The Influence of Velocity Based Resistance Training on Neuromuscular Strength and Power Adaptations in Semi-Professional Rugby Union and Professional Rugby League Players

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature: 

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Co-authored works

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Author contributions

The Master's candidate Gurdeep Singh was the primary contributor (90%) to the research within this thesis and any analysis and interpretation from the associated results. All co-authors have approved the inclusion of the joint work in this thesis.

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List of abbreviations

AU	Arbitrary units	PP	Peak power
APRE	Autoregulatory progressive resistance exercise	PV	Peak velocity
R^2	Coefficient of determination	P_{max}	Peak power output
CV	Coefficient of variation	RFD	Rate of force development
CMJ	Countermovement jump	RPE	Rating of perceived exertion
ES	Effect size	RTF	Reps to fatigue
EMG	Electromyography activity	RHIE	Repeat high intensity effort bouts
FPS	Fixed pushing speed	Sal-C	Salivary cortisol
GPS	Global positioning system	SPS	Self-selected pushing speed
IMCA	Intended maximal concentric action	SD	Standard deviation
ICC	Intra class correlation coefficient	SEE	Standard error of estimate
Kg	Kilograms	SSC	Stretch shortening cycle
LPT	Linear position transducer	SJ	Squat jump
MV	Mean velocity	3RM	Three repetition maximum
MVC	Maximal voluntary contraction	TUT	Time under tension
MVF	Maximal voluntary force	TPT	Traditional percentage based training
$m.s^{-1}$	Meters per second	VL	Vastus lateralis
MPV	Mean propulsive velocity	VBT	Velocity based training
MVT	Minimum velocity threshold	W	Watts
MHC	Myosin heavy chain composition		
N	Newton’s		
1RM	One repetition maximum		
PF	Peak force		

Abstract

The vast majority of resistance training programming in rugby union and rugby league training environments have for decades utilized traditional percentage based training (TPT) methods to develop the physical components required for successful performance, in particular strength and power. However, a major shortcoming of this method is that it does not take into account athlete's daily biological status and readiness to train. Thus, movement velocity is a variable that could be of great interest when designing resistance training programmes to optimize neuromuscular strength and power adaptations. At present, there is a paucity of research that has detailed the influence movement velocity has on enhancing neuromuscular strength and power adaptations in semi-professional rugby union and professional rugby league players. Thus, the purpose of this thesis was to; 1) review the current literature pertaining to VBT methods and its current applications in resistance training, 2) document the velocity profiles of semi-professional rugby union and professional rugby league players across various load spectrums and, 3) determine the influence of a 5-week velocity based training (VBT) programme on neuromuscular strength and power adaptations in professional rugby league players. Through an extensive literature review, it was identified that several key areas exist for incorporating movement velocity in the design and implementation of resistance training. Chapter three investigated the velocity profiles of semi-professional rugby union and professional rugby league players across a loading spectrum of 20-95% 1RM during the bench press, back squat and power clean exercises. Regardless of playing code, this investigation revealed that unique VBT zones exist for loads lifted between 20-95% 1RM for the exercises. The unique VBT zones identified for each code and exercise may provide a novel approach in accurately prescribing daily training loads for a pre-selected training intensity based on an athlete's ability to maintain a prescribed movement velocity. During Chapter four, a 5-week case study design training intervention was conducted with five professional rugby league players to investigate the influence of performing resistance training within specific VBT zones. Pre and post-intervention measures of performance included maximal countermovement jump (CMJ), squat jump (SJ) and 3RM performances for the bench press, back squat and power clean exercises. In addition, measures of psychological wellness (as determined by questionnaire) and physiological stress (as determined by salivary cortisol) were conducted throughout the intervention period. Following the 5-week training intervention, the VBT participants substantially improved neuromuscular CMJ and SJ performance. In addition, greater increases in training load were performed by the VBT group when compared to the intended values based off TPT methods.

Furthermore, although the VBT group performed greater training loads, no substantial variance in reported session RPE values were observed between both groups. In terms of recovery, the VBT group reported higher weekly wellness questionnaire scores and elicited less physiological training stress for light and heavy intensity training weeks when compared to the TPT group. In conclusion, this investigation provides evidence that performing isoinertial resistance training within specific VBT zones may be an effective training stimulus to enhance neuromuscular strength and power performance whilst limiting excessive fatigue in professional rugby league players. In addition, movement velocity should be a primary focus within rugby union and rugby league training environments when designing and implementing strength and power training programmes.

CHAPTER ONE: PREFACE

1.1 Thesis rationale and significance

The physiological demands of rugby union and rugby league are highly complex, requiring athletes to possess high levels of muscular strength and power (Duthie et al., 2003; Gabbet et al., 2008). Additionally, an athlete's capacity to rapidly generate high levels of muscular force are considered key characteristics of successful competition performance (Gabbet et al., 2008). It can be considered that the role of a strength and conditioning professional is to provide athletes with individualized resistance training programmes that maximize their ability to transfer strength and power training to competition performance.

At present, the majoriy of strength and power resistance training programmes have placed a great deal of emphasis toward enhancing muscular strength and power with traditional percentage based methods. For example, when training for muscular power, endurance, hypertrophy or strength, the following percentages of an athlete's baseline one repetition maximum (1RM) are typically prescribed; 30-85%, ≤ 65%, 60-85% and, ≥80% of 1RM respectively (Baechle & Earle, 2008). However, a major shortcoming of this traditional method is that the velocity component of a given exercise is often an overlooked and under-utilized performance measure.

Previous research has demonstrated that the greatest muscular strength and power improvements occur when specific resistance training is performed at or near the optimal training velocity (Behm & Sale, 1993). Additionally, it has been shown that a close relationship exists between relative load and the movement velocity that is attained during resistance training (R^2 = 0.98) (Gonzalez-Badillo & Sancehez-Medina, 2010). This relationship makes it possible to determine with great precision the real intensity of effort or work being incurred by an athlete at loads performed between 30% to 95% of 1RM. Thus, a velocity based training (VBT) method could complement traditional percentage based training (TPT) by allowing individuals to train within specific velocity zones across different load spectrums during strength and power training phases. In addition, having a velocity based focus may have important implications for the accurate prescription of training loads based on an athlete's ability to maintain a prescribed movement velocity. Such an approach may also aid in fatigue monitoring by utilizing autoregulatory type programming and further research is warranted in this area.

From the existing literature it is evident that VBT shows promise in providing an effective alternative training stimulus to improve strength and power adaptations when compared to TPT training methods. However, there is very limited research addressing the effects of optimizing VBT in improving neuromuscular strength and power adaptations.

Thus, the primary aim of this thesis was to address the overarching question of; "what is the influence of utilizing specific velocity training zones across different load spectrums as a means to optimize the development of strength and power in semi-professional rugby union and professional rugby league players?" The secondary aim was to examine and compare the psychological wellness and salivary cortisol stress response between VBT and TPT programmes to determine if VBT induces the same psychological and physiological stress response as TPT.

This thesis will aim to provide a substantive and original contribution to our knowledge in implementing and understanding the use of specific velocity zones across different load spectrums as a means to maximize neuromuscular strength and power adaptations. This will be achieved by conducting three studies; 1) reviewing the current literature pertaining to VBT methods and its current applications in resistance training, 2) documenting the velocity profiles of semi-professional rugby union and professional rugby league players across various load spectrums and, 3) determining the influence of a 5-week VBT programme on neuromuscular strength and power adaptations in professional rugby league players. These studies will provide new insights in how to effectively implement and optimize strength and power resistance training with the use of velocity to the field of strength and conditioning practice. Although, the majority of the research will have a direct relevance to rugby union and rugby league strength and power resistance training programming, the findings of the research will have significant applications to a variety of athletic and sporting codes.

1.2 Research aims and hypothesis

The major aims of the work provided in this thesis were to:

1) Develop a better understanding of the strength and power velocity profiles across different load spectrums for the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players.
2) Develop a better understanding of specific VBT zones across different load spectrums as a training stimulus to elicit subsequent strength and power

adaptations in semi-professional rugby union and professional rugby league players.

