete's strength capacity, whether an athlete is responding positively to a resistance training program and could be a valuable tool for assessing the time course of muscular fatigue levels after a Rugby Union match. Additionally, the isometric belt squat could provide insight into the changes in neuromuscular capacity over a Rugby Union season. As reported by Redman et al. (2021), it has been consistently demonstrated that Rugby League athletes demonstrate large improvements in strength measured via 1-RM concentric back squat alongside moderate increases in lower-body muscular power in preseason measured via a barbell jump squat and hack squat measuring jump height with a linear position transducer. Subsequently, these Rugby League athletes maintained strength and slightly increased power during competition. Currently, no similar data on the progression/regression of lower body strength is available for Rugby Union athletes.

Figure 2: Standardised position of the isometric belt squat.

Therefore, the aim of this research is to 1) determine the familiarisation period of an isometric belt squat, 2) determine the reliability of the isometric belt squat both within- and between-sessions, and 3) use the isometric belt squat to evaluate the changes in strength professional Rugby Union athletes sustain across a competitive season.

Conclusion

This literature review focused on the importance of strength for Rugby Union athletes, why measuring strength is important, and the different types of strength assessment methods. This literature review reports a positive relationship between isometric strength testing methods (such as the IMTP) and traditional concentric 1-RM strength testing; however, these methods should be considered as complementary due to the different neuromuscular domains they measure (James et al., 2023; Wang et al., 2016; Blazevich et al., 2002; McMaster et al., 2014). Anecdotally, it is apparent that an isometric mid-thigh pull is not an ideal strength test for Rugby Union athletes to complete each week in-season due to the prevalence of injuries/pain obtained in matches that impact the test, as well as constraints around back and grip strength. However, there is research showing the correlation between an isometric squat and concentric 1-RM squat testing (Blazevich et al., 2002), and research showing that the isometric squat and isometric belt squat are closely related although the belt squat can be considered as providing a better indication of lower-body force generating capability of athletes (Layer et al., 2018). Previous research, therefore, suggests an isometric belt squat may be a feasible, valid, and practical alternative to monitor in-season strength changes in Rugby Union athletes; however, there is no research to currently support the reliability of this test. Therefore, the current thesis examines the reliability and familiarisation period required, using an isometric belt squat in professional Rugby Union athletes, alongside using the isometric belt squat to measure the changes in strength during a competitive season.

CHAPTER TWO: The reliability of the isometric belt squat when assessing strength in professional Rugby Union athletes.

Abstract

Background: Isometric strength testing is a practical and reliable method of measuring strength due to the small amounts of fatigue induced and high correlation it has with one-repetition maximum concentric strength testing. The isometric belt squat is strictly a lower-body exercise well suited to accommodate for upper-body injuries commonly achieved in Rugby; however, there is limited literature to inform its use and reliability in Rugby Union athletes. Therefore, the aim of this research is to assess the familiarisation requirement and reliability (stability reliability) of an isometric belt squat in professional Rugby Union athletes. **Methods:** Eighteen professional Rugby Union athletes completed an isometric belt squat test four times separated by a minimum of 7 days and maximum of 14 days, during a 35-day period to determine reliability. Between-session reliability was quantified through an intraclass correlation coefficient (ICC), coefficient of variation (CV), typical error (TE), smallest worthwhile change (SWC), and p-value, whereas a CV was used to quantify within-session reliability. **Results:** One familiarisation session was required before we observed acceptable reliability between trials. The between-session reliability between Trials 2 to 4 was TE= 504.46 N, CV = 8.7%, ICC = 0.86, p-value = 0.021, SWC0.5 = 647.39 N) whereas the within-session reliability was (CV = 7.2%) **Discussion:** The results showed the isometric belt squat is reliable both between- and within-sessions after one familiarisation session and can be considered a reliable and practical lower-body evaluation of strength. As it is reliable, the isometric belt squat may be implemented into professional team-sports as a weekly evaluation to assess strength progression, fatigue, and recovery. **Conclusion:** Overall, the isometric belt squat is a reliable method of testing strength in professional athletes; however, to be correctly implemented a familiarisation period of one trial is required to maximise between-session reliability.

Key words: lower-body strength, intraclass correlation coefficient, coefficient of variation, familiarisation

Introduction

Rugby Union athletes require high levels of strength to maximise performance in specific components of the game such as tackling, scrummaging, rucking, mauling, sprinting, and jumping (Brazier et al., 2020). Strength is a vital component of power and strength endurance which are also important attributes in Rugby Union performance (Nicholas, 1997). Additionally, greater levels of strength have shown to be indicative of increased levels of performance (Argus et al., 2012). Therefore, maintaining and developing strength as a Rugby Union athlete is a critical element of achieving success as a professional athlete (McMaster et al., 2013; Argus et al., 2009).

Traditional strength testing such as one repetition maximum (1-RM) testing has commonly been used in sports teams to provide insight into an athlete's strength qualities and allowing loading to be adjusted to maintain progressive overloading within an athlete's gym program (McMaster et al., 2014). Such 1-RM strength testing in Rugby Union athletes has previously been attained through predicted measures whereby each athlete's completed a maximal set of one to four repetitions which can be entered into an equation to predict 1-RM (Argus et al., 2012). Anecdotally, due to the difficulties that 1-RM testing poses in competition season for team sport athletes (time consuming and fatiguing), it is not a practical method of frequent strength assessment for Rugby Union athletes. Therefore, other methods of strength assessment such as isometric strength testing have been investigated.

Isometric strength testing is a method of strength assessment that uses a force plate or strain gauge to assess strength qualities such as peak force, mean force, or rate of force development (McMaster et al., 2014). Isometric strength testing can be varied to suit sport-specific attributes, with a common method of assessing strength in Rugby athletes being the isometric mid-thigh pull (IMTP) as the joint angles relate directly to the sport-specific components of the game such as semi-static scrummaging and mauling situations. The IMTP is a whole-body test of an athlete's ability to generate force and a recent study by Comfort et al. (2019) suggests that the IMTP provides a safer, less fatiguing, and less technically demanding measure of strength when compared to traditional concentric 1-RM testing. The IMTP has high reliability between- and within-sessions and has been related to a 1-RM squat, deadlift, and power clean along with other metrics of performance, such as sprint speed (Wang et al., 2016). Of note, the isometric mid-thigh pull utilises the approximate position of the second pull phase of the snatch and clean which is a reliable method to assess full-body maximal strength (Beckham et al., 2013; De Witt et al., 2018). According to Martin et al. (2020) the IMTP (along with other methods of isometric testing) is time efficient, as it reduces the time taken away from training and thus allows more time to be dedicated towards sport-specific training.

