The Influence of Playing Position and Training Age on the

Force-Velocity Profiles of Professional Male Rugby Union Players

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Contents

Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person except that which appears in the citations and acknowledgements. Nor does it contain material which to a substantial extent I have submitted for the qualification for any other degree of another university or other institution of higher learning.

Signature:

Date: 13/04/2022

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Ethical approval

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List of Figures

List of Tables

List of Appendices

List of common abbreviations

F-v	Force-Velocity	LPT	Linear Position Transducer
F_{max}	Maximum Force Output	SJ	Squat Jump
V_{max}	Maximum Velocity Output	CMJ	Countermovement Jump
P_{max}	Maximum Power Output	CV%	Coefficient of Variance
F0	Maximum Theoretical Force	ICC	Interclass Coefficient
V0	Maximum Theoretical Velocity	*FVimb*	Force-Velocity Imbalance
Sfv	Slope of Force-Velocity Relationship	COM	Centre of Mass
SfvOpt	Optimal Slope of Force-Velocity Relationship		

Abstract

Force-velocity profiling is a useful assessment tool for strength and conditioning practitioners to ascertain certain physical characteristics of their athletes, which can directly inform training decisions. Thus, the intention of this dissertation was to 1) review the methods and technologies of force-velocity profiling, 2) review the literature pertaining to sport and positional requirements relating to force and velocity characteristics in rugby union and, 3) determine the influence of playing position and training age on the force and velocity characteristics of professional rugby union players. Chapter two presents an in-depth review of the existing force-velocity profiling methods and technologies. This literature review revealed a select few methods that were valuable to the strength and conditioning practitioner in the field due to their effectiveness and simplicity. Chapter three identifies the key physical and physiological requirements of rugby union and the unique differences between positional roles as it pertains to force and velocity characteristics. The primary findings of this literature review were that rugby union players as a group have a tendency towards force dominant characteristics. Furthermore, forwards had an even greater tendency for a higher force generating profile when compared to backs. Chapter four contains the original experimental investigation which determined the influence of playing position and training age on the force-velocity characteristics of professional rugby union players during the loaded squat jump and maximal back squat exercise. The primary findings from this study were that forwards were able to produce far greater absolute force than backs and that no statistically significant relationship existed between training experience and force-velocity characteristics. However, there was a significant correlation ($p < 0.05$) between training experience and the optimal slope of the force-velocity relationship. The inclusion of F-v profiling as an assessment tool for rugby union players is valuable for informing training decisions where the goal is improving ballistic performance or identifying existing force-velocity characteristics.

Chapter 1: Introduction and rationale

1.1 Background

The requirements to be an elite level rugby union player are rooted in physical ability, namely, to be able to exert large amounts of muscular force and power (Cronin & Sleivert, 2005; Cormie et al., 2011a; Samozino et al., 2013). Contextually, players must also produce this force at a range of contractile velocities in a game situation such as high contractile forces during scrummaging and high contractile velocities when kicking, depending on position. Thus, mechanical force, velocity and power are key considerations when training for rugby union. Therefore, the role of the strength and conditioning coach for rugby union players is to facilitate the enhancement of their force, velocity and power producing capabilities, and to manage the utilisation of those characteristics in the rugby union context.

Previous research has shown that when using a force-velocity (F-v) profile to inform a training programme the resulting power increase was far greater than in a control group (Jimenez-Reyes et al., 2017). Additionally, it has been shown that individuals with a force or velocity deficiency can experience up to ~30% decrease in ballistic performance for a given power output (Samozino et al., 2012). Therefore, the use of F-v profiling to assess undesirable deficiencies is a valid and justifiable tool to inform the prescription of specific training programmes that increase performance in certain contexts. Thus, F-v profiling could be a complimentary assessment for strength and conditioning practitioners to employ in suitable sporting contexts that require explosive actions i.e., rugby union, basketball, football (Samozino et al., 2012).

There are numerous performance analysis and assessment tools that a strength and conditioning practitioner can employ. A systematic review by Chiwaridzo et al. (2017) on the physiological tests found for rugby union described 63 tests for the various physiological characteristics of rugby union players. These tests assessed; speed (8), agility/change of direction (7), upper-body muscular endurance (8), upper-body muscular power (6), upper-body muscular strength (5), anaerobic endurance (4), maximal aerobic power (4), lower-body muscular power (3), prolonged high-intensity intermittent running ability (5), lower-body muscular strength (5), repeated high-intensity exercise performance (3), repeated-sprint ability (2), repeated-effort ability (1), maximal aerobic speed (1), and abdominal endurance (1) (Chiwaridzo et al., 2017). While horizontal F-v profiling has been thoroughly investigated in the literature (Watkins et al., 2020; Cross et al., 2016; Brown et al., 2016; Haugen et al., 2019) vertical F-v profiling (i.e., assessing movements that apply force vertically), has scarcely been researched in the literature (Argus et al., 2012; La Monica et al., 2016).

The training experience of athletes is a defining characteristic of longevity and performance and is a factor of their training age and the type of training they have performed e.g., multilateral or specific training (Bompa & Buzzichelli, 2019; Carlson, 1988). Training for a specific sport will always lead to some degree of specialisation as an athlete's physiological makeup shifts to better perform in that specific sporting context (Fleck & Kraemer, 2004; Siff & Verkhoshansky, 1999; Stone et al., 2007). The training prescribed for a specific sport will also lead to certain physiological adaptations. When creating a training programme for any athlete, it is vital that a coach considers the athlete's training experience, namely their training age (Bompa & Buzzichelli, 2019). Training age, which differs from chronological and/or biological age (refer to Chapter 3), influences the ability to produce power through variables such as training frequency, intensity, volume, consistency of training, type of training and the potential to sustain an injury. However, we can infer from the literature that the longer an individual has been training, the greater their power production capabilities are. For example, Cormie, McGuigan & Newton (2011) surmised that if an individual performed periodised strength training for ≥3 years, the change in their neuromuscular characteristics would result in drastically increased muscular power outputs. However, the training that is being performed, must be relevant to strength or power production for training age to have a direct influence.

1.2 Purpose statement

The primary intention of this dissertation was to determine the influence of playing position and training age on vertical F-v characteristics. This investigation included professional rugby union players as participants and was completed for the following reasons:

1) To date, no known researchers have determined the influence of playing position on the vertical F-v characteristics of professional rugby union players through the squat jump and maximal back squat movements.
2) To date, no known studies have investigated the influence of training age on F-v characteristics in a professional sporting context.
3) A considerable amount of the training rugby union players perform in the weight room involves vertical force application.

Previous research on F-v profiling has indicated that playing position does impact the force and velocity characteristics through exposure to certain stimuli and the tendency for certain physical and physiological requirements for a given role. There has been significant research performed on the horizontal F-v profiles of professional rugby union players, however the literature for vertical F-v profiling is limited. A large portion of the training performed by rugby union players requires application of force in the vertical axis. By determining the deficiency of force or velocity characteristics in the vertical axis, strength and conditioning practitioners can better implement loading strategies to maximise training performance. The findings of this study could be used to clarify and contribute to those previous findings.

This dissertation attempted to prove the notion in the literature and common belief that playing position has an impact on F-v characteristics, and that training age was also influential on those same characteristics.

1.3 Research aims and hypothesis

The preliminary aims of this dissertation were to 1) examine the literature and determine the most valid and reliable methods of F-v profiling, and 2) examine the existing literature in relation to F-v profiling and rugby union. The primary aims of this dissertation were to 1) identify the positional differences between forwards and backs regarding force-velocity-power characteristics and, 2) identify the influence of training age on the force-velocity-power characteristics of rugby union players. We hypothesised that forwards would display greater absolute and relative force characteristics while backs would display greater absolute and relative velocity characteristics. Furthermore, while generally all rugby union players have a tendency towards force dominance, we hypothesised that forwards would display a greater force dominance than backs. Lastly, we hypothesised that individuals with a greater training age would be able to produce greater relative force at higher velocities than those with a lower training age.

1.4 Structure of the dissertation

Chapter two of this dissertation is a review of the current literature pertaining to F-v profiling. This review provides and outline of acceptable methods of F-v profiling for lower and upper-body testing.

Chapter three contains a literature review on the physical demands of rugby union and the requirements of the players. The review also discusses the use of F-v profiling methods in rugby union. Finally, the review references the current literature on the influence of training age on performance outcomes in similar sporting contexts.

Chapter four is the experimental study whereby professional rugby union players performed a series of squat jumps and a maximal back squat to determine their F-v profile and their maximal force producing ability, respectively.

Chapter five is the final chapter which serves as the conclusion and summary of the dissertation. Practical recommendations, limitations of the present study and opportunities for future research are presented in this chapter.

Chapter 2: Literature review of the methods of force-velocity profiling

2.1 Preface

The purpose of this chapter is to identify and review the literature relating to the methods and technologies of vertical F-v profiling. The topics in this chapter provide a thorough understanding of the processes behind vertical F-v profiling and describes viable methods that have been proven valid and reliable. Certain methods are recommended for strength and conditioning practitioners due to ease of use and cost-effectiveness for field-based assessment and these are highlighted.

2.2 Introduction

The use of F-v profiling to inform the training prescription of athletes has recently been discussed in the literature. If a training programme is designed to increase ballistic push-off performance, namely jumps or change of direction movements, researchers have postulated that the focus of that programme should be to increase maximal vertical power output (VTC-P_{max}), or to decrease *FVimb* (the difference between an actual and optimal F-v relationship). Recent literature has shown that for any given maximal power output (P_{max}) value, undesirable force or velocity deficiencies such as an imbalance skewed heavily towards force or velocity characteristics, can result in a ~30% decrease in ballistic performance (Samozino et al., 2012). These findings demonstrate the necessity for strength and conditioning practitioners to be concerned with utilising robust ways to effectively assess the F-v capabilities of their athletes. A number of these methods exist in the literature and their reliability, validity and effectiveness is discussed in this chapter. For the typical strength and conditioning practitioner, a method that is reliable, cost-effective, and time-efficient will be the appropriate choice for most situations.

The purpose of this literature review is to outline the current technologies and methods of obtaining a valid F-v profile, and to provide information on the benefits of F-v profiling in a sporting context. The information presented in this chapter should be of use to any strength and conditioning practitioner or sport scientist that is aiming to assess the F-v capabilities of their athletes. Provided is a list of acceptable technologies and a discussion of the methods reliability and validity.

2.3 Literature review search methods

An electronic database search was conducted using the search engines PubMed, Taylor & Francis Online and SPORTDiscus to identify potential articles. The following search terms were used: force, velocity, power, profile, squat jump (SJ), vertical jump, and countermovement jump (CMJ). Further literature was obtained from electronic 'related articles' searches and by manually screening the reference lists of the included studies. The specific inclusion criteria included; 1) lower-body and/or upper-body focused F-v profiling, 2) a detailed explanation of the procedures and methods, 3) written in English, and 4) research studies solely conducted with human participants. Papers from 2008 onwards were included in the review. The year 2008 was chosen as the starting point as this was the year Samozino et al. published the paper "*A simple method for measuring force, velocity, and power output during squat jump",* which was the first simplified and accessible method for assessing lower-body F-v characteristics in athletes (Samozino et al., 2008).