3) Examine and compare the psychological wellness and salivary cortisol stress response between VBT and TPT programmes to determine if VBT induces the same psychological and physiological stress response as TPT methods in professional rugby league players.

The following hypotheses were made for the studies undertaken in this thesis:

1) The strength and power velocity profiling across different load spectrums for the bench press, back squat and power clean exercises will provide a large range of velocities at lighter loads when compared to heavier loads due to the propulsive and braking phases that occur at light and heavy loading intensities (%1RM). Additionally, multi-joint compound movements (i.e. power clean and back squat) that require greater activation and synchronization of agonist and antagonist muscle groups will result in a larger spread of velocity profiles across the different load spectrums when compared to the bench press exercise.
2) The prescription of specific velocity training zones across different load spectrums during isoinertial resistance training provides a superior training stimulus in enhancing subsequent strength and power performance/adaptations when compared to TPT methods in professional rugby league players.
3) The psychological wellness and salivary cortisol stress response to a VBT programme elicits the same psychological and physiological stress response when compared to TPT programmes in professional rugby league players.

1.3 Originality of the thesis

Currently, there exists very limited research that has addressed the influence of VBT in improving neuromuscular strength and power adaptations. More specifically, to the best of our knowledge, no study has investigated the influence of optimizing specific VBT zones across different load spectrums as a means to enhance neuromuscular strength and power in professional rugby league players. In addition, no study has investigated the psychological wellness and salivary cortisol stress response between VBT and TPT programmes in professional rugby league players.

1.4 Study limitations

1. Due to in-season competition constraints, a limited number of rugby league participants (n = 11) were available for Study one when compared to the availability of the rugby union players (n = 41). Therefore, the ability to perform between code statistical analyses were limited.

2. During Study one, no pre-intervention 1RM testing was allowed due to the in-season competition constraints placed on the athletes from senior coaching staff. Therefore, the testing loads for the velocity profiling of the bench press, back squat and power clean exercises were based off the participants' previous 1RM values that were obtained within a four week period prior to the commencement of the study. Due to these constraints, it is possible that the testing loads prescribed for each percentage of 1RM (20-95%) may have not necessarily reflected the participants' true maximum strength and power capabilities. However, natural variation in a participant's 1RM ability is an inherent issue with exercise prescription and testing. For example, previous research has demonstrated that an athlete's actual 1RM can change rapidly after a few training sessions and often the obtained value is not the athlete's true maximum due to daily fluctuations in biological status (Gonzalez-Badillo & Sanchez-Medina, 2010).

3. Ten participants originally volunteered to take part in Study two. However, a large dropout of participants occurred due to; 1) in-season competition constraints placed on athletes from senior coaching staff and, 2) injuries sustained during on field training sessions and matches. To overcome this situation, a single subject case study was employed where five professional rugby league players undertook the 5-week training intervention as opposed to the original study design of 5 VBT vs. 5 TPT participant allocation.

4. The proposed statistical analyses during Study two included traditional null hypothesis testing (t-tests), statistical correlation testing and effect sizes. However, due to the large dropout of participants prior to the commencement of Study two, it was only possible to describe all data variables as means and standard deviations and differences in pre and post testing between groups as percentage changes.

5. The training intervention length for Study two was limited to 5-weeks due to the professional rugby league player's in-season competition schedule. Thus, the 5-week training intervention period that comprised of 10 training sessions may have been an

insufficient time period to elicit improvements in strength and power performance in professional athletes.

6. Participant 5 from the TPT group was unable to complete the majority of strength and power post-testing due to an injury sustained during competition in the final week of the intervention. In addition, participant 3 from the VBT was unable to complete the strength testing due to an injury sustained during competition in the final week of the intervention.

7. Due to the inherent nature of rugby league competition, the collisions and impacts encountered during training and competition may have negatively influenced the salivary cortisol stress response. However, this was out of the researcher's control and the salivary collection methods used in this thesis were in accordance with previous research studies conducted by Crewther et al., (2009), Crewther et al., (2013) and, Beaven et al., (2008) which assessed the salivary cortisol stress response to resistance training in rugby union players.

8. In the original design for Study two, pre and post-intervention strength testing involved the performance of a 1RM for the bench press, back squat and power clean exercises. However, immediately prior to the start of Study two, the senior coaching staff of the professional rugby league team requested the researchers to replace the 1RM protocols with 3RM protocols due to injury concerns. Consequently, this may have influenced the negligible improvements in strength performance as the athletes were not accustomed to performing 3RM assessments.

1.5 Study delimitations

1. Semi-professional rugby union and professional rugby league players were chosen as the participants for this thesis. Each participant had extensive resistance training experience and these levels of athlete were chosen to ensure expertise in each of the prescribed lifts. Therefore, changes in performance are more likely to be attributed to the training stimulus as opposed to a learning effect.

2. During Study two, the professional rugby league players were provided with a ≥ one-hour rest period following a field/skill session. This was done to allow for sufficient neuromuscular recovery before commencing their assigned resistance training programme.

3. In order to combat the single subject case study design limitations employed during Study two, multiple pre and post-intervention trials were performed for the CMJ and SJ to account for error and change associated with; measurement error (random change, technological error, biological error), learning effect, and variation in kinetic outputs (systematic change).
4. The professional rugby league players were accustomed to performing weekly wellness questionnaire monitoring as this is a main staple in their weekly assessment of neuromuscular and wellness monitoring procedures.

1.6 Thesis organization

To address the overarching question of "what is the influence of utilizing specific velocity training zones across different load spectrums as a means to optimize the development of strength and power adaptations in semi-professional rugby union and professional rugby league players", this thesis has been divided into five chapters that includes both original research and reviews of the literature.

Chapter two consists of a review of the literature that explores in detail a variety of the key variables pertaining to strength and conditioning practice. Firstly, this review covers the TPT methodologies employed for strength and power neuromuscular adaptations. Next, an overview of VBT methods is presented with particular focus placed on the neuromuscular and sport specific adaptations arising from VBT along with the subsequent training monitoring applications of VBT.

Chapter three comprises of an experimental velocity profiling study that was conducted to determine each semi-professional rugby union and professional rugby league player's velocity profile across a set training load spectrum of 20, 30, 45, 60, 75, 80, 85, 90 and 95% 1RM for the bench press, back squat and power clean exercises.

Chapter four comprises of an experimental case study that examined the effectiveness of a 5-week VBT intervention on improving neuromuscular strength and power adaptations when compared to a TPT programme in professional rugby league players. In addition, the psychological wellness and salivary cortisol stress response between VBT and TPT methods were examined to determine if VBT elicits the same psychological and physiological stress response as TPT.

The fifth and final chapter comprises an overall discussion and summary of the main research findings presented in this thesis. Subsequently, practical recommendations are suggested for strength and conditioning practitioners, in regards to employing VBT and the kinetic variable of velocity as a practical tool to maximize strength and power adaptations and as a means to asses and monitor athlete performance. To conclude, future research recommendations and study limitations are presented.

References are included as an overall reference list of the entire thesis at the conclusion of the thesis. The referencing format is presented in APA 6^{th} format for consistency throughout the entire thesis. The appendices presented include relevant material including informed consent form, information sheets, wellness monitoring form and ethical approval.

CHAPTER TWO: THE INFLUENCE OF TRADITIONAL PERCENTAGE BASED RESISTANCE TRAINING AND VELOCITY BASED RESISTANCE TRAINING PRACTICES ON STRENGTH AND POWER ADAPTATIONS: LITERATURE REVIEW

2.1 Preface

The purpose of this chapter is to review the current literature relating to factors that influence neuromuscular strength and power adaptations. Particular emphasis is placed on the current literature pertaining to the applications of VBT profiling technology and strength and power assessment strategies along with an overview of VBT methods currently used in the literature. Additionally, the neuromuscular and sport specific adaptations to VBT and current monitoring strategies are reviewed. Collectively, the literature review provides a comprehensive understanding of how VBT methods can be implemented in professional sporting environments to enhance subsequent neuromuscular strength and power adaptations when compared to TPT methods.