Anecdotally, and similar to traditional strength test lifts such as deadlift or squat variations, the IMTP can be difficult to implement regularly in-season due to the test being a 'full body' exercise. Commonly Rugby Union athletes obtain upper-body injuries or 'niggles' from games or training resulting in them being unable to complete the test maximally. As reported by Garraway et al. (1995) approximately 22% of injuries per 1000 hours playing hours are upper-body related, therefore a measure of isometric strength that isolates the lower-body could be a more appropriate measure for Rugby athletes in-season while reducing the fatigue and demand traditional testing methods require. An isometric belt squat is a strictly lower-body alternative to the IMTP that may allow more people to complete strength testing in competition. An isometric belt squat also removes the limiting factors of grip strength and high levels of lower-back loading required during an IMTP (Layer et al., 2018). Additionally, when comparing the isometric squat and isometric belt squat, Layer et al. (2018) found males and females completing both movements produced higher peak vertical force in an isometric belt squat alongside a decrease in lower back moments, potentially suggesting it is a better representation of lower-body strength capacity while allowing athletes with upper body injuries to complete testing. However, this research only analysed people with squatting experience, and did not include well-trained team-sport athletes such as professional Rugby Union athletes.

Albeit limited, the literature surrounding the isometric belt squat indicates it could be an efficient lower-body strength test for Rugby Union athletes; however, more research is required. Specifically, an understanding of any required familiarisation period, along with the between-session and within-session reliability will help to inform strength and conditioning coaches to determine whether an isometric belt squat is a useful method of strength assessment. Therefore, the purpose of this study is to evaluate the familiarisation period and reliability (stability reliability) of an isometric belt squat in professional Rugby Union athletes.

Methodology

Research Design

To measure isometric strength in professional Rugby Union athletes, 18 athletes from one professional Rugby Union team volunteered to participate in this investigation. All the athletes were tested on four different occasions which determined their peak force capacity in an isometric belt squat. Each trial was separated by a minimum of 7 days and maximum of 14 days, and all testing completed within a 35-day period. Trial One data was collected in preseason week three, Trial Two data was taken in preseason week five, Trial Three was performed in preseason week six, and Trial Four data was taken in round two of competition. All athletes completed the isometric belt squat during their normal resistance training sessions in a gymnasium where they were accustomed to training. Verbal encouragement was provided to motivate each athlete to give a maximum effort during the test. Testing was implemented within a preseason block and all testing sessions took place between 8:00 a.m. and 12:00 p.m. with athletes being encouraged to apply normal practice nutrition for maximal recovery post-training.

Participants

Eighteen professional Rugby Union athletes (mean ± SD age = 24 ± 1 y, body mass = 104 ± 1.5 kg) were informed of risks associated with the testing protocols and signed a consent form before completing the isometric belt squat. This research project was approved by the Human Research Ethics Committee of the University of Waikato under HREC(HECS)2023#05

Experimental Procedures

Isometric belt squat

Maximal isometric strength (N) was assessed through a belt squat with peak force being the primary strength outcome measure. The VALD force decks (FDLite, VALD Pty Ltd, Australia) and VALD performance software were used to collect data which was automatically uploaded to an online database. A squat belt (Spud Inc) and steel chain with numbered links was connected to a steel plate to assess isometric ground reaction forces. To set each athlete up in the correct squat position, knee and hip angles were measured with a 12-inch Prestige plastic goniometer with each athlete needing to be in the set ranges (125-145° and 140-150°, respectively) with an upright position of the torso (Comfort et al., 2019). Once each athlete was positioned in the correct knee and hip angles, the chain link number was recorded to achieve consistency of angles between trials. A self-selected foot position was utilised and the athlete's hands were placed on their shoulders (left hand to right shoulder, right hand to left shoulder). The belt was placed around the athlete's hips sitting around the top of the gluteus maximus. Each athlete was instructed to complete two submaximal (50 and 70%) 3-second efforts after the set-up to gain familiarisation of the movement; however, no maximal effort was completed. On a separate day one day after the set-up trial, each athlete completed a warm-up of two submaximal efforts (50 and 70%) before conducting two, 3-second maximal efforts. During each maximal effort, each athlete was given visual feedback presented on an iPad which showed them a trace of the amount of force they were producing in real-time. A 30-second rest period was implemented between the two maximal efforts to allow each athlete to recover. Maximum Newtons produced, Newtons per kilogram of body weight, and the respective percentage of imbalance between the left and right leg were recorded for each effort.

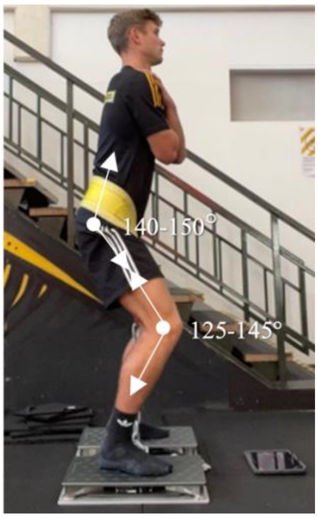


Figure 3: Image of experimental set-up.

Statistical analysis

All data was analysed with IBM SPSS (Statistical Product and Service Solutions, Version: 29.0.0.0 [241]) and data was stored on Microsoft Excel®. Before analysing the data a Shapiro-Wilk test was run to confirm a normal distribution. Descriptive data are expressed as mean ± standard deviation (SD). A Microsoft Excel spreadsheet (Hopkins, 2015) was then used to assess differences between the peak force obtained in the four trials and the intraclass correlation coefficient (ICC) was calculated. The coefficient of variation (CV) was calculated in Microsoft Excel for each individual via the formula (Standard Deviation / Mean)*100. The mean CV was then calculated to show an overall interpretation of each trial. A poor ICC was <0.5, moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) (Liljequist et al., 2019); whereas a CV under 10% was deemed reliable (Currell & Jeukendrup, 2008). The Typical Error (TE) was calculated and the usefulness of trials assessed by comparing the

TE to the SWC. Both TE and SWC were calculated on a Microsoft Excel spreadsheet (Hopkins, 2015). The SWC was calculated for the SWC0.5. This alternate SWC was calculated by multiplying the between-session standard deviation by 0.5 (SWC0.5) which is the alternate of a moderate effect (Hopkins, 2004; Düking et al., 2016). A 'good' usefulness rating was achieved if the TE was below the SWC, ; whereas, usefulness was deemed 'OK' if TE was similar to the SWC, and 'marginal' if TE was higher than the SWC (Hopkins, 2004).

Results

The Shapiro-Wilk test revealed the isometric belt squat data was normally distributed ($p>0.05$). Bonferroni-corrected *post-hoc* between-session comparisons revealed significant differences in the peak force between Trials 1-2, 1-3, 1-4, and 2-4 ($p<0.05$). In contrast, differences between Trials 2-3 and 3-4 were statistically non-significant (Table 4).

The mean peak force of each trial is shown in Table 5 with the change in mean, typical error, CV%, ICC, p-value, and SWC0.5. As shown in the bottom row of Table 5, overall comparisons were made from Trials 2-Trial 4 with the first trial removed to account for the familiarisation trial. Figure 4 shows the mean of each trial plotted on a line graph which highlights the increase in peak force from Trial 1-4 ($p<0.001$).

As the post familiarisation TE (504.56 N) was lower than the SWC0.5 (647.39 N); therefore, the test had a usefulness rating of 'good' (Hopkins, 2004). The within-session data shown in Table 6 (CV=7.2%) indicated that when testing athletes in the isometric belt squat in two trials within a session separated by 5 minutes, reliable results occur.