2.4 Force-velocity imbalance

An important consideration when practically applying F-v profiling is the concept of the force-velocity imbalance (*FVimb*). The *FVimb* is the percentage difference between an athlete's actual F-v profile and their optimal F-v profile (Jiménez-Reyes et al., 2017; Samozino et al., 2012). The actual F-v profile can be determined by any of the valid and reliable methods mentioned in this paper, and the optimal F-v profile is calculated based on equations created by Samozino et al. (2012; 2014). The magnitude of the *FVimb* is determined by the slope of the F-v relationship (*Sfv*). Depending on how steep the slope of that relationship is compared to the optimal profile, determines the magnitude of the athlete's force or velocity deficiencies.

The percentage value of the *FVimb* represents the direction and scale of an athlete's imbalance between their force and velocity capabilities. This value provides the assessor or relevant personnel with the information necessary to determine whether an athlete has force or velocity deficiencies that need to be addressed through prescriptive training. A *FVimb* of 100% indicates that the actual F-v profile is optimal. In comparison, a percentage above 100% displays a force dominance (velocity deficit, see Figure 1), and a percentage lower than 100% displays a velocity dominance (force deficit, see Figure 2.

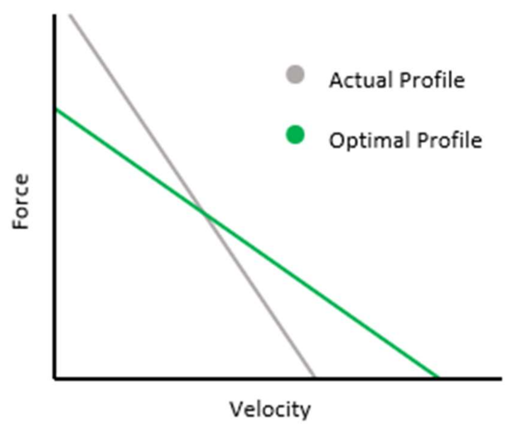

Figure 1. Example F-v profile with velocity deficiency.

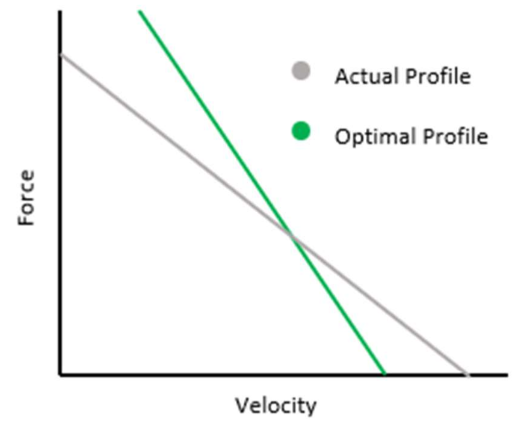

Figure 2. Example F-v profile with force deficiency.

The goal of prescribing training based on F-v profiling is to decrease the magnitude of *FVimb*, which has been shown to increase ballistic performance (Jiménez-Reyes et al., 2017). For the athlete in Figure 1 who is experiencing a relatively large force deficiency, training that focuses on increasing force capabilities will generate the greatest improvement in power output. Appropriate movements for that adaptation to occur include heavy compound movements such as deadlifts, and back squats. Conversely, that athlete in Figure 2 displays a large velocity deficiency therefore, it would be beneficial to place emphasis on movements that take place at high contractile velocities. In this instance, a variety of plyometric movements that are specific to the desired adaptation would be appropriate. In a case where the *FVimb* is minimal, (i.e., the F-v profile is close to optimal), appropriate training would include both maximal force generating movements and high contractile velocity movements as any increase to either force or velocity would result in an increase in power output. In this circumstance, complex training that contrasts between heavy movements and explosive movements would be an efficient method to increase power output (i.e., perform heavy back squat immediately prior to vertical jumps).

A paper by Jimenez-Reyes et al. (2017) aimed to address individualised training effectiveness based on *FVimb.* The study identified the *FVimb* of 84 trained athletes and organised them into training groups based on whether they were force deficient, velocity deficient or well-balanced. The study also used non-optimised and control groups. Each group would train two times per week and was provided with differing training stimuli over a 9-week intervention. The force-deficient group would perform movements close to *F0* and at very slow velocity, such as a >80% back squats for 3-6 sets and 2-6 repetitions. Meanwhile, the velocity deficient group would perform movements at high velocity where the load was close to bodyweight such as squat jumps. Researchers took these results with the assumption that an *FVimb* closer to 100% would increase jumping performance. The force and velocity deficient groups saw an increase in jump performance of +7.2 to +14.2% with very large ES, respectively, while the non-optimised group saw a trivial increase of just +2.3% with trivial ES. These findings validated the assumption that all participants in the individualised groups improved jump performance and optimised their *FVimb*. Participants with large initial *FVimb* saw improvements to *FVimb* and jump performance while not seeing any increase in P_{max} (Jiménez-Reyes et al., 2017). The work of Jimenez-Reyes et al. (2017) builds upon the theoretical study performed by Morin and Samozino (2016), who proposed that if a training programme is designed to improve an athlete's ballistic capabilities, the programme should focus on increasing P_{max} and/or decreasing *FVimb*.

A current limitation of optimal F-v profiling is that there is no method in the literature for generating an optimal slope for upper-body F-v profiling, and vertical F-v profiling for the lower body has scarcely been researched in the literature (Argus et al., 2012; La Monica et al., 2016).

2.5 Methods of F-v profiling

Numerous methods have been presented in the literature to attain F-v profiles with varying degrees of validity and reliability. These methods are employed using assorted technologies such as force plates, photocell systems, linear position transducers and phone applications. The perceived value of these individual methods and technologies may be determined by the context in which it is to be used. These methods, technologies and contexts are discussed throughout this section.

2.5.1 Technologies for F-v profiling

The vertical jump is a common movement used to create a lower body F-v profile of an athlete due to the ease of performing the movement and the applicability to a wide array of sporting codes (Loturco et al., 2017, McMaster et al., 2016; Samozino et al., 2014). Many methods are available to produce a F-v profile utilising the vertical jump; however, some of these methods are not practical for use in the field or by the average strength and conditioning coach due to the technology required. These methods range from using a photocell system, linear position transducer and force plates, which are considered the gold standard. Similarly, the bench press and bench press throw are effective movements to determine force, velocity, and power characteristics for upper-body profiling (Alonso-

Aubin et al., 2021; McMaster et al., 2016). These movements employ similar methods as the lower-body vertical jump with the notable exclusion of force-plates.

2.5.1.1 Photocell systems

Photocell systems work via a line of sight, transmitting and receiving a signal. The system can detect any interruptions to that signal and calculate contact time and flight time. Several studies have been performed to determine F-v profiles of elite athletes using photocell systems, namely the widely used OptoJump system (Microgate, Bolzano-Bozen, Italy). Studies by Samozino et al. (2013), Giroux et al. (2016) and Jimenez-Reyes et al. (2017) all made use of a photocell system to determine the F-v profiles of a total of 227 high-level athletes, ranging from semi-professional to Olympic medallists. The study by Samozino et al. (2013) supported the notion that ballistic performance is dependent on an individual's lower limb F-v profile, and that the magnitude of *FVimb* is indicative of lower limb performance. The study by Giroux et al. (2016) was intended to establish the optimal F-v profile of various world-class athlete groups. The researchers found that through consistent exposure to an activity, the corresponding F-v profile adapts accordingly and that the difference between actual and optimal F-v profile provides the opportunity for further specific performance improvement. The F-v profiles of the groups can be found in appendix C. Furthermore, the study by Jimenez-Reyes et al. (2017) observed the effect of using an individual's F-v profile to inform their specific training and found that reducing the *FVimb* without altering P_{max} led to a performance improvement in jump ability. These finding indicate that the *FVimb* can be an effective tool to inform training prescription. Samozino et al. (2008) proposed a method of determining the variables of the F-v profile; maximum theoretical force; y-intercept of the linear F-v relationship (*F0)*, maximum theoretical velocity; x-intercept of the linear F-v relationship (*V0)*, maximum power (P_{max}), and therefore the slope of the force-velocity relationship, the equation is -*F0/V0* (*Sfv)*. The method proposed by Samozino et al. (2008) was based on Newton's second law that force equals mass multiplied by acceleration. Therefore, the only parameters needed for this method are body mass, jump height, and vertical push-off distance (*hpo*).

Photocells have been proven valid and reliable in estimating jump height in vertical jump movements, with an ICC of 0.98 to 0.99, and a CV of 1.8-6.5% (Attia et al., 2017; Glatthorn et al., 2011). Some reliability issues are present using a photocell system as force and velocity are calculated based on flight time, and flight time is determined by jump height (Jiménez-Reyes et al., 2017). Minor technical errors on the part of the athlete's execution due to the nature of the movement can lead to slightly inconsistent results (Attia et al., 2017; Pérez-Castilla et al., 2018).

2.5.1.2 Linear Position Transducers

Linear position transducers (LPT) are a standard tool in high-performance facilities and are the next step-up in terms of sophistication from a photocell system. An LPT works by anchoring the body of the mechanism to the floor or bottom of a rack and attaching the end of a retractable cable to a point either on an athlete or on a barbell. The LPT can then measure the velocity and distance travelled of the athlete or barbell. The LPT system is well researched and is considered valid and reliable, with an ICC of 0.85 to 0.97, which is considered excellent and a CV of 2.1-8.4% (Cronin et al., 2004; García-Ramos et al., 2017; Garnacho-Castaño et al., 2015). In addition, a study by Padulo et al. (2017) had the explicit intent of using an LPT to determine F-v profiles of competitive athletes. The researchers assessed the lower limb force, velocity, and power of 10 athletes through both the back squat (BS) and leg press (LP) movements. The study found that *V0* (BS = 1.66 ± 0.29, LP = 0.88 ± 0.18), P_{max} (BS = 1366 ± 384, LP = 835 ± 164) and *Sfv (*BS = -2111 ± 631, LP = -4638 ± 1574) values were significant higher during the squat movement, whereas *F0* (BS = 3394 ± 824, LP = 3850 ± 672) values tended to be somewhat greater during leg press. Unfortunately, LPTs, when compared to force plates, will often overestimate the outcome variables for lower body-based movements (Cormie et al., 2007; Crewther et al., 2011). A proposed method to mitigate this overestimation is by restricting the tested movement to only move in the vertical plane, often via a guided barbell machine (McBride et al., 2002; Sánchez-Medina et al., 2013). Conversely, the use of an LPT is likely the "gold standard" when it comes to upper-body profiling, as it is the most widely used and is a litmus test for other methods to be compared against (Rahmani et al., 2018). The use of an LPT during the bench press exercise is considered reliable and valid for measuring displacement and determining force, velocity, and power, with an ICC of >0.99, which is considered excellent (Alonso-Aubin et al., 2021; Cronin et al., 2004; McMaster et al., 2016). Thus, the LPT is an effective alternative for coaches and practitioners to assess athletes in the field.