2.2 Introduction

Rugby union and rugby league are classified as collision based field sports that are intermittent in nature and require high levels of muscular strength and power (Gabbett, 2005a; Roberts et al., 2008). Rugby union and rugby league match play are punctuated with frequent challenging contests involving repeat high intensity effort (RHIE) bouts of maximal accelerations, high impact collisions and frequent static and dynamic tasks when attempting to gain or maintain possession of the ball (Cunniffe et al., 2009; Deutsch et al., 2007; Gabbett, 2005a; Smart et al., 2014). There are distinct differences in the physiological profiles between rugby union and rugby league players that owe to the differing match play demands of each sport. Rugby league features less on-field players than rugby union (13 vs 15) and requires players to retreat 10 meters towards their own goal line for six tackles before possession is handed over. This results in greater sprinting velocities due to large spaces between attackers and defenders and higher contact-orientations in order to keep an opposition player upright and stopping the ball from going to ground for as long as possible. Conversely, rugby union allows contesting for the ball straight after the tackle with players only required to retreat behind the ruck. This results in a greater number of short maximal accelerations and lower contact-orientations that are force-dominant movements (Cross et al., 2015). These demands require players to be proficient in both high force and velocity-dominant exercises (Cross et al., 2015). Consequently, high levels of muscular strength and power play a significant role in the success of rugby union and rugby league match play and have been shown to be key performance measures that demonstrate correlations between line breaks, tackle breaks, tackling efficiency and tries scored (Crewther et al., 2009; Gabbett et al., 2011b; Smart et al., 2014).

The optimal combination of training variables for the development of strength and power performance remains an area of great interest among strength and conditioning practitioners. A key area of conjecture is which training stimulus and load provides optimal improvements in functional strength and power performance and these loads are typically expressed as a percentage of an athete’s one repetition maximum (1RM) for a given exercise. In addition, guidelines for developing or enhancing muscular strength and power in rugby union and rugby league players typically involves quantifying strength and power training by calculating the load x reps x sets which equates to the total volume lifted in a session (Kraemer & Ratamess, 2004). Many researchers have suggested that heavy training loads (>80% 1RM) (Campos et al., 2002; Hakkinen et al., 1985; Tricolli et al., 2005; Wilson et al., 1993) may be superior in enhancing strength and power performance. However, some suggest lighter loads (50-70% 1RM) (Lyttle et al., 1996; McBride et al., 2002) and, some suggest a combination of loads (Adams et al., 1992; Harris et al., 2000).

A method postulated to improve strength and power performance is the power-load relationship that identifies optimal training loads where mechanical power output is maximized (P_{max}) (Baker et al., 2001a; Baker et al., 2001b; Kaneko et al., 1983; Newton & Kraemer, 1994; Wilson et al., 1993). This method suggests that training with loads corresponding to optimum power output should result in improvements of 10-20-meter sprint times and small-moderate improvements in 1RM lower and upper body strength performance (Blazevich & Jenkins, 2002; Harris et al., 2008). However, major shortcomings of this method include; 1) this training method cannot be applied to developing specific skeletal muscle performance traits of starting strength, speed-strength, strength-speed, accelerative strength, and absolute strength and, 2) there exists considerable inter-individual and exercise specific differences in the load where P_{max} occurs. Conversely, it is suggested how the load that is actually lifted or moved may be more significant in developing functional neuromuscular adaptations (Harris, Cronin, & Keogh, 2007). Thus, the concept of velocity specific resistance training is an important consideration when designing and implementing resistance training programmes. However, the velocity component of a given exercise is often an overlooked and under-utilized performance measure.

Previous research has demonstrated that the greatest muscular strength and power improvements occur when specific resistance training is performed at or near the optimal training velocity (Behm & Sale, 1993). The optimal training velocity can be defined as a prescribed movement velocity that influences both neural and muscular components that consequently maximizes functional strength and power performance (Behm & Sale, 1993). In addition, it has been shown that a close relationship exists between relative load and the movement velocity that is attained during resistance training ($R^2 = 0.98$) (Gonzalez-Badillo & Sanchez-Medina, 2010). This relationship makes it possible to determine with great precision the real intensity of effort or work being incurred by an athlete at loads performed between 30% to 95% of 1RM. Thus, a velocity based training (VBT) method could potentially replace the use of traditional percentage based training (TPT) by allowing individuals to train within specific velocity zones across different load spectrums during strength and power training phases. VBT is a method used by strength and conditioning practitioners to determine the optimal loading strategies for strength and power training by using the velocity at which an athlete can move an external load that is independent of 1RM (Mann, Ivey, & Sayers, 2015). Training within specific VBT zones provides a novel approach in identifying specific loads that will enhance the specificity of resistance training that takes into account an athlete's fluctuations in performance as a result of the stressors encountered during training and competition (Mann et al., 2015). Therefore, movement velocity may be considered a fundamental component in rugby union and rugby league resistance training programming, as it is demonstrated the velocity at which loads are lifted may determine the resulting training effect and its transference to sports performance (Gonzalez-Badillo, Rodriguez-Rosell, Sanchez-Medina, Gorostiaga, & Pareja-Blanco, 2014).

The majority of past research regarding velocity specificity has been conducted with the use of isokinetic dynamometry equipment. Because isokinetic muscle actions are considered to be less specific to actual sporting movements the results from isokinetic research are somewhat questionable (Cronin, McNair, & Marshall, 2002). Therefore, isoinertial (i.e. constant mass) training appears to be more specific to actual sporting movements and would be more applicable in practical settings. This may be due to the actual movement of isoinertial training being determined by the contractile impulse applied by the musculoskeletal system and the magnitude of the external load. Consequently, isoinertial training would be associated with a higher movement velocity, provided the intention is to accelerate a load with maximum dynamic effort (McBride et al., 2002; Schilling et al., 2008). A highly cited study in the literature conducted by Behm and Sale (1993) suggest that the principal stimuli that elicits velocity specific training adaptations is the intention to move explosively. According to Behm and Sale (1993) this "internal velocity" (i.e. muscle contraction speed) is believed to be more important during strength and power training regardless of contraction type, load or actual movement velocity. However, there exists contrary evidence that suggests that velocity specific improvements in neuromuscular strength and power are more likely elicited by utilizing the actual movement velocity that could play a significant role in determining velocity-specific effects to resistance training (Kaneko et al., 1983; McBride et al., 2002). For example, Gonzalez-Badillo and colleagues (2010) demonstrate that each percentage of 1RM loading intensity has its own unique velocity training zone. Therefore, training with light (0-55% 1RM), moderate (60-75% 1RM) or high intensity (80-95% 1RM) loads with the intention to move explosively, as controlled by load within specific velocity training zones may optimize adaptation of specific skeletal muscle performance traits including; starting speed, speed-strength, strength-speed, accelerative strength and absolute strength/power. Consequently, this may improve goal-oriented resistance training tasks by inducing neuromuscular adaptations within skeletal muscle, altering its force-velocity characteristics and adaptations within the neural system, increasing the recruitment of higher threshold motor units and enhancing the coordination and activation of agonist, synergistic and antagonist muscle groups (Almasbakk & Hoff, 1996). However, the mechanisms responsible for the velocity-specific resistance training effects on intrinsic skeletal muscle characteristics and performance enhancement are currently not well understood and requires further investigation.

There currently exists a paucity in the literature in addressing the effects of performing resistance training within specific velocity zones across different load spectrums as a means to maximize neuromuscular strength and power performance in semi-professional rugby union and professional rugby league players. In addition, by examining the influence VBT has on enhancing strength and power performance, this will provide a greater understanding of the relative importance VBT has on programme design and its effect on neuromuscular strength and power adaptations. In regards to this contention, comparisons between TPT and VBT methods are discussed within this review of the literature. First, the TPT methods relating to strength and power methodologies and adaptations are discussed. Second, the velocity profiling technology and strength and power assessment strategies along with an overview of VBT methods currently used in the literature are reviewed. In addition, the neuromuscular and sport specific adaptations to VBT are reviewed. Thereafter, monitoring training volume and load in resistance training are discussed. Finally, VBT practical application recommendations are provided and we highlight the potential areas for future research.