Table 4: Trial comparison of level of significance, mean difference in force between trials, and Standard error between trials.

Trial	Trial Comparison	Mean Difference (upper, lower 95% CI)	Std Error	Significance
1	2	-1048.4 (-1852.1, -244.7)	267.2	0.007
	3	-1274.2 (-1990.2, -558.1)	238.0	<.001
	4	-1717.2 (2492.6, -941.8)	257.8	<.001
2	1	1048.4 (244.7, 1852.1)	267.2	0.007
	3	-225.8 (-725.2, 273.6)	166.0	1.000
	4	-668.8 (-1257.6, -79.9)	195.7	0.021
3	1	1274.2 (558.1, 1990.2)	238.0	<.001
	2	225.8 (-273.6, 725.2)	166.0	1.000
	4	-443 .0(–984.0, 98.0)	179.8	0.153
4	1	1717.2 (941.8, 2492.6)	257.8	<.001
	2	668.8 (79.9, 1257.6)	195.7	0.021
	3	443.0 (-98.0, 984.0)	179.8	0.153

Table 5: Between-test measures of reliability, including the comparison of change in mean, typical error, CV, ICC, p-value, and SWC0.5 between trials.

	T1	T2	T3	T4	Change in mean (N)	Typical error	CV %	ICC	p-value	SWC0.5
Peak Force (N)	5142.4 ± 1214.2	6190.8 ± 1436.3	6416.6 ± 1274.4	6859.6 ± 12158.6						
T2 vs T1					1048.41	778.87	14.3	0.68	0.007	664.95
T3 vs T2					225.76	484.00	8.6	0.89	1.000	678.88
T4 vs T3					443.00	524.32	8.7	0.83	0.153	608.94
All trials mean: T1 to T4					572.39	609.87	10.5	0.79	<0.001	637.56
Post-FAM mean: T2 to T4					334.38	504.56	8.7	0.86	0.021	647.39

T1: Trial 1 data taken in preseason week three;T2: Trial 2 data taken in preseason week five; T3: Trial 3 data taken in preseason week six; T4: Trial Four was taken in round two of competition; CV: coefficient of variation ; ICC: intraclass correlation coefficient; SWC0.5: SWC calculated by multiplying the between-session standard deviation by 0.5 ; FAM: familiarisation

Table 6: Within-session mean peak force, standard deviation, and test of reliability.

Test	One	Two	CV (%)
Mean Peak Force (N)	6625 ± 1245	6724 ± 1631	7.2

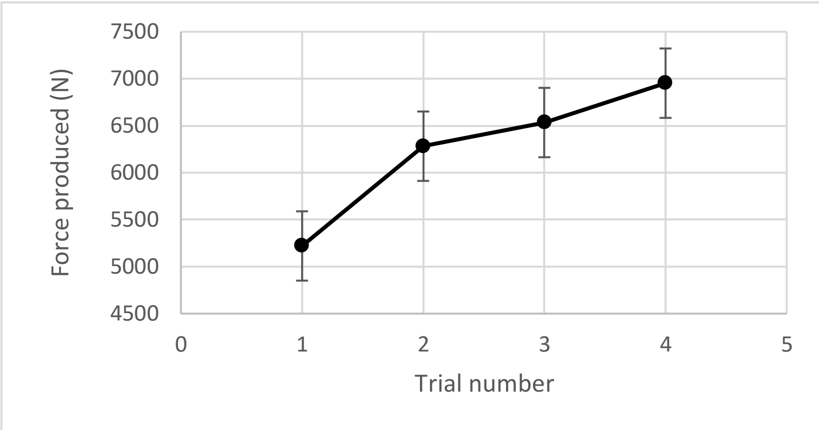


Figure 4: Line graph of the mean peak force of each trial plotted over the 4 reliability sessions.

Discussion

The primary purpose of this study was to evaluate the familiarisation period and reliability (stability reliability) of an isometric belt squat in professional Rugby Union athletes. To the authors knowledge this is the first study to assess the reliability of an isometric belt squat in this population. When all four trials were included, the CV exceeded the 10% threshold proposed by Liljequist et al. (2019); Currell & Jeukendrup, (2008); whereas following one familiarisation session measures of absolute and relative reliability were deemed 'good'. These measures corresponded to the 'usefulness' of the data improving from marginal to good as the TE was less than the SWC0.5 following a familiarisation session. The within-session reliability of the isometric belt squat (CV = 7.2%) indicated that the isometric belt squat is reliable within a single session, as little variation was seen between efforts separated by approximately 5 minutes (CV<10%) (Currell & Jeukendrup, 2008). Therefore, the isometric belt squat has shown to be a useful measure with good between- and within-session reliability.

A significant increase in force output between Trials One and Two with a stabilisation of force between Trial Two and Three indicating that athletes with no prior experience in the isometric belt squat require one familiarisation trial before reliable peak force measures can be obtained. An increase in force output due to familiarisation in strength testing commonly occurs due to factors such as, learning the correct technique, an increased ability to tolerate loads, increased motor unit recruitment, and decreased coactivation of antagonist muscle during testing (do Nascimento et al., 2013). Overall, our findings indicate that athletes needed one trial to become familiar with the isometric belt squat and control any confounding variables that may impact strength evaluation; furthermore, strength can begin to be assessed in the second trial as the familiarisation period has occurred (Sampson et al., 2012). Trial Two was not statistically different to Trial Three, and Trial Three was also not statistically different to Trial Four. It is noteworthy that, despite the non-significant increase between trials, the force output shows a steady increase across the four trials as expressed in Figure 4. Thus, although a stabilisation of results occurs, as reflected in force output and reliability, the PF continues to increase with other factors such as a suspected increase in strength driving the observed results.

As shown in Table 5, Trials Two and Four were statistically significant ($p=0.021$) regardless of the metrics obtained (ICC = 0.87, CV = 8.7%). As these trials were separated by 21 days with Trials Two and Three were within the preseason period, increased strength is potentially affecting the overall reliability due to significant increased observed between testing sessions separated by multiple weeks. Due to preseason being commonly utilised as a time for increased strength training, an increase in isometric strength may be expected as previous research has demonstrated strength improvements in a similar cohort over this time period (Argus et al., 2009; Baker et al., 2001; Gannon et al., 2016). Therefore, these results suggest isometric strength can significantly increase in trials separated by >14 days even after accounting for familiarisation.

This study was conducted using a similar design to recent studies on the reliability of an isometric back squat (Drake et al., 2018; Blazevich et al., 2002). Similar to the findings from this study, Drake et al. (2018) found peak force in an isometric back squat had a mean ICC of 0.885 between the test-retest which occurred after each athlete had completed three familiarisation periods. Therefore, the isometric back squat also had “good” reliability; however, each athlete was required to complete the test and additional two times when compared to the isometric belt squat before stability reliability was observed (Drake et al., 2018). The quicker familiarisation period the isometric belt squat has shown may anecdotally be due to the movement being less technical than the isometric squat. Additionally, it has previously been reported that the isometric belt squat has lower back moments and greater peak vertical force when compared to the isometric back squat (Layer et al., 2018). Therefore, an isometric belt squat may be a better suited, efficient test for athletes with back pain, and the higher values attained by Layer et al. (2018) (203 vs 246 N) may indicate that the belt squat is a better representation of the lower-body force capacity of an athlete.