Studies by Alonso-Aubin et al. (2021), Garcia-Ramos et al. (2017) and McMaster et al. (2016) made use of an LPT to assess the upper-body F-v profile via the bench press or bench press throw of a total of 139 participants. The paper by Rahmani et al. (2018) utilised a 3-dimensional accelerometer (Myotest pro) to compare results against a proposed method using a cable zip tie fixed around the rail of the guided barbell machine. The cable zip tie provided the maximum height the barbell reached as it was elevated by the barbell during the flight phase but would remain fixed on the rail at the final height once contact with the barbell ceased. The researchers found a strong to almost perfect agreement between the two methods (ICC > 0.99) for both force and velocity measures. Reliability presented as CV% for force and velocity was 4.8-6.7% and 7.7-15.7%, respectively. Thus, the Myotest system has been proven as a valid and reliable method of assessing upper body F-v profiles, with an ICC of > 0.96, which is considered excellent (Comstock et al., 2011). Furthermore, the cable tie method proposed by Rahmani et al. (2018) provided a cost-effective alternative that can be readily employed for any testing scenario.

2.5.1.3 Force Plates

Force platforms are considered the gold standard for assessing vertical jumps (McMaster et al., 2014; Nigg & Herzog, 1994; Read et al., 2016) and therefore, this method is the one which other tools are compared against (Cronin et al., 2004; Garnacho-Castaño et al., 2015; Giroux et al., 2014; Jiménez-Reyes et al., 2014; Jiménez-Reyes et al., 2017; Samozino et al., 2008). Typically speaking, force platforms in their complete form are expensive and cumbersome to deploy in field-based scenarios and are often only seen in a clinical setting (Walsh et al., 2006). However, smaller force plate products are now available such as the ForceDecks system (Vald Performance, Brisbane, Queensland). These smaller systems are designed to be mobile and are deployable in a gym or other field-based testing scenarios. Several papers have examined the relationship between the squat jump (SJ) and countermovement jump (CMJ) on force plates. Jimenez-Reyes et al. (2014) found that the CMJ F-v relationship is shifted up and to the right when compared to a SJ movement. The increased performance during the CMJ is due to the utilisation of the stretch-shortening cycle's elastic potential energy and a greater muscle active state due to the preparatory downward movement (Bobbert & Casius, 2005). Force plates are not without limitations though and depending on the method of calculation, slightly different results can be provided particularly for jump height. For example, the flight-time calculation method to determine peak jump height is the simplest but usually overestimates the jump height due to lack of consistency in landing and take-off procedure. This method involves determining the time spent in flight, t_{flight}, which is the time from take-off to landing, and the velocity at take-off, v_{to} as depicted in the following formula;

$$v_{to} = \frac{g t_{flig}}{2}$$

From these values, a time-displacement curve can be made which provides peak jump height. Conversely, the impulse-momentum method is slightly more complicated but proves to be the most reliable to calculate peak jump height and is calculate from the following formula;

$$\int_{t_i}^{t_{to}} F_{GRF} dt - \int_{t_i}^{t_{to}} mg dt = J_{GRF} - J_{BW} = m v_{to}$$

This method considers two independent impulses, the impulse due to the ground reaction forces, J_{GRF}, and the impulse due to the jumper's body mass, J_{BW} (Linthorne, 2001). Although this method is deemed to be the most accurate, it is sensitive to the proper selection of the instant a jump has commenced. Alternatively, the work-energy method to determine peak jump height is calculated using the following formula;

$$\int_{y_i}^{y_{to}} F_{GRF} dy - \int_{y_i}^{y_{to}} mgdy = W_{GRF} - W_{BW} = 1/2mv_{to}^2$$

The work-energy method happens to be the least reliable due to the double integration required to determine to calculate the jumper's centre of mass and is even more susceptible to the inaccurate selection of the instant a jump has commenced (Linthorne, 2001). Due to these factors, the work-energy method should be avoided (Linthorne, 2001). Therefore, force plates will remain the gold standard for clinical testing due to the breadth of metrics that can be gained in addition of F-v profiling (e.g., determination of limb asymmetries and rate of force development metrics).

Nomenclature			
t_{fligh}	time of flight from takeoff to landing	F	force
t_{to}	time at instant of takeoff	d	lowest point in countermovement jump
t_i	initial time	g	gravity (9.8m/s^2)
v_{to}	vertical takeoff velocity	F_{GRF}	ground reaction force
y_{fligh}	height of flight	J_{GRF}	impulse due to ground reaction force
y_{to}	height at instant of takeoff	J_{BW}	impulse due to jumper's body mass
y_i	initial height	W_{GRF}	work done due to ground reaction force
t	time	W_{BW}	work done due to jumpers' body mass
m	mass		

2.5.1.4 Phone Applications

The use of mobile phone applications such as MyJump (My Jump Lab, Madrid, Spain) are becoming more prevalent as a highly cost-effective and valid tool for measuring jump height (ICC 0.997, CV 3.6%) (Balsalobre-Fernández et al., 2015; Stanton et al., 2015). Again, using the equation proposed by Samozino et al. (2008), jump height is the only variable the app needs to measure for a practitioner to assess the F-v profile. A study by Cruvinel-Cabral et al. (2018) reported near perfect correlations between the jump heights obtained via the MyJump app and contact mats (r = 0.999) and the results were extremely reliable (ICC = 0.948, CV% = 10.096). These results are supported by a study by Bogataj et al. (2020) that found the MyJump app had strong correlations when compared to the OptoJump system (*r* = 0.97) and was also highly reliable (ICC > 0.89, CV% of < 5%). At present, to the best of our knowledge there are no studies that have used the MyJump application for assessing the F-v profile of an athlete, however based on these results the use of the application would be a justifiable method. Future research should be performed comparing F-v profiles taken with the MyJump application and with an established method such as force plates.

2.6 Conclusion

This literature review presented many valid and reliable methods to accurately assess the F-v profile of athletic populations. Methods pertaining to the assessment of lower-body F-v and power characteristics are more abundant in the research and have been more thoroughly tested. Notably, the method presented by Samozino et al. (2008) proves to be a simple to administer, cost-effective, and accurate way to assess a lower body F-v profile through the use of three measurements that most assessment technology can provide; body mass, height of push-off (*hpo*) and jump height. Conversely, methods for assessing the F-v and power characteristics of the upper-body are less prevalent in the literature. However, McMaster et al. (2016), Garcia-Ramos et al. (2017) and Alonso-Aubin et al. (2020) have presented studies where upper-body F-v profile assessments were performed. Currently, unlike the lower-body methods, no method exists for assessing the *FVimb* of the upper-body F-v profile.

While significant progress has been made in the last decade on establishing valid and reliable methods of F-v profiling that can be deployed efficiently in most sporting contexts, there is still room for further developments. For example, a method for assessing the optimal F-v profiles of upper-body movements would be immensely valuable for many sporting contexts, especially when used in conjunction with the already established method for assessing the optimal F-v profiles of lower-body movements (Samozino et al., 2012). In the event that an upper-body optimal F-v profile method is established, performing a study with a similar methodology to the investigation presented in Chapter Four would provide further insight into the force-velocity-power differences between positional groups and the influence of training age on those characteristics.

Chapter 3: Literature review of force-velocity profiling in rugby union

3.1 Preface

The purpose of this chapter is to identify and review the literature relating to the game and positional requirements of rugby union players. The topics in this chapter identify the physical and physiological requirements as it pertains to F-v characteristics. This review also acknowledges the existing literature on training experience and the potential influence it can have on performance metrics.

3.2 Introduction

Rugby union is a team-based contact field sport with unique physical and physiological demands that need to be met in order to succeed at the highest level. Elite rugby union players exhibit a distinct combination of high force-generating capabilities and high levels of aerobic and anaerobic physical conditioning. One of the primary physical determinants of performance in rugby union is a player's ability to generate great amounts of mechanical power during jumps and sprint accelerations (Cronin & Sleivert, 2005; Cronin & Hansen, 2005; Morin & Samozino, 2016). Importantly however, this power must be produced at high contractile velocities with respect to the environment a player is operating in. As power output is the product of force multiplied by velocity, these two factors are the primary determinants of mechanical power output in sporting movements (Cormie et al., 2011a; Cormie et al., 2011b; Samozino et al., 2013). Previous investigators have shown that individuals with greater levels of strength have a far greater ability to produce power than individuals with lower levels of strength (Stone et al, 2003; McBride et al, 1999; Baker & Newton, 2006; Baker & Newton, 2008). The influence of strength on power is that of increasing the force end of the F-v relationship (Hakkinen, 1989; Newton & Kraemer, 1994; Wilson et al, 1993). Therefore, in highly strength trained individuals, an increase in movement velocity can yield significant increases in power production.

A rugby match is comprised of two 40-minute halves where 30 players, two teams of 15, attempt to score points by gaining or maintaining possession of a ball and breaking through the defensive structure of the opposing team. Scoring is achieved when the ball is placed in the designated area at the end of the 100-metre field. The primary mechanism to halt an advancing player is for the defensive team to tackle the ball carrier resulting in a ruck where players can contest for possession of the ball. The low orientation of players during a ruck results in force-dominant movements (Cross et al., 2015). It was reported at the 2019 Rugby World Cup that there were 160+ rucks per game across the tournament, outlining the frequency of this position and the necessity for players to be able to repeatedly produce high force efforts (McCormick, 2021). Competitive rugby union players must also express significant velocity-based capabilities throughout a match as players frequently experience bouts of maximal acceleration and certain players, namely outside backs, are utilised primarily for their exceptional maximal velocity capabilities. Therefore, the ability to express greater levels of muscular strength and power directly influence the efficiency and effectiveness of a rugby union player as these physiological factors have been correlated to key performance indicators such as tackling efficiency, tackle and line breaks, and tries scored (Crewther et al., 2009; Gabbett et al., 2011; Smart et al., 2014). Indeed, while muscular strength and power influence playing performance, their effective development is crucial for coaches looking to optimise their players.

The purpose of this chapter is to detail the game and positional demands of rugby union players and how they may relate to their F-v characteristics. Finally, the current literature on the potential influence of training experience on physical, physiological and performance characteristics is presented.