2.3 Literature review search methods

The search for scientific literature relevant to this review was conducted using the AUT library and Google Scholar databases. Key search terms used were, ‘velocity’, ‘neuromuscular adaptations’, ‘strength and power’, and ‘rugby union and rugby league’. In order to further broaden the literature search, a manual reference list screen for related articles was conducted on each of the retrieved articles and published reviews (Cormie et al., 2011). Using the aforementioned search strategies, 1,888 potentially relevant articles were returned. Following a review of the titles and abstracts, the total was narrowed to 107 articles by implementing the following inclusion criteria; 1) the literature was published in English, 2) appeared in a peer reviewed journal from 1960 to December 2015 and, 3) articles needed to reference “rugby union”, “rugby league”, “velocity”, “movement velocity”, “resistance training” and its relation to strength and power adaptations to TPT and VBT methods.

2.4 TRADITIONAL PERCENTAGE BASED TRAINING METHODOLOGIES

2.4.1 Strength resistance training methodology and adaptations

Maximum strength can be defined as the maximum amount of force (dynamic or isometric) an athlete can produce against an external load and is typically assessed with the one repetition maximum (1RM) for a given exercise (Zatsiorsky & Kraemer, 1995). It is suggested that the dosage required to develop maximal strength is generally described as high in frequency (3-5 weekly sessions), moderate volume (3-6 sets x 2-6 repetitions x load (kg), high intensity (80-100% 1RM), and utilizing long rest periods (3-5 minutes) (McMaster et al., 2013; Peterson et al., 2005; Ratamess et al., 2009). In addition, the design of strength training programmes are often a composite of manipulating several acute resistance training variables (i.e. repetition velocity, exercise type, order, sets and repetitions, percentage of 1RM and rest duration). Exercise intensity (%1RM) is generally acknowledged as the most important stimulus related to enhancing strength adaptations and is commonly identified with relative loading intensities of an athlete’s percentage of 1RM (Kraemer & Ratamess, 2004). The overall structure of a strength training cycle is typically periodized into macro-cycles (1 year cycle) which is then further subdivided into mesocycles (2-3 month cycles) and micro-cycles (4 week cycles) in an attempt to achieve optimal maximum strength improvements throughout preparation, competition and transition periods (Burgener, 1994; Fleck, 1999; Matveyev, 1992). From a practical perspective, an advantage of prescribing strength training from the aforementioned acute resistance training variables is that it provides strength and conditioning practitioners with a simple and cost effective means to individualize athlete training loads for a pre-selected training intensity. However, a major shortcoming of this method is that it requires the direct assessment of an athlete’s 1RM for a given exercise which provides limitations. For example, the direct assessment of a 1RM can be a time consuming process (Braith, Graves, Legget, & Pollock, 1993) and the obtained 1RM value may not necassarily reflect the athlete's true maximum strength due to daily fluctuations in biological status (Gonzalez-Badillo & Sanchez-Medina, 2010).

Improvements in maximum strength may also be attributed to a combination of neural, metabolic, hormonal and muscular morphological adaptations. The initial strength gains that occur following a training period are attributed to neural adaptations which include increased neural activation, firing frequency, intermuscular and intramuscular coordination, motor unit synchronization and excitation and, peak electromyography muscular activity (Hakkinen et al., 1985; Jones et al., 1989; Sale, 1988; Zatsiorsky & Kraemer, 1995;). However, following several months of resistance training, further strength gains are attributed to morphological adaptations which include increases in muscle cross-sectional area, musculotendinous stiffness and thickness and changes in fascicle length and pennation angle that are thought to further develop maximum strength capabilities (Blazevich & Sharp, 2005; Folland & Williams, 2007; Fry, 2004; Hakkinen, 1994; Hakkinen et al., 1985; Moritani & DeVries, 1979). Furthermore, the training status of an athlete plays an important role in the rate of maximum strength improvement.

Specifically, trained athletes are considered to have limited potential for maximal strength gains and are required to perform higher intensities and execute heavy loads to increase maximal strength (Kraemer & Ratamess, 2005). This is in agreement with Hakkinen and colleagues (1985) who demonstrated that loads >80% 1RM are required to produce further neural adaptations in advanced resistance trained athletes. Similarly, Berger, (1962) and Campos et al., (2002) demonstrated that loads corresponding to >80% 1RM were most effective for increasing maximum dynamic strength. This may be due to heavier loads being characterized by slower movement velocities that consequently result in longer contraction durations or time under tension (TUT) that are important for strength and hypertrophic adaptations to occur. In addition, heavier loads produce greater forces that are suggested to maximally recruit higher threshold fast twitch muscle fibers that specifically enhance dynamic 1RM strength (Hakkinen et al., 1985). However, as with training intensity, it is suggested that training volume (sets x reps x load) may perhaps be just as important in eliciting improvements in strength adaptations in trained athletes.

That is, altering one or several of the aforementioned resistance training variables may stimulate several systems including the metabolic and hormonal response (Kraemer & Ratamess, 2004; Tan, 1999). Previous research has suggested that configuring a strength training stimulus to promote the accumulation of metabolites such as lactate may increase the secretion of various anabolic (i.e. testosterone and human growth hormone) and catabolic (i.e. cortisol) hormones (Crewther, Cronin, & Keogh, 2005) which may facilitate further adaptations in maximal strength in resitance trained athletes (Crewther et al., 2005; Kraemer & Ratamess, 2005; Mangine et al., 2015). It is generally believed that testosterone and cortisol control short-term and long-term changes in protein metabolism, muscle size and force potential (Kraemer & Ratamess, 2005). In addition, it is proposed that testosterone not only facilitates endocrine mechanisms in the anabolic process, it may also have a direct effect on neural receptors such as increasing the amount of neurotransmitters being released and the length and diameter of dendrites that may be of particular importance in force and power production (Kraemer & Ratamess, 2005).

Therefore, it can be suggested that in trained athletes, due to their limited potential for strength improvement, utilizing high intensity loads (>80% 1RM) or configuring a strength training stimulus that elicits greater secretion of anabolic hormones may facilitate further adaptations in maximal strength. However, this contention remains of great debate in the literature and it may be that a combination of the numerous neural, metabolic, hormonal, and muscle morphological responses to strength training may influence further adaptations in maximum strength rather than one single mechanism. Conversely, it may be that trained athletes require a wide variety of programme design whereby the intensity and velocity of movement may be more significant in developing further adaptations in maximum strength with further investigation warranted in this area (Cormie et al., 2011).

2.4.2 Power resistance training methodology and adaptations

Power can be defined as the ability to generate maximal force rapidly under the concentric portion of the power-time curve when utilizing a given load (Sapega & Drillings, 1983). The load that maximizes power output is often referred to as the P_{max} load which is often predicted based on a polynomial equation applied to the individual power-load curve and is expressed as either mean or peak power (Baker et al., 2001a; Baker et al., 2001b; Bevan et al., 2010; Harris et al., 2007; McGuigan et al., 2009). From a practical perspective, maximal power represents the greatest instantaneous power produced during a single movement performed with the goal of producing maximal velocity at take off, release or impact (Kraemer & Newton, 2000; Newton & Kraemer, 1994). This usually consists of performing movements such as sprinting, jumping and throwing tasks that apply to a wide variety of sports. However, one of the fundamental principles underlying power production is an athletes baseline strength status. As power is the product of force multiplied by velocity (Stone et al., 2003), an individual cannot possess a high level of power without first being relatively strong (Cormie et al., 2011).

The required dose to develop maximal power is considered to be optimized with three to five weekly sessions, performed at or below 60% 1RM with three to six sets of two to six repetitions performed for each exercise (Baker & Newton, 2006; Cormie et al., 2011; Kawamori & Haff, 2004). However, previous research has suggested that resistance trained athletes may require higher loading intensities (70-85%) in order to maximize power output (Baker & Newton, 2006; Kaneko et al., 1983; Newton et al., 1997; Wilson et al., 1993). These suggested higher training loads are in agreement with McBride et al., (2002) and Wilson et al., (1993) who demonstrated that heavier loads (i.e. 4 sets of 3-6 reps at 70-90% 1RM) improved power production in resistance trained men by increasing the force component.