A reliable method of strength assessment allows strength and conditioning coaches to assess and monitor the effectiveness of a athletes training program which has traditionally been achieved via 1-RM testing (Comfort & McMahon., 2015). As isometric testing is considered a practical, safe, and less time-consuming testing protocol, recent research suggests it is often favoured over traditional concentric 1-RM testing (Comfort et al., 2019). Furthermore, previous research has shown isometric squats are a reliable and valid method of strength assessment due to the observed correlations they have with traditional concentric 1-RM testing.

An added benefit of isometric testing is the ease of standardisation as joint angles can be set and specified to match sport-specific positions (Bazyler et al., 2015; Blazevich et al., 2002). The standardisation of the isometric belt squat used in this study was informed by research into the IMTP. Comfort et al. (2019) standardised the appropriate knee and hip angles (125 to 145°, 140 to 150°) required in an IMTP to achieve the highest reliability between trials. In our study, each athlete's chain link was adjusted until they were in the set knee and hip angle ranges and could maintain an upright position of their torso. Each athlete's chain link was then recorded to reduce the time taken to complete each test by not having to measure knee and hip angles each trial. By standardising the set up for this study we improved the practicality of implementing multiple trials in separate days and contributed to the reliability of the position used. Furthermore, recent research into the isometric belt squat has shown athletes in a sagittal knee angle of 120-160° produce more force than those completing the test with a knee angle of 80-120° or 160-180° (Treece & Nordin, 2023). Therefore, the knee and hip angles suggested by previous literature to maximise force production was implemented into this study.

With respect to 'usefulness' as reported by the overall typical error between Trials Two and Four, the mean TE was 504.46 N indicating the difference contributed by the athlete and rater (Hopkins, 2015). Researchers have reported that the SWC0.5 can be utilised to show 'meaningful' change to group analysis as the SWC0.2 may lack the sensitivity required (Brady et al., 2017); therefore, as the TE (504.56) was below the SWC0.5 following familiarisation (647.39). The overall usefulness rating of 'good', demonstrates that the isometric belt squat is both reliable and useful and practitioners can be confident that changes of >647.39 N represent a 'meaningful change'.

As this study has shown the isometric belt squat is a reliable method of strength assessment after the athlete has completed one familiarisation session. Thus, the isometric belt squat can be implemented to evaluate an athletes lower-body strength levels in an efficient and practical manner. As a result, practitioners can confidently assess the effectiveness of training interventions and may implement the isometric belt squat to monitor true in-season changes in athlete strength.

Practical Applications

The isometric belt squat can be considered a useful and reliable measure of strength with acceptable absolute and relative reliability that can be applied in sport environments attempting to evaluate lower-body strength levels in well-trained team-sport athletes. Our data shows that one familiarisation session is required before an athlete produces reliable results between sessions; however, within-session reliability is acceptable. Standardisation of the knee and hip angles was implemented and is recommended to achieve these reliable lower-body strength measures. Therefore, strength and conditioning coaches wanting to use the isometric belt squat should provide athletes with the opportunity to complete one separate trial with an isometric belt squat prior to using this isometric test to evaluate changes in lower-body strength levels.

CHAPTER THREE: The utilisation of an isometric belt squat to determine changes in strength during a professional Rugby Union competition

Abstract

Background: The requirement to develop multiple aspects of physical capacity within a professional Rugby Union season creates challenges for maintaining and developing strength. Concurrent training requires a balance of multiple training modes (e.g. conditioning, skill, strength) which can compromise strength gains. **Methods:** Fifteen professional Rugby Union athletes competing the Super Rugby competition completed an isometric belt squat at five different occasions throughout a 15-week block: End of preseason (T1), start of competition (T2), mid-competition one (T3), mid-competition two (T4), and end of competition (T5) with each of these testing blocks being completed when athletes were in a strength, power, or speed focused phase of training. A one-way ANOVA and Effect size (ES) statistics were used to detect and quantify the change in strength between the multiple time points. **Results:** There was a small decrease in peak force between the end of preseason and start of competition (-5.45%, ES = -0.51 ± 0.67, p = 0.070). Within the season, small changes in peak force were apparent (T3-T2: +5.25%, ES = 0.44 ± 0.45, p = 0.107; T4-T3: (-1.57%, ES = -0.20 ± 0.35, p = 0.455; and T5-T4: +2.53%, ES = -0.30 ± 0.18, p = 0.272). Overall change in strength across the season (T5-T1) was trivial (+0.44%, ES = 0.04 ± 0.39, p = 0.871). **Conclusion:** Despite the physical and travel demands of Super Rugby, lower-body strength can be maintained in professional Rugby Union athletes across competition with appropriate periodisation and exercise prescription.

Introduction

Rugby Union is a physically demanding, tactical, and skill-based contact sport that requires athletes to maintain and develop the attributes strength, power, endurance, and speed to meet the critical demands of competition (Duthie et al., 2006). As shown by Argus et al. (2012) Rugby Union athletes competing at higher levels of competition typically have greater strength attributes. However, due to the concurrent training methods Rugby Union athletes are required to complete, maintaining strength throughout a competitive rugby season is often difficult (Gannon et al., 2016). Concurrent training combines methods of training (e.g., strength and endurance training) in an attempt to maximise an athlete's development by improving the efficiency of training (Methenitis et al., 2018). Concurrent training incorporates both strength and endurance training which may compromise adaptations due to potential interference effects and a lack of specificity (Appleby et al., 2012); however, concurrent training forms the basis of training for Rugby Union athletes (Jones et al., 2016). As concurrent training needs to be balanced to manage the training load of other sport-specific methods of training such as conditioning, the periodisation of training programs need to be strategically employed to ensure athletes can maintain/develop strength (Appleby et al., 2012).