3.3 Literature review search methods

An electronic database search was conducted using the search engines PubMed, Taylor & Francis Online and SPORTDiscus to identify potential articles. The following search terms were used: force, velocity, power, profile, squat jump (SJ), vertical jump, countermovement jump (CMJ), training experience and training age. Further literature was obtained from electronic 'related articles' searches and by manually screening the reference lists of included studies. The specific inclusion criteria included 1) force or velocity characteristics, 2) rugby union, 3) training experience, 4) a detailed explanation of the procedures and methods, 5) written in English, and 6) research studies with human participants.

3.4 Relevant physical demands of rugby union

Rugby union is a full body contact sport and players of all positions require high levels of strength and the ability to produce high forces in short amounts of time with their upper and lower body segments (Duthie et al, 2003; Argus et al, 2012; Smart et al, 2013; Crewther et al, 2011). However, due to the positional requirements of players during a game, there are distinct physical and physiological differences between forwards and backs (La Monica et al, 2016). Forwards are required to compete more frequently in rucks and mauls, make tackles against larger opponents (i.e., other forwards), and compete in set piece scrums and lineouts (Nicholas, 1997; McLean, 1992; Menchinelli et al, 1992). These positional requirements mean forwards must typically be stronger and larger than the backs. Conversely, the backs are typically smaller and tend to be much faster to meet their positional requirements of spreading the ball across the field and beating opponents through speed or line breaks (Nicholas, 1997; McLean, 1992; Menchinelli et al, 1992). Based on these characteristics, we can infer that playing position should impact the slope or balance of the F-v profiles of rugby union players as forwards will likely be more force dominant, while backs will likely be more velocity dominant.

All positions in rugby union, some more than others, are required to overcome resistive forces throughout a game. These resistive forces are expressed as rucks, mauls, scrums and tackles. Due to the inherently different roles of forwards and backs during a match, it is logical that the players themselves would have differing physical characteristics. For example, McMaster et al. (2016) found that when testing the upper-body F-V profiles of semi-professional rugby players, forwards were moderately stronger, had a significantly greater F_{max}, and expressed more absolute power than backs. However, trivial differences in V_{max} were reported. Furthermore, La Monica et al. (2016) found that forwards had significantly greater cross-sectional area of the vastus lateralis muscle than backs (38.3 ± 9.1 vs. 28.8 ± 7.3), which suggests that forwards have a greater capacity for potential force production (Maughan et al., 1984). In contrast, a study by Barr et al. (2014) reported that backs had greater acceleration (5.73 vs. 5.49 ms^{-1}) and maximal speed (9.08 vs. 8.3 ms^{-1}) when compared to forwards, which is indicative of their velocity dependent role. From these studies, we can infer that forwards tend to be more force dominant and backs tend to be more velocity dominant. The magnitude of these dominances may vary depending on the position itself, as it would be expected that a front row player would be even more force dominant than a flanker. The role of a front row player is to provide stability in the scrum and win possession of the ball through force and proper technique. As such, a front row player is subjected to and applies great forces during scrummaging (Quarrie & Wilson, 2000). It has also been reported that front row players perform the least number of sprints in a match (8.73 ± 4.52), reflecting the requirements of their force dependent role (Cunningham et al., 2016). Conversely, a flanker, is required to cover the opposition half-back in the event of losing a scrum for example, and as such, is required to accelerate and sprint far more often than the front row players. Flankers also apply much less force during scrummaging due to their less optimal scrum position and their aforementioned role in defending the opposition half-back (Quarrie & Wilson, 2000). Cunningham et al. (2016) reported that flankers performed more sprints (14.07 ± 5.29) than the front row, second row, and half backs, which reflects their more velocity dependent role. Likewise, an outside back would be expected to be more velocity dominant than a centre. The role of an outside back is to be the fastest player on the field to be both an offensive weapon and a defensive necessity covering large amounts of ground quickly. Cunningham et al. (2016) stated that outside backs (wings and full back) performed the most sprints in the game (28.89 ± 6.11), while also covering significantly more high-speed running distance than half backs and all forwards positions, along with mid-field players (no. 10, centres). While that same report states that mid-field players performed only slightly less sprints (27.86 ± 6.32) in a match than the back three (28.89 ± 6.11) and covered a similar amount of high-speed running distance, it can be assumed that centres are more often involved in ruck positions and are expected to crash the ball into defenders to break the line more often than the outside backs.

3.5 Force velocity profiling and rugby union

Several studies have investigated the horizontal F-v relationships of players in rugby union (Cross et al., 2016; Brown et al., 2016; Haugen et al., 2019; Watkins et al., 2021). However, few studies have compared the vertical lower-body force-velocity profiles of forwards and backs (La Monica et al., 2016), and even fewer studies using professional level participants (Argus et al., 2012). A study by Watkins et al. (2021) which identified the horizontal force-velocity profiling differences between forwards and backs found that sprint times and maximal velocity characteristics improved linearly with positional number, and that forwards had a more force-dominant profile when compared to all backs. Interestingly though, the study found that loose forwards, while maintaining a more force-dominant profile and slower sprint times, had similar velocity characteristics to inside backs, demonstrating the variability of specific positional demands within the forwards and backs groups. It appears that forwards and backs may have similar mechanical power production capabilities, however the force or velocity characteristics that account for power production do vary greatly. The difference in power capabilities may become more apparent at higher levels of competition due to training experience and physical maturation (Argus et al., 2012).

As discussed in chapter 3.4.2, the horizontal and vertical F-v profiles of rugby union players vary based on their playing position as each position has a different role that demands differing force or velocity characteristics. McMaster et al. (2016) investigated the difference between the countermovement bench press throw and concentric-only bench press throw, which provides insight into the ballistic capabilities of an athlete. Both profiles allow for force and velocity deficiencies to be identified; however, the additional constraints of the concentric-only bench press throw help to identify whether an athlete lacks stretch-shortening cycle (SSC) capabilities. From the results of this study, it was observed that forwards appeared to be more force-dominant in these movements and backs appeared to be more velocity-dominant (McMaster et al., 2016). The researchers also concluded that P_{max}, F_{max} and V_{max} measures may be a suitable metric to identify proficient and deficient capabilities in ballistic performance (McMaster et al., 2016). Generally, rugby union players are trained to overcome and displace resistive forces and thus tend to display an F-v profile imbalance towards force characteristics (Samozino et al., 2013).

3.6 Effects of training age on force and velocity characteristics

The age of an athlete can be separated into three distinct categories: chronological age, biological age, and training age. Chronological age is simply the number of years since birth and should be considered the bare minimum age distinction taken into account when working with an athlete. Biological age provides a far more effective insight into the physical capabilities of an individual than chronological age (Bompa & Buzzichelli, 2016; Drabik, 1996; Mero et al., 1990). Biological age represents the culmination of various factors including chronological age and the state of numerous biomarkers such as the concentration of prostacyclin in fibroblasts, cell membrane viscosity, electroretinogram, baroreflex regulation of heart rate, concentration of lymphocytes, leucocyte density and velocity, grip strength, corneal endothelium and the buccal epithelium, neck muscle mobility, and vital capacity (Jackson et al., 2003). The state of these biomarkers varies depending on various factors such as lifestyle, genetics, and diseases. The most effective way to ascertain biological age in athletes is through the assessment of sexual maturation due to the increase in circulating testosterone (Mero et al., 1990; Gurd & Klentrou, 2003; Rilling et al., 1996). An athlete with a greater biological age can demonstrate a proportionately greater physical maturation and will therefore tend to be stronger and faster than another athlete with the same chronological age but a lower biological age (Bompa & Buzzichelli, 2016; Mero et al., 1990; Gurd & Klentrou, 2003). Finally, training age can be considered as the experience of an athlete within a preparatory sporting context. Brewer (2007) defined training age as “the number of years an individual has been preparing for a sporting activity”. Individuals with a greater training age would logically be expected and are more likely to have a greater training foundation. However, this can be dependent on the number of years spent performing multilateral vs. specialised training. An individual who has spent their formative years performing multilateral training (non-specific strength and conditioning, cross-training for other sports) will typically have a better foundational basis for future athletic development than an athlete that has performed specialised training from a very early age (Balyi & Hamilton, 1993; Smith, 2003).

In the context of rugby union, an increase in performance characteristics due to chronological age was found by Darrall-Jones et al. (2015), who reported greater muscular strength and aerobic performance from elite U18 rugby union players compared to elite U16 players. While this study was focused on chronological age as a determining variable, it can be inferred that the U18 players also had a greater sport specific training age than their U16 counterparts. Conversely, a study by Chiwaridzo et al. (2017) reported a significant association between age category and playing standard in the vertical jump test, 2kg medicine ball chest throw, Yo-Yo intermittent recovery tests, and skill-based tackling and catching tests for rugby players of various ages and levels. It is likely that the differences in the resulting data would come from differing training ages and varied exposure to sport-specific stimuli. However, it must be noted that for studies comparing age category or playing standards, chronological and biological age-related changes in physiology and morphology must be considered.

3.7 Conclusions

This literature review presents the positional differences in force and velocity characteristics between rugby union forwards and backs found. While rugby union players generally tend to be more force dominant as a group, forwards exhibit a force dominant profile while and backs have been shown to be more velocity dominant. These differences in force and velocity capabilities between positional groups is due to the distinct positional requirements within these groups. For instance, forwards participate in more instances of overcoming resistive forces such as rucks, mauls and scrums, and are required to tackle larger opponents. In contrast, backs are involved in more instances of high contractile velocity movement such as accelerating, sprinting and changing direction due to their role of spreading the ball across the field and attacking the defensive line with speed.

Finally, it is evident that chronological, biological and training age significantly influence physical performance. Greater training ages typically result in a greater foundation for performance due to more exposure to stimuli. However, it is difficult to separate the effects of training age and chronological age as it is uncommon for an individual to have a greater training age but a lesser chronological age when compared to another individual.

Chapter 4: Force velocity profiling of professional rugby union players

4.1 Preface

Given that the use of force-velocity profiling for informing training prescription is well established, it would be beneficial to coaching staff and sport scientists to further understand the influence of an athlete's background on their F-v characteristics. It is well-documented that rugby union players are biologically and physiologically varied depending on playing position due to the specific requirements of that role during a game, and the inherent training required for that role. Therefore, logically it could be assumed that forwards would likely be more force dominant than backs, who in contrast would likely be more velocity dominant. Additionally, the influence of training experience plays an important role on the prescription of training for any athlete. The expectations of a coach on an athlete are typically drawn through assessment, however prior to assessment, learning details about an athlete's background such as training history, previous sporting experience etc, can provide valuable information required to make educated decisions about prescribing training variables.

4.2 Introduction

The force and velocity characteristics of athletes and their contribution to power output are vital components to many sporting contexts. All sporting actions are inherently determined by their force-velocity-power requirements, and these actions include but are not limited to pushing, pulling, jumping, sprinting, tackling, kicking and throwing (Cunniffe et al., 2009; Robbins et al., 2013; Nibali et al., 2013; Stone et al., 2003; Newton et al., 1997). It has long been the role of a strength and conditioning professional to develop these force-velocity-power qualities through the manipulation of training prescription to fit the athlete and their sporting context. The manipulation of training prescription is the method with which strength and conditioning professionals address the weaknesses of their athletes and as such, effective assessment and monitoring could be considered equally as crucial. The assessment of athletic capabilities and characteristics is a common occurrence in high-level sporting environments and the methods are ever evolving to become more efficient and more accurate.