The basis for the prescription of heavy loads for resistance trained athletes is suggested to be related to hypertrophic adaptations and greater motor unit recruitment as near maximal force production is needed to maximally recruit higher threshold fast twitch muscle fibers. In contrast, it is suggested that lighter loads (20-60% 1RM) also be used to optimize power output due to the higher movement velocities achieved at these loads that may enhance intramuscular coordination such as synchronization and firing frequency of motor units (Cormie et al., 2011; Cronin & Crewther, 2004; Hakkinen et al., 1985). Consequently, strength and conditioning practitioners have implemented a range of traditional percentage based power training modalities that include; ballistic, plyometric and weightlifting type exercises in an attempt to develop maximal power capabilities.

An advantage of the aforementioned training modalities is that they allow for loads to be accelerated throughout an entire range of motion, they increase muscular contraction force output and electromyography (EMG) muscular activity during the concentric phase and, they produce greater velocity and power outputs with high intensity training loads (70-85% 1RM) (Bosco et al., 1982; Cormie et al., 2007; De Villiers & Venter, 2015; Haff et al., 1997; Kawamori et al., 2005; Komi & Gollhofer, 1997; Newton et al., 1996; Voigt et al., 1998). In addition, it is suggested that these exercise modalities may allow for a greater overloading of the neuromuscular system that is hypothesized to contribute to adaptations in greater neural activation and enhanced rate of force development (RFD) which is considered of paramount importance for successful athletic performance (Cormie et al., 2007; McBride et al., 2002; Newton et al., 1999). However, disadvantages of traditional percentage based power training methods include that P_{max} output is greatly influenced by the type of muscle action performed and the magnitude of load applied to a specific movement pattern. This will affect factors such as the stretch reflex, storage of elastic energy, neural activation and, recruitment of higher threshold fast twitch muscle fibers (Bosco et al., 1982; Komi & Gollhofer, 1997; McBride et al., 1999; Newton et al., 1996; Wilson et al., 1993; Voigt et al., 1998). In addition, the optimal load that maximizes P_{max} output is highly inter-individual and exercise specific whereby it is suggested that performing loads that maximize P_{max} outputs may be no more effective than performing traditional heavy resistance training (>80% 1RM) (Harris et al., 2008).

Collectively, the ability to generate maximal power is critical to successful athletic performance and is influenced by an athlete's strength status. In addition, maximal power appears to be influenced by a variety of neuromuscular factors that include muscle cross-sectional area and fiber type composition as well as motor unit recruitment, firing frequency, and synchronization. Furthermore, maximal power is also influenced by the type of muscle action performed and the magnitude of load applied to a specific movement pattern. However, the suggested exercises and loading intensities needed for maximal power output appear to be conflicting and provide confusion as to the appropriate selection of loads and exercises that may maximize P_{max} output. Therefore, the development of an effective power training strategy should consider the actual movement velocities achieved for a specified exercise with further investigation warranted in this area.

2.5 VELOCITY BASED RESISTANCE TRAINING METHODOLOGIES

2.5.2 Linear position transducer velocity profiling technology

The use of technology within the strength and conditioning industry to measure and monitor an athlete's physical status continues to grow significantly. The use of linear position transducers (LPT), global positioning systems (GPS) and accelerometers used in combination or separately, are examples of technology that are currently being utilized in the strength and conditioning field for the purpose of measuring performance and monitoring training (Sato et al., 2015). Monitoring the progress of an athlete's training is an essential role of the strength and conditioning professional. The monitoring process allows the efficacy of prescribed training programmes to be evaluated and indicates whether adjustments are needed to the prescribed training stimulus (Harris, Cronin, Taylor, Boris, & Sheppard, 2010).

Previous research has demonstrated that LPT devices provide valid and reliable kinetic measures of strength and power performance at the point of attachment for a given exercise ($CV < 3\%$, $r = 0.59 – 1.00$, $p < 0.05 – 0.001$) (Crewther et al., 2011b; Drinkwater et al., 2007). These devices house a stainless steel cable that is wound on a precisely machined constant diameter cylinder-shaped spool that turns as the measuring cable reels and unreels (Harris et al., 2010). As the LPT's cable reels and unreels along with a moveable object (i.e. Olympic barbell), the rotating spool and sensor creates an electrical signal proportional to the cables linear extension and velocity (Harris et al., 2010). This converts a physical attribute (i.e. power) into a form of measurement or transfers information of the kinetic and kinematic quality of movement. The velocity of a specified movement can then be calculated from the displacement and time [velocity = displacement (d) / time (t)]. Acceleration can also be calculated from the changes in velocity over time [acceleration = velocity (v) / time (t)] (Harris et al., 2010).

The majority of LPT devices now include software that can provide real-time feedback on strength and power output via display screens or handheld devices such as iPhones and tablets. Such feedback provides real-time quantifiable evidence of the true effort or work being performed by an athlete to the strength and conditioning practitioner. This feedback measure may result in increases in a goal-orientated movement task within a strength or power session by enhancing a specific skeletal muscle performance trait such as strength-speed. It is demonstrated by Gonzalez-Badillo and Sanchez-Medina (2010), that although a participant's 1RM value may increase after a period of strength training, the velocity that is obtained at each percentage of 1RM remains stable. In contrast, if a participant's 1RM value does not change significantly following a period of strength training, velocity capabilities may have still improved at various loads (Harris et al., 2010). Additionally, it is considered that the intention to move a load explosively and the actual movement velocity obtained during a specified movement task are vital stimuli to optimize strength and power adaptations (Cormie, McGuigan, & Newton, 2011). That is, the intention to move a load explosively irrespective of contraction type, load and movement are believed to influence velocity specific adaptations to resistance training (Behm & Sale, 1993). However, the majority of literature indicates that velocity specific adaptations to resistance training are elicited by the actual movement velocity of a specified movement (Caiozzo et al., 1981; Kaneko et al., 1983; McBride et al., 2002). Thus, both the intention to move a load explosively and the actual movement velocity achieved for a specified movement are both vital stimuli required to elicit velocity specific neuromuscular strength and power adaptations to resistance training (Cormie et al., 2011). Therefore, strength and conditioning practitioners should place less emphasis on increasing 1RM values and the total load lifted in a session and place greater focus on moving loads across different load spectrums at higher movement velocities when developing neuromuscular strength and power performance.

When measuring velocity during basic non-ballistic type strength training exercises such as the bench press and back squat, the measurement of mean concentric velocity is considered to better represent the ability of the athlete to move a load throughout the entire concentric phase (Jidovtseff, Harris, Crielaard, & Cronin, 2011). In addition, when measuring velocity during ballistic type power exercises such as the power clean and jump squats, the measurement of peak velocity is considered to yield higher consistency between sessions (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). This is easily measurable and achievable with LPT devices that allow strength and conditioning practitioners to monitor velocity at set training load spectrums and examine a range of kinetic data that can provide a detailed diagnostic of the effectiveness of a resistance training session. In addition, LPT's allow a quick and reliable means in enabling strength and conditioning practitioners to accurately prescribe training loads based on an athlete's ability to maintain a prescribed movement velocity that may also aid in fatigue monitoring. Furthermore, strength and conditioning practitioners can identify the point on the load spectrum where the mechanical variable of interest such as peak power is maximized (P_{max}). Cormie and colleagues (2011) demonstrate that the ability to generate maximal power output is not only influenced by the type of movement applied but also the load that is applied to that movement. It is suggested that power output varies dramatically across different loading intensities (0-85% 1RM) that may consequently influence the type and magnitude of performance improvement obtained, as well as the resulting neuromuscular adaptation (Baker et al., 2001a; Cormie et al., 2007; Kawamori et al., 2005).