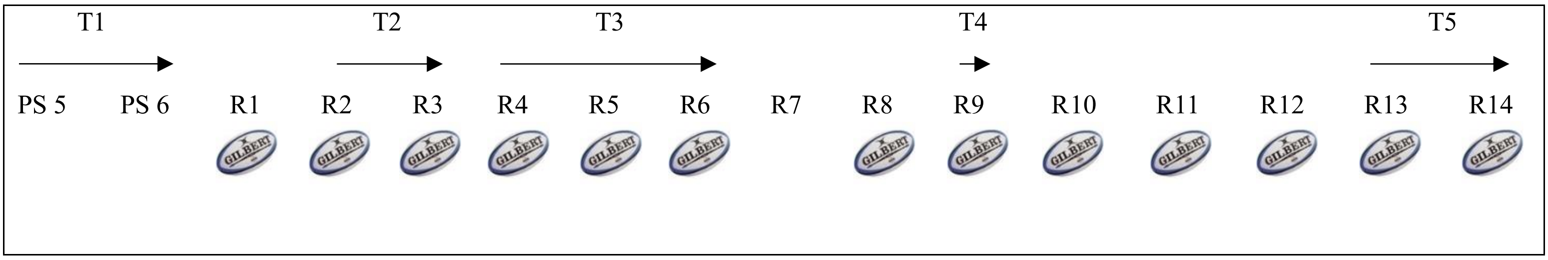
There is limited time within the competitive season to improve physical aspects in Rugby Union due to the short turnaround between matches, travel, and skill and tactical training requirements. As a result, a competition preseason with a training block dedicated to developing physical traits (e.g., strength, power, aerobic and anaerobic fitness) is a crucial time (Argus et al., 2010). As previously shown by Gannon et al. (2016), lower-body strength is increased the greatest amount in a 12-week Rugby Union preseason (2.7%), and although an increase through to mid-season occurs, it is reduced (1.9%). While an improvement from start of pre-season to end of competition was achieved (+4.1%), an increase in lower-body strength during competition has shown to be challenging during a long season (+1.9%). Similarly, Mitchell et al. (2016) observed a maintenance in lower-body strength in backs, but a contrasting decrease in forwards (-4%) across an International Rugby Sevens season. These authors however, found an increase in upper-body strength (+5%). The maintenance in lower body strength across competition indicates increasing strength throughout a Rugby Union season is possible; however, it is often challenging to achieve (Gannon et al., 2016; Mitchell et al., 2016). As shown by these investigations into the change in strength across a competitive Rugby Union season it is unclear whether it is possible for athletes to consistently gain strength over a competitive season (Gannon et al., 2016; Mitchell et al., 2016).

Previous research has investigated the changes in strength through various methods, two of which are a traditional one-repetition maximum (1-RM) test in a back squat, and an isometric squat (Argus et al., 2009; Mitchell et al., 2016; Baker et al., 2001; Gannon et al., 2016). As Rugby Union athletes commonly obtain back injuries (10% of injuries per 1000 playing hours) using movement patterns that increase load on the back will limit the ability to maximally test athletes (Comfort et al., 2019; Layer et al., 2018; Garraway, 1995). Additionally, as the isometric back squat increased lower back moments and the isometric belt squat has shown higher peak force values (206 vs 243 N), the isometric back squat is not necessarily the most valid representation of lower-body force-generating capacity (Layer at al., 2018). Therefore, the alternative to these methods, the isometric belt squat, has shown to be an effective lower body test of strength that increases peak vertical force and decreases lower back moments when compared to an isometric squat (Layer et al., 2018). Anecdotally, the isometric belt squat is a practical, appropriate test as it is strictly a lower-body method of strength assessment, allowing Rugby Union athletes with upper body injuries to continue to evaluate strength in-season. Additionally, work from the previous chapter has demonstrated that the isometric belt squat is a reliability and useful method to assess lower-body strength. Therefore, as there is currently limited research on the isometric belt squat, we aimed to use this reliable method of strength assessment to evaluate each athlete's change in strength over a competitive Rugby Union season.

Methodology

Research Design

To measure isometric strength in professional Rugby Union athletes, 15 athletes from one professional Rugby Union team volunteered to participate in this investigation. All athletes were tested on five different occasions to determine their individual isometric strength levels measured through an isometric belt squat. The isometric belt squat was chosen due to the practicality of the test. The five trials were spread across a 15-week period and all athletes completed all five trials. Each athlete completed the isometric testing during their normal resistance training sessions and verbal encouragement was provided to provide motivation during the test. Testing was implemented in both preseason and in-season for each athlete. While in preseason (T1) the athletes were in a strength phase, whereas T2, T3, T4, and T5 were in season and fluctuated between mixture of speed, power, and strength training (see Figure 5). Specifically, Trial 1 was completed in Weeks 5-6 of pre-season 5-6, Trial 2 data was collected in competition rounds 2-3 (approximately two weeks after T1), Trial 3 was performed in competition round 4-6, Trial 4 was completed in competition round 9, and Trial 5 was collected in competition rounds 13-14 (of a 15-week season). All testing took place between 8:00 a.m. and 12:00 p.m. with athletes being urged to apply normal practice nutrition for maximal recovery post training. As part of the athlete's gym programming, testing from any given trial was collected over a two-week period. Additionally, each athlete's playing minutes were collected at the end of each round. At the end of competitive season the individual games were collated to provide each athletes individual playing minutes across the season.



T: Trial; PS: Preseason week; R: Round of competition

Figure 5: Timeline of trials spanned across season.

Participants

A total of fifteen professional Rugby Union athletes playing full-time completed this strength test (age 25 ± 3 y, weight 104.9 ± 16.4 kg). Athletes were informed of risks associated with this test and signed a consent form before completing the isometric belt squat. This research project has been approved by the Human Research Ethics Committee of the University of Waikato HREC(HECS)2023#05

Experimental Procedures

Isometric belt squat

Maximal isometric strength (N) was assessed through a belt squat. VALD force decks (FDLite) and an iPad were used to collect data which was automatically uploaded to an online database. A belt squat belt (Spud Inc.) and steel chain with numbered links was connected to a steel plate to create isometric resistance. To set each athlete up in the correct squat position, knee and hip angles were measured with a 12 inch Prestige plastic goniometer with each athlete required to be in the set knee and hips angle ranges (125-145° and 140-150° respectively) in an upright position (Comfort et al., 2019). The chain links were numbered and once each athlete was in the correct knee and hip angles, each athlete's chain link number was recorded to standardise the knee and hip angles between trials. A self-selected foot position was utilised and the athletes hands were placed on their shoulders (left hand to right shoulder, right hand to left shoulder). The belt was placed around the athletes hips sitting around the top of the gluteus maximus. Each athlete was instructed to complete two 3-second submaximal efforts (50 and 70%), after the set-up to gain familiarisation of the movement; however, no maximal effort was completed. On a separate day after the set-up trial, each athlete completed a warm-up of two submaximal efforts (50 and 70%) before conducting two 3-second maximal efforts. During each maximal effort, each athlete was given visual feedback presented on an iPad which showed them a trace of the amount of force they were producing in real-time. 30

seconds rest was implemented between maximal efforts to allow each athlete to recover. Each athlete's maximal strength was recorded using the peak force in Newtons, Newtons per kilogram of body weight, and the respective percentage of imbalance between the left and right legs.

Statistical analysis

All data was analysed with IBM SPSS Statistical Product and Service Solutions (SPSS, Version: 29.0.0.0 [241]) and data was stored on Microsoft Excel®, 2023. All isometric belt squat data showing peak force values are represented as mean ± SD. A one-way ANOVA model was used to determine whether significant differences were present across the five testing sessions. Changes in strength were identified and reported through percentage change and through effect size (ES) statistics. The ES statistics were calculated from the mean difference between each trial / the pooled standard deviation of differences of each trial) to describe the magnitude of differences in peak force between the four different stages of the season (T1-T2, T2-T3, T3-T4, and T4-T5) while also observing the overall change from the beginning to the end of season (T5-T1). Changes in peak force were analysed as trivial (ES<0.2), small (ES 0.2-0.6), moderate (ES 0.6-1.2), large (ES 1.2-2.0), and very large (ES>2.0) (Hopkins, 2004). The threshold for statistical significance was set at $p \leq 0.05$.