The measurement of absolute and relative force-velocity-power characteristics is critical for athletes due to the aforementioned importance of these qualities in various sporting contexts. However, the quantification of the balance between force and velocity characteristics has also proven to be useful for prescribing informed training plans based on evidence. For example, recent research describes the implications on performance for athletes that have significant force-velocity imbalance (*FVimb*). A study by Samozino et al. (2012) showed that a *FVimb* could result in a ~30% decrease in ballistic performance regardless of whether the imbalance was due to a force or velocity deficiency (Samozino et al., 2012). Furthermore, a paper by Jimenez-Reyes et al. (2017) demonstrated that when training is prescribed based on addressing an athlete's force or velocity deficiency, the individuals experienced a 7.2 – 14.2% increase in jump performance, while the non-optimised and control groups experienced a trivial improvement of 2.3% (Jimenez-Reyes et al., 2017). These papers emphasised the importance of accurately assessing the absolute and relative force-velocity-power characteristics of athletes and using those results to inform future training prescription if the goal is ballistic performance.

Given the differing biological and physiological requirements of positional groups in rugby union (i.e., size, speed, strength, power, *FVimb*), it would be advantageous to better understand the force and velocity tendencies within these positional groups. All positions in rugby union are required to possess high levels of absolute strength and power for both the upper body and lower body segments (Duthie et al., 2003; Argus et al., 2012; Smart et al., 2013; Crewther et al., 2011). Furthermore, rugby union players generally tend to present with F-v imbalances toward force dominance due to their sport specific requirements of overcoming and displacing resistive forces (Samozino et al., 2013). However, forwards are often considered to be the more force dominant positional group whereas backs are considered to be the more velocity dominant group (McMaster et al., 2016; Nicholas, 1997; Barr et al., 2014; La Monica et al., 2016). These differing dominant characteristics are due in large part to the physical requirements of the individual playing positions within these positional groups. These physical requirements cause forwards to display different anthropometry than backs, forwards are typically heavier and thus the absolute forces they can produce are greater. Consequently, the majority of training time is spent in a manner to increase the performance in a given position leading to these force or velocity dominances.

Meyer et al., (2013) defined training age as "the amount of time accumulated from both periodic and longitudinal participation in training programs and sport related activities that foster the development of musculoskeletal health, basic movement patterns and overall physical fitness (p.2)". Training experience can provide valuable insight into the longevity and performance of an athlete. It would be logical to assume that an individual with a greater training age will have a greater training foundation. This assumption is also backed by literature, as Cormie, McGuigan and Newton (2011) found that individuals who had been performing periodised strength training for ≥3 years have drastically increased muscular power output capabilities when compared to lesser trained individuals (Cormie, McGuigan & Newton, 2011). One must note that when measuring or discussing the effects of training age, it is difficult to not also include chronological age and physical maturity in that discussion. Chronological age referring to the number of years since birth and physical maturity referring more to biological age which accounts for the development of numerous biomarkers (refer to Chapter 3.6).

A considerable amount of the time spent training and physically preparing to play rugby union is spent performing movements that require application of force in the vertical axis. The inclusion of vertical F-v profiling allows objective recording of progress regarding overall power production. The purpose of this study is to establish the influence of playing position and training age on these vertical F-v profiles which can be used to better inform training decisions by providing a valuable, objective metric for the contribution of force and velocity characteristics to overall power production. We hypothesised that forwards would display greater absolute and relative force characteristics while backs would display greater absolute and relative velocity characteristics. Furthermore, while generally all rugby union players have a tendency towards force dominance, we hypothesised that forwards would display a greater force dominance than backs. Lastly, we hypothesised that individuals with a greater training age would be able to produce greater relative force at higher velocities than those with a lower training age.

4.3 Methods

4.3.1 Experimental approach to the problem

The aim of this study was to ascertain the influence of playing position on the vertical F-v characteristics of professional rugby union players and the potential influence of training experience on those same characteristics. Professional rugby players were chosen as they are highly trained and typically exhibit a large variance in chronological age and training experience. The F-v profiles were determined through participants performing squat jumps across a range of loads from 0-100% of body mass with a linear position transducer attached to their body via a waist belt. The back squat movement was chosen in contrast to measure maximal lower body strength. Both the back squat and squat jump movements appear frequently in the literature and are common exercises in a high-level training environment. The training age (at a provincial rugby level or higher) of players was determined through a qualitative questionnaire (appendix D) that players filled out during the initial consent and screening phase.

4.3.2 Participants

For this investigation, 14 trained professional male rugby union players (n = 14, age = 23.4 ± 2.4 yrs) between the ages of 18-35 were recruited. The inclusion criteria for this study were as follows; 1) professional male rugby union players aged 18-35 years, 2) no current acute or chronic injuries or medical conditions, 3) involved in a high-performance resistance training programme for ≥ 6 months, 4) appropriate joint mobility and technique to perform the back squat and squat jump and, 5) not using any performance enhancing or banned substances (World Anti-Doping Agency, 2021). The purpose of the study, testing procedures and the risks associated with participating in the study were explained prior to obtaining written consent to participate. This study was approved by the Auckland University of Technology Ethics Committee on 4/11/21, approval number 21/180 (AUTEC).

4.3.3 Testing procedures

Initially, all participants undertook a familiarisation session seven days prior to the first testing session to ensure they understood the procedures and were comfortable performing the movements to the best of their ability. During the familiarisation and testing sessions, the participants were asked to perform back squats and jump squats at varying intensities to expose them to the movements with some degree of loading. Coaching cues were given to participants if their technique was deemed outside of an acceptable range. The acceptable range was determined by the primary researcher and was only acted upon in the instance an athlete's current technique was such that it hindered the ability to perform the movement effectively or hindered the potential results beyond a reasonable degree. Testing took place over two days with three days in-between testing sessions. Prior to any testing taking place, participants took part in a standardised warm-up that was relevant to the testing protocol of that session. The warm-up for squat jumps included multiple sets of depth drops from boxes, box jumps, and squat patterns to prepare the participants for dropping with load and explosive jumping. Prior to testing for maximal back squat, all participants were taken through a standardised warm-up including foam rolling and multiple sets of duck walks, fire hydrants and a squat pattern to prepare for maximal effort back squatting. All metrics from both testing sessions were recorded from a linear position transducer (LPT) (GymAware PowerTool, Kinetic Performance PTY Ltd., Mitchell, ACT, Australia). The GymAware LPT has been proven valid and reliable for the squat jump and back squat exercises (CV 2.1 – 8.5%, ICC 0.85 – 0.97) (Cronin et al., 2004; García-Ramos et al., 2016; Garnacho-Castaño et al., 2015).

4.3.3.1 Participant information

Participants were each provided a consent form (see appendix A) and a participant information sheet (see appendix B) which outlined the details of the study and what was required of them. Included in the consent form was a short survey that contained questions directed toward training experience (see appendix D). Upon completion of this survey, the participants were taken into a private area to have their weight (kg) taken on a calibrated scale. Participants were then asked to lie down on their side while a measurement was taken from their greater trochanter to the tips of the toes while plantarflexed. The limb length measurement was used during the statistical analysis to determine the height of push-off (*hpo*).

4.3.3.2 Squat jump

The squat jump testing was performed during the first session after participants completed a warmup set of squat jumps which also served as a reminder of proper technique and procedure. Participants performed barbell squat jumps with loads of 0%, 25%, 50%, 75% and 100% of body mass. A linear position transducer (LPT) was attached to the participant via a belt that was secured tightly with the attachment point slightly above the greater trochanter. The position of the belt ensured that the GymAware tether was lined up with greater trochanter for the accurate measurement of jump height.

The starting position for the squat jump was defined as an approximately 90-degree knee angle and corresponding approximate 90-degree hip angle (see Figure 4 for illustration). The corresponding height of their centre of mass (COM) was recorded via the GymAware software by checking the length of the tether.

Safety pins were used during this test for the safety of the participants, as jumping with 100% body mass can be potentially hazardous (See Figure 4). The safety pins were set at a position just below the participants' starting position, and the participant would take the weight of the barbell and hover over the pins in their starting position. During the first repetitions, the height of the individuals COM was checked using the GymAware software as outlined above. In subsequent repetitions, this distance was checked prior to commencement of the jump and if the distance was out by more than 2cm, the repetition would not be used. Participants performed two individual attempts with correct form at each load for both movements with at least 1-minute rest between attempts and at least 2-minutes rest between attempting a new load. If a repetition was performed incorrectly (e.g., with a countermovement, landing without full extension and plantarflexion), the participant repeated that repetition. The best attempt at each load was used in the analysis. The squat jump is considered a safe movement and is a test frequently performed in the literature regarding research of power output and ballistic performance (Samozino et al, 2012; Djuric et al, 2016; Jiménez-Reyes et al; 2018; Rahmani et al, 2018).

The squat jump analysis was performed using the method proposed by Samozino et al. (2008) whereby the measures needed to determine *F0*, *V0*, P_{max} and *Sfv* are jump height (*h*, Figure 6), starting position height (h_s, Figure 4), and the height of push-off (*hpo*, Figure 5). Refer to Figure 3 for an illustration that demonstrates these positions in relation to jumping.

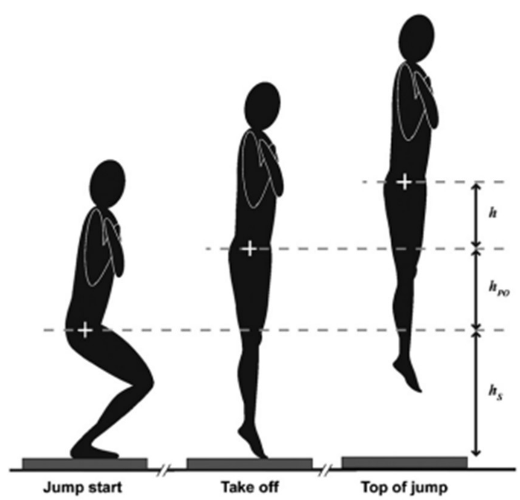

Figure 3. Illustration of jump squat measurements

Figure 4. Starting position (h_s).

Figure 5. Push off height (h_{po}).

Figure 6. Jump height (h).