A study conducted by Baker and colleagues (2001a) demonstrated that power-trained athletes maximized power output in the jump squat when performing loads at P_{max} (55-59% 1RM, 1851 ± 210W), which was significantly different to performing loads of 40kg

(1587 ± 242W), 60kg (1711 ± 206W), 80kg (1796 ± 218W), and 100kg (1823 ± 230W) relative to each participants 1RM full squat. Similarly, Baker et al., (2001b) demonstrated that power-trained athletes maximized power ouput in the bench press throw when performing loads at P_{max} (55 ± 5.3% 1RM, 598 ± 99W), which was greater than performing loads at 40kg (482 ± 54W), 50kg (533 ± 70W), 60kg (568 ± 83), 70kg (588 ± 95W), and 80kg (580 ± 112W) relative to each participants 1RM bench press. Collectively, these results suggest that power-trained athletes may require higher loading intensities in order to maximize power output for a given exercise than the previously suggested lower intensity ranges of 30-45% 1RM (Kaneko et al., 1983; Newton et al., 1997; Wilson et al., 1993). Therefore, LPT devices may allow for the prescription of individual and daily exercise specific loads that may maximize P_{max} output rather than arbitrarily setting training loads that may not be appropriate for that given day due to daily fluctuations in biological status.

In contrast, prescribing loads that maximize P_{max} outputs provide limitations in that this method cannot be applied to developing specific skeletal muscle performance traits that include; starting strength, speed-strength, strength-speed, accelerative strength, and absolute strength during a periodized resistance training programme. Additionally, there are a number of calculation techniques utilized to analyse power data during unloaded and loaded conditions that include multiplying the force-time curve by the velocity-time curve, resulting in a power-time curve for the movement analysed (Cormie, McBride, & McCaulley, 2007; McBride et al., 2002). However, this calculation method provides limitations in that it does not account for the exclusion of system mass in force calculations. A study conducted by McBride et al., (2002) demonstrated that the power-time, force-time and, velocity-time curves during the concentric phase of unloaded conditions is higher in comparison to loaded conditions due to the increased acceleration throughout a specified movement. Therefore, the resulting power-time curve may have marked decreases in peak power, force and velocity output and consequently underestimate or misinterpret optimal power training loads (Cormie et al., 2007). Thus, VBT may provide a more comprehensive training approach in accurately prescribing daily training loads that maximize strength and power performance.

In summary, LPT devices provide a variety of assessment and monitoring strategies that offer a more in depth understanding of velocity specific strength and power adaptations when compared to traditional field based quantification of sets x reps x load. Taking this into consideration, with the frequent and continued use of LPT technology within sporting organizations, this will lead to improved strength and power programming and subsequent improvements in athletic performance.

2.5.3 Overview of isokinetic and isoinertial velocity based resistance training used in the literature

The specificity principle suggests that greater improvements in strength and power performance are obtained when resistance training is similar to the sports performance pattern. This would suggest that athletes perform resistance training that simulates sport specific muscle actions and velocities that are encountered during sporting competition. A number of studies have investigated the effects of velocity specific isokinetic training with both slow and fast velocity training of the elbow flexors and leg extensors/flexors (Coburn et al., 2006; Kaneko et al., 1983; Wilson et al., 1993). In addition, the majority of isoinertial studies have investigated the effects of velocity specific isoinertial training with either low-load high velocity or high-load slow velocity training (Baker et al., 2001a; Moss et al., 1997; Wilson et al., 1993). It is generally accepted that isokinetic muscle actions are considered to be less specific to actual sporting movements and the practical applications of the results from isokinetic research are somewhat questionable (Cronin et al., 2002). Additionally, isoinertial resistance training is suggested to be more specific to actual sporting movements as it facilitates the nervous systems ability to activate agonist, antagonist and synergistic muscle activity that is essential to successful sporting performance (Cronin et al., 2002).

A study conducted by Kaneko and colleagues (1983) investigated the influence of load-controlled isokinetic velocity specific adaptations in the elbow flexors with training loads of 0, 30, 60 and 100% of isometric voluntary contraction force. The results demonstrated that training with heavy load (100% MVC) mainly improved performance at the high portion of the force-velocity curve whereas, training with light load (0-30% MVC) mainly improved performance at the high velocity portion of the curve. It was concluded that resistance equal to 30% of maximal isometric strength in an elbow flexor movement maximized power output. Similarly, Moss et al., (1997) investigated the effect of maximal isoinertial strength training in the elbow flexors at loads of 15, 35 and 90% of 1RM. The results demonstrated that training with light loads of 15% and 35% of 1RM resulted in velocity specific improvements in 1RM strength (6.6% and 10.1%). In contrast, it was also demonstrated that training with heavy loads (90% 1RM) significantly increased maximal strength (15.2%) and power output at 15% 1RM. Additionally, Wilson and colleagues (1993) demonstrated that high velocity training maximized power output with isoinertial loads equivalent to 30% of participant's maximum isometric force that produced significant improvements in CMJ (17.6%) and isokinetic leg extension (7%) performance when training with light loads and high velocities. Conversely, Baker and colleagues (2001a) demonstrated that mechanical power output is maximized at 55-59% of full squat 1RM in trained athletes. Collectively, the aforementioned studies results suggest that athletes may maximize power output at slightly higher intensities (48-63% 1RM) than previously recommended (30-45% 1RM) intensities. In addition, it is also suggested that lighter intensities (30-45% 1RM) may be effective in stimulating higher movement velocities and it would appear that a range of intensities may maximize velocity and power output. In contrast, a study conducted by Coburn and colleagues (2006) demonstrated that isokinetic leg extension in 30 adult women (age 19-29 years) who had not participated in a resistance training programme three months prior to testing, increased peak torque significantly at slow velocity training (30°/s) when compared to fast velocity training (270°/s). Specifically, it was demonstrated that slow velocity training increased peak torque (24.4%) at both slow and fast velocities, whereas fast velocity training increased peak torque (11.5%) only at a fast velocity. A similar study conducted by Prevost and colleagues (1999) demonstrated contradictory results in 18 novice resistance trained males (age 19-35 years) whereby the slow velocity training group demonstrated no change in peak torque. However, the fast velocity training group significantly increased peak torque (22.1%) only at the fast training velocity. Conversely, other isokinetic investigations have demonstrated that high velocity training induces strength gains at both slow and fast velocities, whereas slow velocity training provides improvements only at slow velocity training conditions (Coyle et al., 1981; Lesmes et al., 1978; Moffroid & Whipple, 1970). Collectively, these studies suggest that training at specific movement velocities may be an important consideration in improving strength and power performance.

The mechanisms underlying velocity specific isokinetic and isoinertial resistance training adaptations from the aforementioned studies are by no means clear. The results from these studies appear to be conflicting with the majority of isokinetic studies suggesting that subjects performing resistance training at fast velocities will mainly improve performance at fast velocities than those who train at slow velocities and vice versa. Furthermore, the majority of isoinertial studies suggest that performing resistance training at a range of loading intensities specific to a participants individual 1RM may optimize velocity and power output. Many methodological aspects may have influenced the differences between studies such as firstly defining what constitutes slow and fast velocity training and whether one exercise velocity is optimal for improving functional performance. Since high velocity and high load resistance training effects different portions of the force-velocity curve, it can be suggested that combining both slow and fast velocity movements as part of comprehensive resistance training programme may optimize adaptation within the neuromuscular system by performing a range of velocities encountered during sporting competition. In contrast, the effect of combining both slow and high velocity training as part of a comprehensive resistance training programme in order to improve functional neuromuscular performance are currently not well understood. In addition, isokinetic dynamometry muscle actions are considered to be less specific to actual sporting movements therefore, it is important future research involving velocity specific resistance training in athletes utilize isoinertial techniques with further research warranted in this area.

2.5.4 Velocity based resistance training neuromuscular adaptations

The mechanisms responsible for VBT neuromuscular adaptations are currently not well understood. It has been suggested that velocity specific adaptations to resistance training may be due to several factors including; enhanced coordination and specificity of movement, increased discharge of high threshold motor units, enhanced intramuscular and intermuscular coordination and increased stress placed on fast twitch muscle fibers (Cronin et al., 2002; Enoka, 1997; Tricoli et al., 2001). Since fast and slow twitch fibers differ in contractile properties, a training induced enhancement of fast twitch fiber activation may have a marked effect on velocity specific adaptations (Tricoli et al., 2001). According to Behm and Sale (1993), the principal stimuli responsible for eliciting velocity specific adaptations are the motor unit activation recruitment patterns associated with the intention to move a load explosively regardless of actual movement velocity and load. In addition, Jones and colleagues (2001) suggest that the use of intended maximal concentric action (IMCA) lifting techniques may increase neuromuscular peak power (PP) and peak velocity (PV) capabilities across a range of loading intensities (40-90% 1RM) provided the subject attempts maximum acceleration with each repetition. However, McBride et al., (2002) demonstrated a significant finding in that the velocity at which a participant trains, as controlled by load, results in velocity specific changes in muscular electrical activity and improvements in peak force (PF) and P_{max} muscular capabilities. Therefore, it appears that the intention to move a load explosively and the actual movement velocity as controlled by load are both vital stimuli for improving velocity specific neuromuscular performance capabilities and possible neural adaptations.