Results

Change in strength

Across the competition season (T5-T1), peak force was not statistically different (Figure 6; +0.44%, ES = 0.04 ±0.39, p = 0.871). Furthermore, the results from this study indicate the mean peak force for trial 5 (end of season) was the highest of each of the trials (Figure 6). Between the end of preseason and start of competition (Trials 1 to 2) the change in peak force was small (-5.45%, ES = -0.51 ± 0.67, p = 0.070). The change in peak force at the start of season to midseason point one (Trials 2 to 3) was small (+5.25%, ES = 0.44 ± 0.45, p = 0.107). Between Trials 3 to 4 (midseason point one to midseason point two) there was a small change in strength (-1.57.%, ES = -0.20 ± 0.35, p = 0.455). Finally, the change in midseason point two to end of season was small (Trials 4 to 5: +2.53%, ES = -0.30 ± 0.18, p = 0.272). .

Playing minutes

Across the competition period the total playing minutes each athlete possessed did not affect their strength levels (r = 0.0003). Large variation occurred across athletes; one athlete with 208 playing minutes increased strength

(16.97%), one athlete with 1212 minutes, maintained strength (-1.37%), and one athlete with 45 playing minutes decreased strength (-10.18%), highlighting the variation observed in lower-body strength levels across the season.

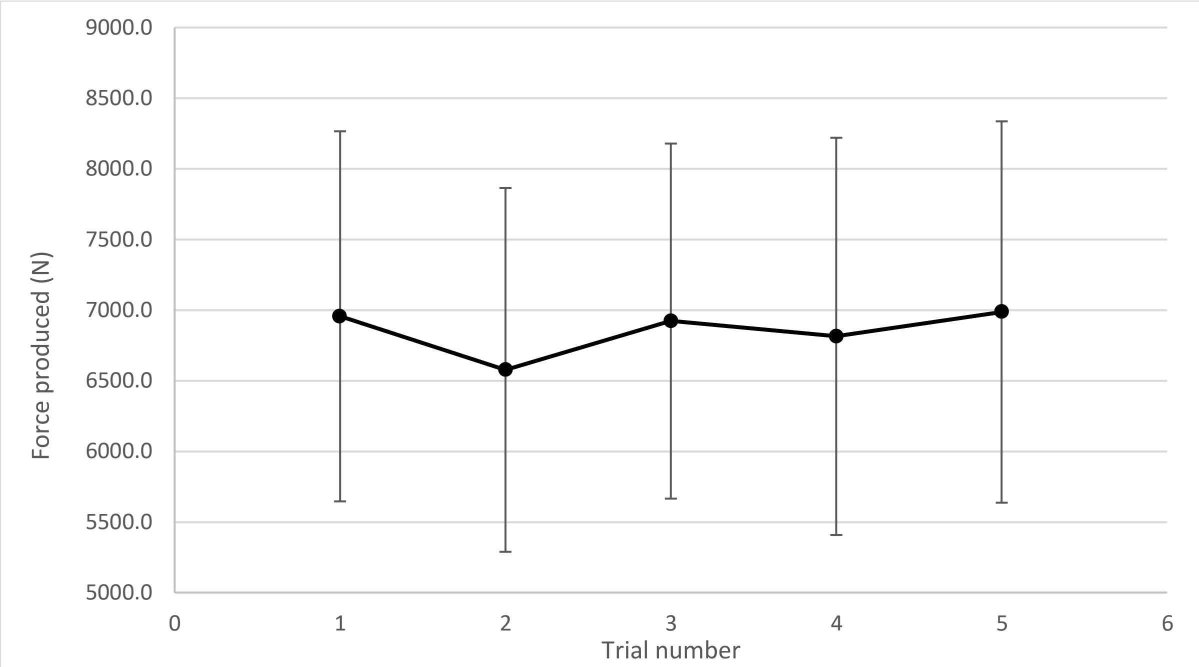


Figure 6: Mean peak force at each trial over the competitive season, with error bars showing the standard deviation of each trial.

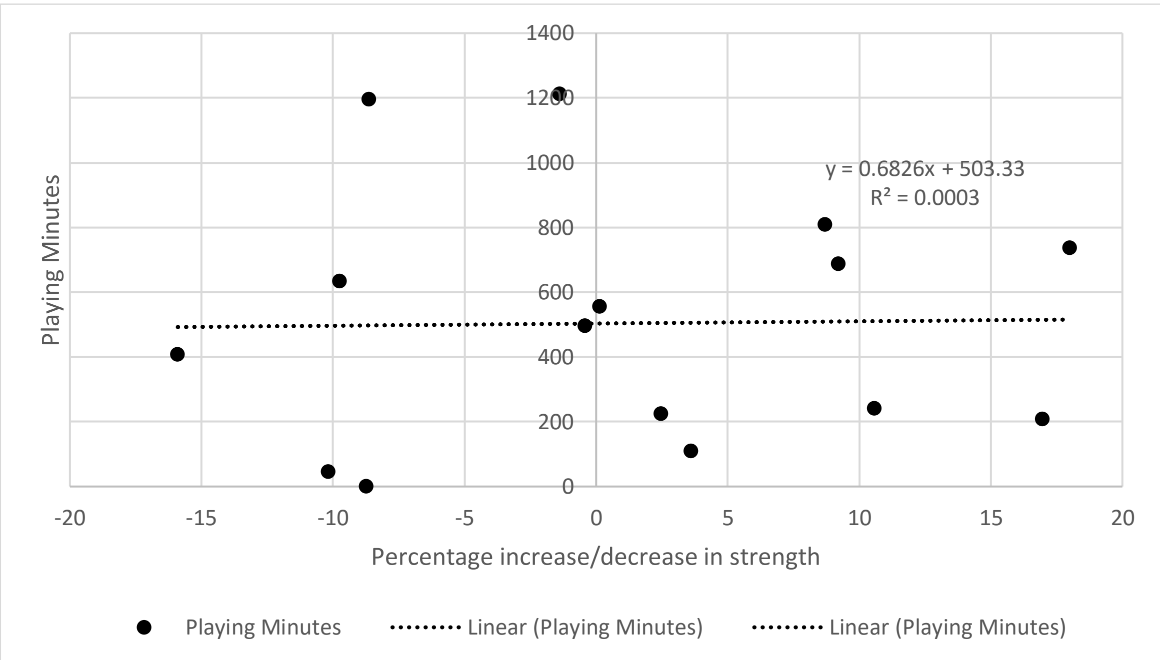


Figure 7: Correlation between playing minutes and percentage change in strength over the season.

Discussion

The purpose of this study was evaluate changes in strength in professional Rugby Union athletes across a competitive season. The mean peak force produced from this study indicates that, on average, athletes maintained strength levels from the end of preseason to end of the season suggesting strength maintenance is possible across a season while completing concurrent training and playing matches. It was also notable that the players with high playing loads were also able to maintain their lower-body strength.