4.3.3.3 Back squat

The back squat movement was performed during the second testing session. The load gradually increased at the participant's discretion until a 1RM maximal effort had been performed within approximately 4-6 sets. A maximal effort was defined as a successful attempt at a load with no assistance from a spotter with no egregious breakdown of form. Participants were given an additional attempt at a failed weight if the attempt was close to being successful, or if the participant verbally acknowledged they believe they could complete it successfully. Participants were allowed to perform two to three maximal effort attempts to ensure they reached their true attainable maximal effort. An LPT (GymAware Powertool, Kinetic Performance PTY Ltd., Mitchell, ACT, Australia) was attached to the knurling of the barbell close to the collar and was used to measure mean power (W), mean power (W/kg), mean velocity (m/s), peak power (W), peak power (W/kg) and peak velocity (m/s). From these variables, mean force (N), mean force (N/kg), peak force (N) and peak force (N/kg) were ascertained using a simple derivative equation for power.

$$F = P/V$$

4.3.4 Statistical analysis

All variable results were tested for normality and analysed through descriptive statistics of means and standard deviations. Independent samples T-tests were used to identify whether there was a statistical difference between the associated population means. Bivariate partial correlations were used to explore the relationship between the independent variables and the dependent variables in the force-velocity profile (power (W), force (N), velocity (m/s-1) while adjusting for a confounding variable, in this case, body mass (Pallant, 2016).

Statistical significance was set at P ≤ 0.05, with all analysis carried out using Statistical Package for the Social Sciences (SPSS) (Version 22.0 for Mac, SPSS Inc., Chicago IL, USA). Effect size magnitude were calculated using the Hedges G (1985) criteria where < 0.35 was a trivial effect, 0.35 – 0.80 was a small effect, 0.80 – 1.50 was a moderate effect and >1.50 was a large effect size (Hedges, 1985). Hedges G was used due to the small sample size in this study (n = 14), the Hedges G being the recommended effect size criteria for sample sizes below 20.

4.4 Results

4.4.1 Participants

The descriptive details of the study participants are outlined in Tables 1 and 2. A significant difference in body mass existed between forwards and backs (forwards = 117.53 ± 7.04, backs = 93.42 ± 7.98, p <.001, g = 3.24).

Table 1. Participant information

	n	*M*	*SD*
Age	14	24.36	2.44
Body Mass (kg)	14	107.19	14.30
Training Experience	14	5.36	2.76
Playing Experience	14	4.21	2.12

Table 2. Participant information comparing positional groups

	Forwards			Backs			Mean Difference	95% Confidence Interval		*t*	*p*	Hedge's *g*
	n	*M*	*SD*	*n*	*M*	*SD*		Upper	Lower			
Age	8	24.5	2.39	6	24.17	2.71	0.33	2.644	-3.311	-0.24	0.81	0.13
Body Mass (kg)	8	117.53	7.04	6	93.42	7.98	24.11	-15.347	-32.869	-6.00	<.001*	3.24****
Training Experience (yrs)	8	5.13	2.03	6	5.67	3.72	-0.54	3.908	-2.825	0.35	0.73	0.19
Playing Experience (yrs)	8	3.75	1.58	6	4.83	2.71	-1.08	3.587	-1.421	0.94	0.36	0.51

Significance * = p <0.05.
Effect Size (ES) Hedge's *g* * = Trivial (<0.35), ** = Small (0.35-0.80), *** = Moderate (0.80-1.50), **** = Large (>1.50).

4.4.2 Squat jump

The maximal theoretical force (*F0*) for forwards was significantly greater when compared to backs (forwards, *M* = 4354 *SD* = 1033, backs, *M* =3288, *SD* = 557, *p* = 0.04, *g* = 1.23). However, no significant difference in the relative force existed between these positional groups (forwards, *M* = 37.25, *SD* = 9.7, backs, *M* = 35.17, *SD* = 4.67, *p* = 0.64, *g* = 0.26). Furthermore, a strong, positive correlation was found between maximal power (P_{max}) and *Sfv* (*r* = 0.66), and P_{max} and *V0* (*r* = 0.91) in both forwards and backs. Conversely, a strong, negative correlation existed between the maximal theoretical force (*F0*) and the slope of the F-v profile (*Sfv*) (*r* = -0.93), and *F0* and the maximal theoretical velocity (*V0*) (*r* = -0.73) in the combined data of forwards and backs (refer Table 3). There was a strong, positive correlation between training experience and the optimal slope of the force-velocity profile (*SfvOpt*) (*r* = 0.57).

Performing zero-order correlation coefficient inspections indicated that controlling for body mass had very little effect on the relationship between most of the measured variables. However, controlling for body mass had some effect on the relationship between P_{max} and *Sfv* (*r* = 0.49), this was the only relationship that became statistically non-significant when not controlling for body mass (refer Table 5).

4.4.3 Back squat

The mean and peak force (N) during the back squat was significantly greater for forwards (*M* = 2846.27, *SD* = 424.76) when compared to backs (*M* = 2304.63, *SD* = 260.81, *p* = 0.02, two-tailed, *g* = 1.48). However, no statistically significant difference existed in relative force (N/kg) between forwards (*M* = 25.10, *SD* = 2.55) and backs (*M* = 24.66, *SD* = 1.44, *p* = 0.71, two-tailed, *g* = 0.20) (refer Table 4).

No statistically significant correlations were found between training age and any of the back squat variables.

The zero-order correlation coefficient inspection indicated that the relationship between peak power and peak force was the only relationship that became statistically non-significant when not controlling for body mass (refer Table 6). Controlling for body mass had little to no impact on the relationships between all other back squat variables.

Table 3. Force and velocity measures of the squat jump

	Forwards			Backs			Mean Difference	95% Confidence Interval		*t*	*p*	Hedge's *g*
	n	*M*	*SD*	*n*	*M*	*SD*		Upper	Lower			
F0 (N)	8	4354.64	1033.67	6	3288.90	557.65	1065.74	-44.77	-2086.71	-2.27	0.04*	1.23***
F0 (N/kg)	8	37.25	9.70	6	35.17	4.67	2.08	7.331	-11.49	-0.48	0.64	0.26
Sfv (N.s/m)	8	-1357.72	798.61	6	-802.32	350.52	-555.40	1320.91	-210.12	1.58	0.14	0.85
Sfv (N.s/m/kg)	8	-11.61	6.92	6	-8.53	3.39	-3.08	9.807	-3.66	0.99	0.34	0.54
V0 (m/s)	8	4.14	2.09	6	4.44	1.08	-0.30	2.350	-1.75	0.32	0.76	0.17
P_{max} (W)	8	4132.31	1249.01	6	3575.70	705.02	556.62	687.07	-1800.31	-0.96	0.35	0.53
P_{max} (W/kg)	8	35.28	10.63	6	38.45	8.19	-3.17	14.57	-8.23	0.61	0.56	0.33
SfvOpt (N.s/m/kg)	8	-18.01	1.51	6	-18.42	1.86	0.41	1.55	-2.37	-0.46	0.65	0.25

Significance * = p <0.05.
Effect Size (ES) Hedge's *g* * = Trivial (<0.35), ** = Small (0.35-0.80), *** = Moderate (0.80-1.50), **** = Large (>1.50).

Table 4. Force and velocity measures of the back squat

	Forwards			Backs			Mean Difference	95% Confidence Interval		*t*	*p*	Hedge's *g*
	n	*M*	*SD*	*n*	*M*	*SD*		Upper	Lower			
Barbell Weight	8	178.75	30.91	6	140.83	20.10	37.92	-6.22	-69.62	-2.61	.02*	1.41***
Mean Power (W)	8	909.13	332.56	6	1000.00	291.08	-90.88	462.64	-280.89	0.53	0.60	0.29
Mean Power (W/kg)	8	7.93	2.52	6	10.59	2.43	-2.66	5.59	-0.261	1.98	0.07	1.07
Mean Velocity (m/s)	8	0.32	0.11	6	0.43	0.11	-0.11	0.24	-0.015	1.92	0.08	1.00
Mean Force (N)	8	2846.27	424.76	6	2304.63	260.81	541.64	-111.57	-971.71	-2.74	0.02*	1.48***
Mean Force (N/kg)	8	25.10	2.55	6	24.66	1.44	0.44	2.10	-2.98	-0.38	0.71	0.20
Peak Power (W)	8	2681.38	775.40	6	2602.83	722.86	78.54	808.63	-965.71	-0.19	0.85	0.10
Peak Power (W/kg)	8	23.36	7.24	6	27.57	5.81	-4.20	12.07	-3.66	1.17	0.27	0.63
Peak Velocity (m/s)	8	0.83	0.25	6	0.98	0.18	-0.14	0.40	-0.11	1.21	0.25	0.67
Peak Force (N)	8	3211.11	318.51	6	2633.98	401.54	577.13	-158.85	-995.41	-3.01	0.01*	1.62****
Peak Force (N/kg)	8	27.82	2.85	6	28.12	2.55	-0.31	3.52	-2.90	0.21	0.84	0.11

Significance * = p <0.05.
Effect Size (ES) Hedge's *g* * = Trivial (<0.35), ** = Small (0.35-0.80), *** = Moderate (0.80-1.50), **** = Large (>1.50).

Table 5. Pearson product-moment partial correlations between jump squat measures and training experience accounting for body mass

Scale	**1**	**2**	**3**	**4**	**5**	**6**
1. Training experience	-					
2. *F0* (N)	-0.43	-				
3. *Sfv* (N.s/m)	0.31	-0.93**	-			
4. *V0* (m/s)	0.18	-0.73*	0.86**	-		
5. P_{max} (W)	-0.02	-0.41	0.66*	0.91**	-	
6. *SfvOpt* (N.s/m/kg)	0.57*	-0.08	-0.04	-0.34	0.47	-

* = $p < 0.05$, ** = $p < 0.001$ (two-tailed).

Table 6. Pearson product-moment partial correlations between back squat measures and training experience accounting for body mass

Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Training Experience	-							
2. Barbell Weight (kg)	0.48	-						
3. Mean Power (W)	-0.32	0.11	-					
4. Mean Velocity (m/s)	-0.44	-0.16	0.96**	-				
5. Mean Force (N)	0.36	0.92**	0.31	0.04	-			
6. Peak Power (W)	-0.07	0.04	0.56*	0.54	0.33	-		
7. Peak Velocity (m/s)	-0.21	-0.17	0.59*	0.63*	0.15	0.97**	-	
8. Peak Force (N)	0.39	0.78*	0.37	0.15	0.86**	0.63*	0.43	-

* = $p < 0.05$, ** = $p < 0.001$ (two-tailed).

4.5 Discussion

Force-velocity profiling is an effective assessment tool in most sporting contexts and can be performed with minimal equipment and with great accuracy. The use of F-v profiling is beneficial to strength and conditioning practitioners due to the results directly informing appropriate training prescription.

The intention of this study was to further clarify and understand the role of playing position and training age on the vertical F-v profiles of professional rugby union players. It was hypothesised that differences between the positional groups would exist. Specifically, forwards would produce greater force values than backs, while backs would produce greater velocity values than forwards. The proposed effect can be attributed to the positional requirements of these groups and the tendency for certain force and velocity characteristics to belong to players in one of these groups. In addition, it was also hypothesised that athletes with greater training experience would be able to produce higher relative forces at higher velocities when compared to a less experienced athlete.