Conversely, a study conducted by de Oliveira and colleagues (2013) investigated the effect of high velocity concentric knee extension resistance training over a 6-week training intervention on the RFD at early (<100 $m.s^{-1}$) and late (>100 $m.s^{-1}$) phases of rising muscle force. The results demonstrated that RFD increased 39-71% at time intervals up to 90 $m.s^{-1}$ from the onset of muscle contraction, whereas no change occurred at later time intervals. Similarly, Anderson and Aagaard (2006) demonstrated that RFD is influenced by diverse factors at early (<100 $m.s^{-1}$) and late phases (>100 $m.s^{-1}$) from the onset of muscle contraction. It is suggested that the early phase of RFD is largely influenced by neural drive (Gruber & Gollhofer, 2004) and intrinsic muscle properties including fiber type and myosin heavy chain composition (MHC) (Anderson, Anderson, Zebis, & Aargaard, 2010). However, the late phase of RFD is demonstrated to be closely related to factors that promote improvements in maximal strength. In addition, Tillin and colleagues (2012) demonstrated that short-term high velocity strength training improved maximal voluntary force (MVF) (11%) at all measured time points from the onset of muscle contraction. The improvement in MVF is suggested to be primarily due to enhanced agonist neural drive, motorneuron recruitment, firing frequency and peripheral adaptations in increased muscle-tendon unit stiffness (34%) between 50% and 90% MVF. Furthermore, a study conducted by Hakkinen and colleagues (1985) demonstrated that high velocity strength training (0-60% 1RM) were accompanied by and correlated with the increase in fast twitch muscle fiber cross-sectional area and the percentage of fast twitch fibers of the involved muscle correlated ($p < 0.05$) with the improvement in isometric RFD (24%) and the rate of onset in muscle activation (38%). This suggests that velocity specific adaptations in RFD or rate of onset in muscle activation is influenced by high velocity specific movements that contribute to the increase in rate of neural activation. Similarly, Ivy and colleagues (1981) demonstrated that PP and rate of power production were correlated (0.57 to 0.73) with the percentage of type II fibers and Tricoli et al., (2001) confirm that participants with a higher type II fiber percentage were able to produce higher power at specific trained velocities. In regards to skeletal muscle architectural adaptations, Blazevich and colleagues (2003) demonstrated that participants who performed only high velocity training exhibited a decrease in vastus lateralis (VL) fascicle angle and an increase in VL fascicle length ($p < 0.05$ at distal, $p < 0.1$ at proximal). The observed morphological changes in decreased fascicle angle and increased fascicle length may in turn allow more sarcomeres to be arranged in series that may facilitate greater rapid transmission of force to the tendon that may consequently increase contractile RFD and contractile impulse (Fukunaga et al., 1997; Gans & Gaunt, 1991; Kawakami et al., 1993; Kumagai et al., 2000; Storey et al., 2012). With this in mind, morphological adaptations are likely due to the force and velocity characteristics of a given exercise rather than the movement pattern performed (Blazevich et al., 2003). Moreover, these muscular architectural characteristics appear to coincide with the determinants of maximum velocity of muscular shortening that are suggested to be consistent with improvements in strength, power and sprint performance (Abe, Kumagai, & Brechue, 2000).

Therefore, it can be suggested that two possible neuromuscular adaptations to VBT may include mechanisms of adaptations within the skeletal muscle itself (Duchateaus & Hainaut, 1984) and adaptations within the nervous system that may affect the muscle force-velocity curve and preferential recruitment of higher threshold motor units. It appears that the intention to move a load explosively and the actual movement velocity as controlled by load are both vital stimuli for improving velocity specific neuromuscular performance capabilities and possible neural adaptations. Furthermore, placing emphasis on producing high velocity movements across a range of loading intensities (40-90% 1RM), rather than producing maximal force may provide a more effective training stimulus in improving neuromuscular strength and power performance when compared to sustained high-load low velocity contractions.

Collectively, this may have important implications for resistance training prescription as the instruction of accelerating a load with maximum velocity may be just as important as prescribing individual training loads that may substantially improve neural drive, intrinsic muscle activation and fiber type and pennation angle morphology. It appears that velocity specific resistance training may provide desirable neuromuscular and muscle morphological adaptations that may enhance athletic performance. However, the neuromuscular and muscle morphological adaptations to velocity specific resistance training are currently not well understood with further investigation warranted in this area.

2.5.5 Load-velocity relationship

The determination of an individual athlete load-velocity profile for a particular exercise may be of great interest to strength and conditioning practitioners as this allows individual tracking of an athlete's progress over training blocks and velocity specific adaptations across a spectrum of velocity demands (Jovanovic & Flanagan, 2014). An ongoing dilemma faced by strength and conditioning practitioners is the issue of how to accurately quantify, assess and monitor a prescribed training stimulus in order to maximize strength and power adaptations. A common method used in the field to assess and monitor strength and power performance is with the use of a traditional one repetition maximum (1RM) test. However, major shortcomings of the direct assessment of 1RM include a higher association with injury risk and the process can be time consuming and impractical for large groups such as team sports (Braith et al., 1993). Additionally, it is observed that an athlete's actual 1RM can change quite rapidly after only a few training sessions and often the obtained value is not the athlete's true maximum that can be associated with daily fluctuations in biological status (Gonzalez-Badillo & Sanchez-Medina, 2010). For example, Jovanovic and colleagues (2014) demonstrated that an ~18% difference exists above or below a previously tested 1RM which suggests a ~36% difference exists around a pre-training block 1RM due to daily variability in biological status and readiness to train. Alternatively, the repetitions to fatigue (RTF) test, performed with a submaximal weight has been widely investigated to identify the relationship between loading intensity (%1RM) and repetition failure to establish a repetition maximum continuum. This method certainly eliminates the need for a traditional 1RM test. However, increasing evidence demonstrates that repetition failure does not necessarily convey the magnitude of muscle strength and may be counterproductive by inducing excessive fatigue and mechanical and metabolic strain (Gonzalez-Badillo & Sanchez-Medina, 2010).

Movement velocity is a variable that could be of great interest in assessing and monitoring a prescribed training stimulus. The relationship between load and velocity can be described by a simple linear regression equation that produces a slope and intercept of the line. The strength of this relationship can be described by simple statistics including the coefficient of determination (R^2) and standard error of the estimate (SEE) (Vincent & Weir, 2012). A recent study conducted by Gonzalez-Badillo and colleagues (2010) demonstrated that a close relationship exists between relative load and the movement velocity that is attained during resistance training (R^2 = 0.98) (Gonzalez-Badillo & Sanchez-Medina, 2010) (refer to Table 1). During this investigation, 120 strength trained male participants performed a baseline bench press isoinertial strength test (T1) with increasing loads up to the participants' 1RM whilst an LPT was attached to the bar. This was done to determine the individual load-velocity relationship in the bench press exercise. A subset of 56 participants then performed a follow-up test on a second occasion (T2), following a 6-week resistance training intervention. During the intervention the participants performed their usual resistance training routine of two to three sessions per week that included three to five sets of 4-12 repetitions at 60-85% 1RM for the bench press exercise. The results demonstrated that a very close relationship between mean propulsive velocity (MPV) and load (%1RM) (R^2 = 0.98) was observed and despite a mean increase of 9.3% in the participants' 1RM from T1 to T2, MPV for each percent of 1RM remained stable and the load-velocity relationship was also confirmed regardless of individual relative strength. These results confirm that an inextricable relationship exists between load and MPV and consolidates the use of velocity as an important measure of performance in strength and power resistance training (Bazuelo-Ruiz et al., 2015). Therefore, this relationship makes it possible to determine with great precision the real intensity of effort or work being incurred by an athlete at loads performed between 30% to 95% of 1RM. In addition, this relationship provides an effective evaluation of maximal strength without the need to perform a 1RM test and allows accurate prescription of daily training loads according to velocity, rather than percentages of 1RM (Gonzalez-Badillo & Sanchez-Medina, 2010).