The greatest increase in strength was 'small' and occurred in the early season time period between Trials Two and Three (+5.25%, ES = 0.44 ± 0.45, p = 0.107) ; whereas the largest drop in strength occurred between end of preseason and the start of competition. Although this was the largest drop in strength (379.40 N), as reported in the previous chapter, an unpublished study conducted in our laboratory shows the drop in strength was lower than the TE (504.56) and SWC0.5 (647.39); therefore was not a 'meaningful' change in strength. Previous research indicates, preseason training has shown to be the best opportunity to increase strength due to less conflicting variables affecting the implementation of periodised resistance training (Argus et al., 2010). As concurrent training is intensified and affects resistance training as the season commences, athletes may see a slight decrease in strength while they adapt to the increased load of skill-based training and intense competitive matches, especially those with a long training history of concurrent strength and endurance training (Baker, 2001). Therefore, the initial drop in strength we observed at the start of competition may be due to athletes adjusting to a drop in resistance training volume/focus and increased fatigue posed by matches during competition (Argus et al., 2009; Raeder et al., 2016).

The research into the change in strength across a professional Rugby season varies, and is a disputed topic (Argus et al., 2009; Mitchell et al., 2016; Gannon et al., 2016). Our findings do align with Gannon et al. (2016), who observed a maintenance in lower body strength during a 33-week professional Rugby Union season (+1.3%). In contrast, Mitchell et al. (2016), reported that Rugby Sevens Athletes decreased lower-body strength across a 28-week international season, showing lower-body strength is difficult to maintain in this cohort. However, as reported by Argus et al. (2009), professional Rugby Union athletes can increase lower-body strength over a competitive season (+8.5%). In general, previous research suggests increasing lower body strength across a competitive season in rugby codes is an equivocal topic. Hence, despite the potential for slight enhancements in strength through periodised training programs, increasing strength during competition while engaging in concurrent training remains a challenging area that warrants deeper investigation (Baker et al., 2001; McMaster et al., 2013). Given the limited opportunity for an increase in strength professional athletes often have and the large strength gains that typically occur in preseason, this is often a difficult task to complete (Argus et al., 2009; Mitchell et al., 2016; Gannon et al., 2016). The different sports investigated in these studies may have affected the observations in maximal strength levels. Both studies investigating professional Rugby Union athletes found a maintenance or increase in strength, whereas the investigation into professional Rugby Sevens athletes observed a decrease. This decrease may be due to the variability of sporting requirements. Rugby Sevens includes an increase of sporadic tournaments played, high density playing minutes, and lower physical impact when compared to professional Rugby Union, potentially effecting the ability to maintain/increase strength.

Furthermore, the contrasting results surrounding the changes in strength observed over professional seasons may also be due to the different testing methodologies utilised. We determined strength changes in competition via the isometric belt squat as it previous research suggests the isometric belt squat is a good alternative to the isometric back squat due to the decrease in lower back moments and increase in peak force that have been recorded (Layer et al., 2018). Anecdotally, the isometric belt squat was effective due to the minimal skill required to produce maximal force. As mentioned in the previous chapter, an unpublished study conducted in our laboratory has shown the isometric belt squat is reliable after one familiarisation period (ICC = 0.86, CV = 8.7%) and is better suited in competition due to it being a strictly lower body test which accommodates for the upper body injuries Rugby Union athletes may sustain. Therefore, the isometric belt squat is a reliable, practical, and better suited test when compared to other common methods of isometric strength testing.

During competition, augmented fatigue from increased playing minutes may contribute to a decrease in strength (Raeder et al., 2016). An increase in training load produces more fatigue has shown to decrease maximum strength values; therefore, an increase in playing minutes may decrease the quality of resistance training resulting in a decrease in maximum strength across the season (Raeder et al., 2016). Our data demonstrates that, each athlete's change in strength appears to be independent of their total playing minutes for the season, with the correlation being 'very weak' ($R^2 = 0.0003$; Sarjanna et al., 2023). Specifically, we can see that low playing minutes were not necessarily associated with better strength maintenance (e.g. 45 minutes, -10.18%), and that regardless of high playing minutes, certain athletes managed to maintain strength (e.g. 1,212 minutes, -1.37% respectively). The maintenance of strength in athletes that completed a high number of playing minutes suggests these athletes have an increased ability to handle training load. As these athletes were mostly high-level players with a high training age, their ability to gain strength is likely limited. However, their ability to maintain strength throughout the season while completing a high number of playing minutes suggests they are a robust athlete which may contribute to their selection for games each week. While all playing minutes were recorded for this professional Rugby Union team, multiple athletes may have been playing for lower-level clubs and increasing playing minutes (which we do not have access to) and that other variables that would contribute to the overall training load were not captured.

This investigation found a maintenance of lower body strength during a competitive Rugby Union season is achievable. We do acknowledge that isometric strength test can be considered to be an independent physical capacity relative to dynamic strength; and thus we recognise that an isometric belt squat may not be an applicable measure when evaluating changes in dynamic strength (which are predominantly trained). Despite this limitation, isometric strength is an important measure of performance due to sport-specific components such as scrummaging and mauling situations that require the production of maximum force (James et al., 2023; Nicolas, 1997; Quarrie & Wilson, 2000) and demonstrated relationships to sprinting and dynamic strength measures (Wang et al., 2016). As a result, increasing isometric strength may play a role in improving sport-specific performance in a match, which highlights its importance. Furthermore, regardless of concurrent training potentially affecting the increase in strength, professional athletes have been shown to have limited opportunity for an increase in strength (Baker et al., 2001). Therefore, while an increase in strength is targeted during a competitive season it is often a difficult task; however, ensuring each athlete has an appropriately designed periodised program can assist to minimise decrease in strength while potentially providing an increase in strength over a season (McMaster et al., 2013).

Practical Applications

The findings from this study into the changes in strength in professional Rugby Union athletes indicate it is possible to maintain lower-body strength across a competitive season. Concurrent training may positively or negatively increase the effect of an increase in strength in certain individuals; however, it has been expressed in this study that an overall maintenance in strength across a professional Rugby Union season is achievable. However, it is still unknown what factors influence a change in strength levels as playing minutes did not explain this; therefore, tracking the overall load on the body (psychological, sleep, all activity completed) may help explain the various increases/decreases in strength. Highlighting these factors would identify robust athletes and potentially explain the factors influencing an increase/decrease in strength in other team/collision sports.

CHAPTER FOUR: Discussion, Practical Applications, Strengths, Limitations, Future Research, Conclusion

Practical Applications

Discussion

Practical Applications

Study One concludes the isometric belt squat is a reliable measure of strength that is feasible and applicable in team-sport environments attempting to evaluate maximum strength levels. One familiarisation session is required before an athlete produces reliable results between sessions and standardisation of the knee and hip angles should be implemented to induce these reliable numbers. Strength and conditioning coaches aiming to use the isometric belt squat need athletes to complete one separate trial before it can be used to evaluate a change in strength levels. Additionally, the second study found that the maintenance of lower-body isometric strength during a competitive season is achievable; however, it is still unknown what factors influence the observed fluctuations in strength levels. An evaluation of overall load (sleep, activity levels, and psychological stress) may help determine which factors influence a change in strength.