The main findings of this investigation were 1) forwards produced more absolute force than backs in both the squat jump and back squat however, no differences in relative force existed between positional groups, 2) the present study did not identify any significant correlation between training experience and force or velocity metrics.

The physical differences between forwards and backs are well documented in the literature. Logically, these differences can be expected to arise due to the anthropometrical differences and characteristics relating to their positional requirements. As hypothesised, forwards presented with a greater maximal theoretical force (*F0*) value than backs in the jump squat movement and presented with greater mean and peak forces than backs in the back squat movement. The relative force differences seen between forwards and backs are likely due to anthropometrical differences but may also be due to the various positional requirements of rugby union players. It has been established that forwards are generally more force-dominant than backs, while backs are generally more velocity-dominant (Watkins, 2021; La Monica et al., 2016; Cunningham et al., 2016; Crewther et al., 2009). Forwards and backs by their very nature are exposed to differing stimuli over the course of a game and these tendencies toward force or velocity dominance may be explained by the physical characteristics required to play a certain position at a high level. Forwards are required to engage in greater frequencies of tackling, scrummaging, rucking and mauling events (Crewther et al., 2009; Nicholas, 1997; McLean, 1992; Menchinelli et al, 1992). Therefore, training and playing as a forward involves consistent exposure to overcoming high resistive forces. A study by La Monica et al. (2016)

reported that the cross-sectional area of the vastus lateralis muscle was significantly greater in forwards (38.3 ± 9.1) than in backs (28.8 ± 7.3,) which provides evidence of the differing force requirements between positional groups. Conversely, backs are required to engage in greater instances of maximal velocity sprinting and brief periods of rapid acceleration (Quarrie & Wilson, 2000; Cunningham et al., 2016). Therefore, in a similar vein to the forwards, the horizontal F-v characteristics of a back are developed through consistent exposure to these instances of maximal velocity sprinting and rapid acceleration. A study by Barr et al. (2014) reported that backs present with greater acceleration (5.73 vs. 5.49 ms-1) and maximal speeds (9.08 vs. 8.3 ms-1) when compared to forwards. In line with this notion, it was expected that backs would display a greater maximal theoretical velocity (*V0*) value than forwards when measuring vertical F-v characteristics. Again, we would expect to see backs present with greater mean and peak velocity values during the back squat than forwards. However, no significant differences were seen for mean and peak velocity and mean and peak power values. The lack of statistical significance could be due to the relatively small sample size. However, McMaster et al. (2016) reported similar results when testing forwards and backs upper-body force-velocity profiles, noting that forwards were generally stronger, had significantly greater F_{max} and were able to express more absolute power with trivial differences in V_{max}. Due to the vertical components of both the game itself and weight room training being markedly similar regardless of position, peak and mean force and velocity values displayed no significant difference between positional groups. This result differs from the positional differences in horizontal F-v profiling that has been established in the literature, with split times decreasing and velocity characteristics increasing relative to positional number. That is, forwards presented with a more forceful and slower velocity horizontal F-v profile, while backs were the opposite (Watkins et al., 2019).

Samozino et al. (2012) describes the mechanical F-v profile as the ratio between *F0* and *V0* and provides the equation:

$$S_{fv} = -\frac{F_0}{V_0}$$

This equation indicates that the lower the value of *Sfv*, the steeper the slope of the relationship between force and velocity. A steeper slope represents greater force capabilities compared to velocity capabilities (Samozino et al., 2012; Cormie et al., 2010). In this study, there was a noticeable magnitude of difference between relative *Sfv* and *SfvOpt* within the respective groups. Forwards presented with a mean *Sfv* of -11.61 ± 6.92 $N.s.m^{-1}.kg^{-1}$ and a *SfvOpt* of -18.01 ± 1.51 $N.s.m^{-1}.kg^{-1}$, while backs presented with a mean *Sfv* of -8.53 ± 3.39 $N.s.m^{-1}.kg^{-1}$ and a *SfvOpt* of -18.42 ± 1.86 $N.s.m^{-1}.kg^{-1}$. These observed results display that on average, the participants in this study were velocity dominant and therefore should aim to develop their vertical force capabilities to minimise the imbalance between *Sfv* and *SfvOpt*. This observation that rugby players to be velocity dominant could be explained by their exposure to greater contractile velocities during training. The individual F-v profiles of the participants in this study ranged from 19% to 131% of their optimal profiles. Interestingly, rugby players have previously been identified in the literature as a sporting discipline with great variance in participant F-v profiles (Samozino et al., 2012). The authors identified a range of *Sfv* values from -16.8 to -4.9 $N.s.m^{-1}.kg^{-1}$ which translates to a range of F-v profiles from 36% to 104%. This range is indicative of the varying roles rugby players are required to play not only within the forward and back dynamic, but within those independent groups themselves. This investigation found a correlation between training experience and the optimal force-velocity slope (*SfvOpt*). As such, a greater training age resulted in a decrease in the steepness of the slope of the optimal F-v relationship. This decrease in steepness could present itself as either lessened *F0*, greater *V0* or a combination of both.

The optimal F-v profile of a given athlete is dependent on certain characteristics such as limb extension range, P_{max} and inertia (Samozino et al., 2012). As stated by Samozino et al. (2012) "two individuals with the same P_{max} and Hpo are likely to achieve different results due to their respective F-v profiles i.e., to their respective ratios between maximal force (*F0*) and maximal velocity (*V0*) capabilities." (Samozino et al., 2012, p. 318). For each of these individuals, a unique and individually specific optimal F-v profile exists (i.e., an optimal ratio between maximal force (*F0*) and maximal velocity (*V0*) capabilities that would achieve an optimal performance). The results of this study indicate that the years of resistance training experience will influence the ratio of *F0* and *V0* within the optimal slope. Specifically, by lessening the steepness of the linear relationship between force and velocity i.e., bringing the negative value associated with *Sfv* closer to 0.

Samozino et al. (2012) demonstrated that an increase in ballistic performance is achieved by 1) increasing power capabilities and, 2) moving the F-v profile closer to the optimal profile (Samozino et al., 2012). To make the desired changes in the slope of the F-v relationship, specific training protocols should be employed (Cormie et al., 2010; Kaneko et al., 1983). For an athlete with an *FVimb* towards force deficiency, it would be exceedingly beneficial to improve velocity characteristics through ballistic training (<30% of 1RM) (Samozino et al., 2012; Cormie et al., 2010; Cronin & Sleivert, 2005; McBride et al., 2002). Whereas an athlete with an *FVimb* towards velocity deficiency should aim to improve force characteristics with heavy loading (>75% of 1RM).

It can be inferred from the literature that training experience likely has an effect on performance metrics, as long as the training effect is relevant to the desired metric. A study by Cormie, McGuigan & Newton (2011) posited that individuals performing periodised strength training for longer than three years would be capable of greater power outputs. In contrast to our hypothesis, no significant correlations were found between force, velocity or power metrics in this study. However, this could be due to limited specific training experience. The average training experience for forwards was 5.13 ± 2.03 years, and for backs was 5.67 ± 3.72 years. While it is likely that the players had been performing weight training for these years, it is also likely that strength or power training relevant to the movements performed in this study were also taking place. That is, strength training with the purpose of increasing squat or squat jump performance. Another important note is that of biological age, which is inherently different from chronological age and can be considered a better indication of performance potential. In athletes of the same chronological age, it appears that athletes with a greater biological age tend to be stronger, faster, and better performers (Mero et al., 1990; Gurd & Klentrou, 2003).

4.6 Conclusions

The main finding of this study were the presence of notable differences in the F-v profiles between positional groups for the jump squat and back squat. Specifically, that forwards produced more absolute force than backs, however no difference in relative force produced was observed. These differences provide further indication towards the physiological and physical characteristic tendencies of rugby union players. The information outlined in this dissertation is potentially advantageous for strength and conditioning practitioners involved in semi-professional and professional rugby union environments as the expected characteristics of athletes can be used to inform training decisions. For instance, the benefit of training force qualities for forwards and backs is likely to have greater power implications due to addressing the inherent imbalance present in rugby union players. However, informed training decisions should come from a proper assessment and categorising the physical capabilities of athletes to some extent is beneficial when based on the requirements of their playing position.

Chapter 5: Summary

5.1 Summary

The preliminary aims of this dissertation were to 1) examine the literature and determine the most valid and reliable methods of F-v profiling, and 2) examine the existing literature in relation to F-v profiling and rugby union. The first literature review (Chapter two) discusses the application of numerous valid and reliable methods and technologies for accurate F-v profiling. For lower-body assessments, force plates remain the gold standard testing procedure within a clinical setting. However, for the field or gym-based strength and conditioning practitioner, there are more appropriate and cost-effective solutions. For example, the method proposed by Samozino et al. (2008) that utilises body mass, jump height and height of push-off (*hpo*) can utilise any technologies or equipment that will accurately measure those three variables (e.g., smart phones, Gymaware devices). For upper-body assessments, the method proposed by Rahmani et al. (2018) that utilised a zip-tie on a guided barbell machine to measure the barbell height during a bench press throw proved to be a suitable option with the limitation of requiring a guided barbell machine.

The second literature review (Chapter 3) explored the physical and physiological requirements of rugby union and how the requirements differed based on positional role. For example, forwards are involved in more instances of overcoming resistive forces, which presented as rucks, mauls and scrums during a game, and were required to tackle larger opponents more often (i.e., other forwards) (Nicholas, 1997; McLean, 1992; Menchinelli et al, 1992). Conversely, backs are involved in more instances of rapid acceleration and high-velocity sprinting in order to make line breaks and beat the opposition defensive line (Nicholas, 1997; McLean, 1992; Menchinelli et al, 1992).

The primary aims of this dissertation were then to investigate the influence of; 1) playing position, and 2) training age, on the F-v characteristics of professional rugby union players. The intention of the study performed in Chapter 4 was to address these aims. From this investigation we found that forwards displayed greater mean and peak force in the back squat and greater absolute *F0* in the jump squat when compared to backs. We hypothesised that in contrast, backs would display greater velocity characteristics than forwards however, our investigation found no statistical difference between forwards and backs in velocity characteristics. Moreover, our investigation found little evidence to suggest a quantifiable influence of training age on F-v characteristics, with the only significant correlation observed being between training age and optimal slope of the F-v relationship. We found that as training age increased, the optimal slope of the F-v relationship decreases (i.e., the value of *SfvOpt* got closer to 0).