Strengths

The isometric belt squat was quick and simple to set up as the only change between each athlete was the change in the length of the chain to suit the athletes correct knee and hip angles (which was pre-recorded on a sheet). The testing period was therefore quick to complete (<2 minutes) and enabled each athlete to complete the testing protocol during their normal gym session. The isometric belt-squats time efficiency contrasts typical 1-RM testing that often requires a dedicated session (or sessions) and are thus time consuming. The decreased technical proficiency and lower-body focus of the isometric belt squat also allow for the athletes to demonstrate lower-body force generating capacity without the constraints associated with other testing methods.

Recording each athlete's chain link in the set-up ensured the reliability of the initial protocol. Pretesting in our laboratory suggested if an athlete's knee angle was too high or low the peak force of each trial dropped as they were not able to leverage themselves correctly. Peak force also dropped when the athlete was not in an upright position but rather leaning forward.

While completing the isometric belt squat each athlete was presented the force-time trace line that expressed how much force they were producing in real time. Visual feedback has previously been demonstrated to increase jump squat performance in Rugby Union athletes (Randell et al., 2010) which helped encouraged athletes to produce more force and gain a better representation of their maximum strength.

Limitations

Due to being expensive, the force decks involved in this study may not be easily accessible in some environments which makes it difficult to replicate this study or effectively implement the isometric belt squat in general. Additionally, the investigation into the changes in strength only had fifteen athletes. While we had more athletes completing the strength testing, multiple athletes did not complete the test at each time point included in the study resulting in an incomplete data set. A larger population may give a better representation of the fluctuations in strength each athlete endures. Furthermore, additional athletes may allow for the observation of position-specific differences which would create normative values to report and compare to. Another limitation of Study Two (changes in strength across competition) was that we did not obtain start of preseason strength levels which did not allow us to observe the changes in strength that occurred in preseason. Therefore, without early pre-season measures we were not able to quantify the changes in strength observed in the off-season. Moreover, as all athletes used in these two studies were males, this data cannot necessarily be extrapolated to professional female team-sport athletes, and while these two studies only report peak force, the measures of leg imbalance, relative peak force (N/kg) and RFD were collected, however not reported. Rate of force development was not reported as collecting RFD requires the athlete to jolt into the position. Anecdotally, this jolt increases the risk of injuries and was not deemed to be justifiable for Rugby Union athletes under a high training load.

Future Research

The two investigations involving the isometric belt squat in this thesis indicate it is a reliable measure of strength and can be used to evaluate strength after the athlete has completed one familiarisation period. The other findings from this thesis indicate that the maintenance in lower-body strength across a competitive season is achievable, with no increase in lower-body strength across the season observed. Future research into the isometric belt squat may help indicate its correlation to other measures of strength to help gain a better understanding of how it is best applied when assessing strength. Similarly, recording RFD under safe conditions and reporting leg imbalance and relative peak force (N/kg) may show their significance in the isometric belt squat, with the potential to create positional ranges each athlete should sit in for relative peak force.

An investigation into the correlation between the isometric belt squat, concentric 1-RM testing, and other performance measures such as countermovement jump height or 10 m sprint time would also establish any link between testing measures and potentially help coaches appropriately prescribe testing measures suited to each athlete's characteristics or phase of training. The correlation between the isometric belt squat and key game performance measures such as scrummaging, line breaks, metres run, and tackles made may help distinguish how isometric strength correlates to Rugby Union performance. Additionally, further research using the isometric belt squat to measure dynamic strength alongside directly using 1-RM testing to measure dynamic strength may help distinguish the different neuromuscular domains these methods of strength assessment measure and inform individual progression.

As the knee and hip angles used in this study were based on a study into the IMTP, specific testing to determine how different knee and hip angles for the isometric belt squat affect force production and unilateral muscle imbalance may help to inform the knee and hip angles used. Furthermore, creating individualised knee and hip angles based on each athlete's anthropometry may improve the effectiveness of the set-up period and meaningfulness of the test overall. Finally, as the testing periods were not planned out to distinct periods during the season such as start/end of preseason, start/end of competition, aligning the testing dates of the isometric belt squat with key phases of training during the season may help decipher the decrements in strength in the off-season and changes in specific aspects of strength across the pre-season. Furthermore, coordinating testing to coincide with training micro/macrocycles of strength, power, and de-load/reload weeks would help understand the impact moving away from a strength phase has on maximum strength performance.

Future research may also look into monitoring detraining across an offseason period via an isometric belt squat to help determine the effect decreased strength training has on maximum strength. Furthermore, strength and conditioning coaches may use the isometric belt squat as a return to play measure as it is a safe, low fatiguing measure that has the ability to measure bilateral imbalance, while being implemented in all athletes to measure how 'robust' each athlete is.

Conclusion

In summary, this thesis has evaluated the reliability of the isometric belt squat in professional Rugby Union athletes alongside using the isometric belt squat to evaluate the changes in strength in this cohort during a competitive season. The findings from the first investigation conclude the isometric belt squat is reliable both between- and within-sessions after one familiarisation period. Therefore, the athletes from this study indicate one familiarisation test is required before the isometric belt squat can be used to evaluate strength. Additionally, the findings from the second study concluded that athletes maintained their lower-body isometric strength across a competitive season, highlighting the fact that further investigations to inform training and periodisation into the ability to increase strength in professional Rugby Union athletes are required. Overall, the isometric belt squat has shown it is a reliable measure of strength and can be used to describe the changes in strength of Rugby Union athletes across a competitive season.

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Appendix

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THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

24 February 2023

Ryan Danby
Christopher Beaven
Christos Argus

Re: HECS Ethics Approval of Application HREC(HECS)2023#05 "Reliability and efficacy of three isometric tests for assessing strength in elite rugby union players"

Dear Ryan:

Thank you for submitting your amended application HREC(HECS)2023#05 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruit approximately 30 rugby players coming from a professional team (following permission from the team management) for a study that will assess the reliability and efficacy of three similar isometric performance tests.
- Participants will perform their normal gym sessions, which will include the belt squat, squat, mid-thigh pull isometric performance tests, but data will be collected using force plates (Vlad Force Decks).
- Participants can withdraw from the study at any time up until two weeks following the final data collection session.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Consent Form for Participants

Title – Reliability and efficacy of three isometric tests assessing strength in elite rugby union players.

I have read the ***Participant Information Sheet*** *for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.*

I also understand that:

- *I am free to withdraw from the study at any time or to decline to answer any particular questions.*
- *I can withdraw any information I have provided up to two weeks after participating in the research activities by contacting the principal investigator.*
- *Any data or answers will remain confidential in regards to my identity through a coding system.*
- *The data might be published in research reports, journal articles, a Master's thesis, and scientific presentations, therefore every effort will be made to ensure confidentiality and anonymity. However, anonymity cannot be guaranteed.*
- *I know who to contact should I have any further questions about the study or my involvement in it.*

I agree to provide information to the researchers under the conditions of confidentiality set out on the *Participant Information Sheet***.**

Consent to Participate

I agree to participate in this study under the conditions set out in the *Participant Information Sheet***.**

	Participant:	**Researcher:**
Signature:	________________________	________________________
Name:	________________________	________________________
Date:	________________________	________________________