5.2 Practical recommendations

For coaching personnel and sports scientists, F-v profiling offers a meaningful way of assessing and monitoring the force and velocity characteristics of professional athletes. These force and velocity characteristics provide valuable insight into the performance of the individual and can effectively inform future training decisions. This study identified the force and velocity differences between positional groups and the potentially negligible influence of training age on the F-v profiles. By performing F-v profiling on rugby union players, coaches are able to determine deficiencies in an athlete's power output and can effectively prescribe appropriate training interventions to reduce the *FVimb*. Depending on the positional group of a player, these deficiencies vary and must be altered accordingly. Furthermore, given that training experience has an influence over the optimal slope of the F-v relationship, the inclusion of a training background assessment with F-v profiling will provide a better understanding of the contributing variables to a given athletes actual and optimal F-v profiles. The assessment of training age holds further value in contributing to an athlete's background, past training experience, and the extent or degree of training experience. This study shows a tendency for rugby union players regardless of positional group to be velocity dominant. Therefore, strength and conditioning practitioners are encouraged to engage their athletes in a greater volume of high contractile, high load, low velocity movements.

5.3 Limitations

It should be noted that there were various limiting factors that affected this study. Namely, the limited sample size due to the elite-level of the athletes used in this study. Professional rugby union players are a small cohort themselves and sourcing a large quantity for set testing dates proved to be challenging. In addition, the COVID-19 pandemic greatly affected productivity and consistently limited our access to a wider participant pool. At the time of testing, several players that were intended to take part in the study were unable to travel to Auckland. Further testing opportunities became impossible with the Omicron outbreak which further limited social gatherings.

5.4 Future research

The present study further develops the practical application of F-v profiling for professional athletes and provides insight into the benefit of performing F-v profiling in a professional sporting context. The results of this study posit the need for further questioning into the influence of positional demands and training age on performance measures such as F-v profiling.

Further research should be performed using the same methodology of this study, but instead focusing on upper-body F-v profiles. A study by McMaster et al. (2016) identified differences in upper-body F-v profiles between positional groups, however the study did not remark on the influence of training age on those outcomes and the study used semi-professional rugby players as the cohort. Furthermore, future research should be performed into the influence of training age on the horizontal force-velocity profiles of professional rugby players. A study by Watkins et al. (2021) already observed the differences between the positional groups using horizontal F-v profiling. In addition, there is potential to use the current methodology in a comparative study between two similar codes such as rugby union and rugby league. It is crucial in this circumstance that the two groups have large sample sizes and the various training ages are adequately represented to allow for accurate comparison.

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Appendices

Appendix A – Consent Form

Project title: ***The influence of training experience and playing position on the force-velocity profiling of professional rugby union players***

Project Supervisor: ***Dr. Adam Storey***

Researcher: ***Sam Purchase***

○ I have read and understood the information provided about this research project in the Participant Information Sheet

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

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection

○ I agree to provide force-velocity profiling data, performance testing data, anthropometrical data and a short survey about training experience

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 4/11/12

AUTEC Reference number 21/180

Appendix B - Participant information sheet
Date Information Sheet Produced:

27/05/21

Project Title

The influence of training age, and playing position on force-velocity profiles of professional male rugby union players

An Invitation

Hi, my name is Sam Purchase, and I am currently a Masters student at AUT University. I am inviting you to participate in the above-named study which is a research-based investigation conducted by Mr. Sam Purchase and supervised by Dr. Adam Storey. Participation in this study is completely voluntary and any decision to participate or not participate it is entirely your own decision. Your consent to participate in this research study will be indicated by you signing and dating the consent form. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT. Your participation, or lack of participation, will not advantage or disadvantage you in anyway within the Auckland Rugby organisation. The results of this research are intended for publication and will contribute to my Masters and may be submitted to peer-reviewed journals for publication.

What is the purpose of this research?

Force-velocity profiling is an emerging area of research that provides valuable information regarding the power output of an athlete (P = F*V). These profiles are also a useful tool to inform coaches' decision making around programming, by giving insight into the force and velocity determinants of power.

Recent research has shown we can determine an optimal force-velocity profile that identifies the optimal slope for a given athlete to achieve maximal power output. Optimal force-velocity profiles can be compared against an athlete's actual force-velocity profile to identify force or velocity deficiencies and inform future training decisions

At present, there is a lack of specific research that has investigated the influence of certain variables on force-velocity profiling, namely training age (i.e., years of experience training), playing position (i.e., forwards and backs) and maximal neuromuscular strength. Therefore, the primary purpose of this study is to develop further understanding of force-velocity profiling and if these variables influence profiling outcomes. The secondary aim is to determine how much these variables contribute to a force-velocity profile when controlling for other variables such as age, height and weight. As previously mentioned, this research is in fulfilment of my Masters of Sport, Exercise and Health at the Auckland University of Technology, and the information gathered in this study may be used for articles submitted for publication.

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

As this study is looking to identify the force-velocity characteristics of elite rugby union players, you were suggested as the cohort due to availability and proximity to the researchers. As you are a professional rugby union player and classed as an elite athlete, your participation in this study would help to further our knowledge of this area. You are eligible to participate in this study if you are; 1) a professional male rugby union player, 2) have no current acute or chronic injuries or medical conditions, 3) involved in a high-performance resistance training programme for ≥ 6 months, 4) appropriate technical ability to perform the back squat and squat jump, 5) are not using any performance enhancing or banned substances as per the World Anti-Doping Agency Code (2021)

How do I agree to participate in this research?

If you agree to participate in this research study, you will be required to complete a Participant Consent Form which can be obtained from Sam Purchase. Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Familiarisation Session:

Once you have decided to participate in the study and have met the inclusion criteria, you will be required to attend a familiarisation session at your usual training location at least three days prior to the commencement of the first testing session. During the familiarisation session all participants will perform a series of submaximal lifts for the back squat and squat jump with a linear position transducer (LPT) attached to the barbell. The LPT will measure how fast you are moving the barbell during each of these given exercises.

First Testing Session:

The first testing session consists of participants performing the squat jump at varying loads. The test loads are determined on bodyweight and for the squat jump will be 0%, 25%, 50%, 75%, and 100% of your current bodyweight. This session will take no longer than 90 minutes, and within that time you will take part in a standardised warm-up.

Second Testing Session:

The second testing session will have each participant reach their 1-rep maximum (1RM) load on back squat. This is a movement that each participant is likely to have experience with previously. The session will last no longer than 90 minutes and within that time you will perform a standardised warm-up. Once you begin back squatting, you may gradually increase the load on the barbell at your own discretion until you reach that 1RM load under the guidance of the primary researcher.

What are the discomforts and risks?

You will be asked to perform submaximal and maximal resistance testing over the course of the two testing days and therefore may experience some discomfort for a short period of time during each testing session or for some hours thereafter. However, the intensity of the testing will be similar to what you have experienced in your previous testing sessions.

How will these discomforts and risks be alleviated?

Being a professional athlete who regularly performs resistance training and is familiar with the high training intensities performed daily, the intensities experienced during this testing will be similar to what you have experienced in previous testing sessions. If you are experiencing discomfort at any stage during the testing session you are encouraged to inform the researcher supervising the session at the time to best address the problem. If you have any questions regarding the risk or discomfort that you anticipate, please feel free to address these concerns to the researcher so that you always feel comfortable throughout the process.

What are the benefits?

Participants will gain a personalised profile which will contain their 1RM, peak power and peak velocity performance for the back squat and squat jump. New knowledge for researchers and practitioners will be gained as we look to explore the relationship certain variables have with force-velocity profiling to further industry knowledge of this emerging tool. The wider professional sporting community will benefit by taking advantage of force-velocity profiling to inform training decisions by coaches and implement new testing protocols for athletes. The results of this research are intended to be used in my Master's thesis and may be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your privacy will be protected at all times by the data being de-identified (i.e., coded numbers such as I.D 432 will be assigned to your data instead of your name), and the researcher will not disclose any participants involvement in this study. No names or pictures will not be used in reporting unless the participant gives written consent following the AUT protocols and is organised via the AUT University relations team. During the research study, only the applicant and named researchers will have access to the data collected. The results of the study may be used for further analysis and submitted to peer-viewed journals or submitted to conferences. However, only the group averages of the descriptive characteristics (i.e., age, height, weight etc.) will be published, and thus the participants will not be identifiable from the publications related to this study. Your privacy and confidentiality will be upheld as the primary concern when handling the data collected.

All data collected will be stored on password protected computers or in securely locked files. Following completion of the data analysis process your data will be stored by the AUT University SPRINZ research officer in the AUT University SPRINZ secure Ethics and Data facility at the AUT Millennium campus for ten years. Following the ten-year storage period all hard copies of data will be destroyed (shredded) and electronic data will be deleted.

What are the costs of participating in this research?

There will be no financial cost for you being involved with this study. You will be required to commit approximately 4 hours total towards familiarisation and testing sessions.

What opportunity do I have to consider this invitation?

It will be appreciated if you could let us know within two weeks whether you would like to or be available to take part in the study or not. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, participants will gain a personalised profile which will contain their 1RM, peak power and peak velocity performance for the back squat and squat jump. It is your choice whether you share this information with your coach or other people. You will also receive (if you wish), a summary of the research findings. You may also inform the primary researcher if you do not wish to receive this personalised profile.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Adam Storey, adam.storey@aut.ac.nz, 0212124200

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC Dr. Carina Meares, *ethics@aut.ac.nz*, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

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

Researcher contact details:

Sam Purchase

AUT-Millennium, 17 Antares Place, Mairangi Bay
02102480706
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Project supervisor contact details:

Dr. Adam Storey

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Approved by the Auckland University of Technology Ethics Committee on 4/11/21, AUTEC Reference number *21/180.*

Appendix C

Table adapted from Giroux et al. (2016)

	F0		*V0*		P_{max}	
	F	M	F	M	F	M
Control	26.5 ± 3.3	30.0 ± 3.0	2.59 ± 0.40	2.63 ± 0.54	17.2 ± 3.5	19.7 ± 4.3
Cycling	36.0 ± 4.4	36.4 ± 4.5	2.38 ± 0.34	2.86 ± 0.34	21.2 ± 2.7	25.8 ± 2.8
Fencing	27.4 ± 3.2	31.1 ± 4.3	3.03 ± 0.34	3.18 ± 0.88	20.8 ± 3.1	24.3 ± 5.6
Athletic Sprinting	36.0 ± 4.1	37.3 ± 4.4	2.70 ± 0.22	3.18 ± 0.42	24.3 ± 4.0	29.5 ± 4.8
Taekwondo	31.8 ± 3.5	29.9 ± 3.7	2.87 ± 0.25	3.34 ± 0.68	18.2 ± 2.5	24.7 ± 4.8

Appendix D – Questionnaire

The influence of training experience and playing position on the force-velocity profiles of professional male rugby union players

Name:____

Age:____

What position do you play?

____

For how many years have you played rugby at the provincial representative level or higher?

____

For how many years have you been resistance training?

____

Have you been involved in any other sports at a similarly high level? If so, please list them:

____

For how long were you involved in this other sport(s)?

____

Approved by the Auckland University of Technology Ethics

Committee on 4/11/21, AUTEC Reference number 21/180