Load (%1RM)	T1	T2	Difference (T1-T2)
30%	1.33 ± 0.08	1.33 ± 0.08	0.00
35%	1.24 ± 0.07	1.23 ± 0.07	0.01
40%	1.15 ± 0.06	1.14 ± 0.06	0.01
45%	1.06 ± 0.05	1.05 ± 0.05	0.01
50%	0.97 ± 0.05	0.96 ± 0.05	0.01
55%	0.89 ± 0.05	0.87 ± 0.05	0.01*
60%	0.80 ± 0.05	0.79 ± 0.05	0.01
65%	0.72 ± 0.05	0.71 ± 0.05	0.01
70%	0.64 ± 0.05	0.63 ± 0.05	0.01
75%	0.56 ± 0.04	0.55 ± 0.04	0.01
80%	0.48 ± 0.04	0.47 ± 0.04	0.01
85%	0.41 ± 0.04	0.40 ± 0.04	0.01
90%	0.33 ± 0.04	0.32 ± 0.04	0.01
95%	0.26 ± 0.03	0.25 ± 0.03	0.01
100%	0.19 ± 0.04	0.18 ± 0.04	0.00*

Table 1: Changes in mean propulsive velocity ($m.s^{-1}$) attained with each relative load from initial test (T1) to retest (T2), following 6-weeks of bench press resistance training (Gonzalez-Badillo & Sanchez-Medina, 2010).

Constructing an individual athlete load-velocity profile for a given exercise would allow strength and conditioning practitioners to periodically assess an athlete's velocity specific strength and power adaptations obtained across different load spectrums. In addition, the load-velocity profile may optimize the prescription of daily strength and power training loads whilst improving training efficiency, by determining whether the prescribed intensity (%1RM) for a given exercise truly represents the intended focus of a resistance training session. Recent research has proposed using the load-velocity relationship to predict maximal 1RM dynamic strength in the bench press and back squat exercise with submaximal loads (Bazuelo-Ruiz et al., 2015; Jidovsteff et al., 2011; Jovanovic & Flanagan, 2014). Such a prediction may be of great interest to strength and conditioning practitioners as the close relationship between mean velocity (MV) and load lifted according to percentage of 1RM (30-100%, R^2 = 0.98, p<0.001) (Gonzalez-Badillo & Sanchez-Medina, 2010) allows practitioners to estimate daily 1RM values that can be used to assess the daily training status and readiness of an athlete.

A study conducted by Jidovtseff and colleagues (2011) demonstrated a strong correlation ($r = 0.95$) between the relationship of 1RM and load at theoretical zero velocity. The authors concluded that 1RM bench press strength can be accurately estimated using the load-velocity relationship from three to four increasing loads with the same accuracy as the repetition to failure test. Additionally, the authors suggest that MV must be used when estimating bench press maximal 1RM strength, as this better represents an athlete's ability to move a load throughout the entire concentric phase. Similarly, Sanchez-Medina et al., (2010) demonstrate that referring to mean values of the propulsive phase during the bench press exercise when assessing velocity with a load lifted in a concentric action avoids under-estimating an individuals neuromusuclar ability, especially when lifting light and moderate loads. A recent study conducted by Bazuelo-Ruiz and colleagues (2015) utilized MV to predict maximal 1RM strength in the half squat exercise. The results demonstrated a moderate correlation between MV and a load equivalent to body weight that was capable of estimating maximal 1RM half squat strength with an accuracy of 58%. This moderate correlation may be partly explained by the differences in muscular architecture as it is demonstrated that greater fiber lengths and longitudinal fiber arrangement of the primary movers used in the back squat are characterized by faster shortening velocities, whereas the primary movers for the bench press exercise are characterized by shorter fiber lengths and greater pennation angles that subsequently generate greater muscular force capabilities (Lieber & Friden, 2000; Pearson et al., 2009). Consequently, greater repetition velocities can be observed for the back squat exercise due to functional differences in joint positions and levers and fibre type arrangement when compared to the bench press exercise.

Table 2 demonstrates a practical example of establishing a load-velocity profile for a given exercise. It is recommended to perform three to four increasing loads from light to heavy intensities when constructing a load-velocity profile (Jidovtseff et al., 2011). For lighter intensities, three repetitions should be executed at > 1.0 $m.s^{-1}$ (MV), two repetitions at moderate intensity executed between 0.65 $m.s^{-1}$ – 1.0 $m.s^{-1}$ (MV), and one repetiton at high intensity loads that are performed at < 0.65 $m.s^{-1}$ (MV) (Sanchez-Medina et al., 2010). When performing this procedure athletes must express maximal dynamic effort for each repetition regardless of the lifting intensity as only the highest velocity achieved at each load spectrum is considered for analysis (Sanchez-Medina et al., 2010). In addition, the three to four increasing loads from light to heavy intensities must provide a 0.5 m.s^{-1} decrease in velocity to significantly cover the load-velocity relationship (Jidovtseff et al., 2011).

Table 2: Example load-velocity profile protocol for a given exercise (Jidovtseff et al., 2011; Sanchez-Medina et al., 2010)

Reps	%1RM	Mean Velocity (m.s^{-1})	Rest
3	40%	> 1.0 m.s^{-1}	2 mins
2	60%	0.65 – 1.0 m.s^{-1}	2 mins
2	75%	< 0.65 m.s^{-1}	3 mins
1	85%	< 0.60 m.s^{-1}	3 mins

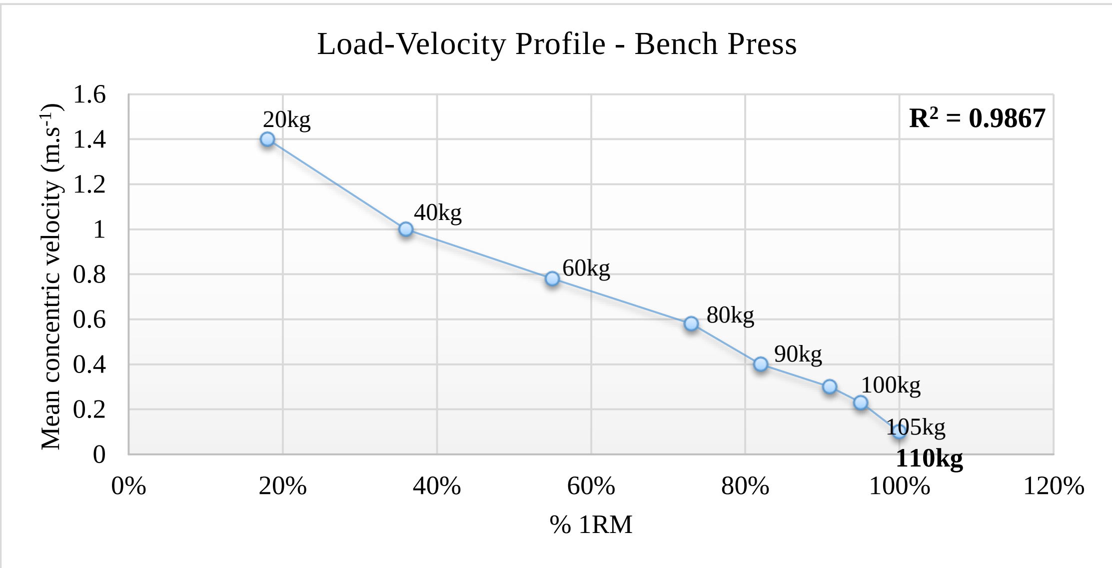


Figure 1: Example of an athletes load-velocity profile for the bench press exercise. Load (%1RM) is plotted on the x-axis and the achieved velocity (m.s^{-1}) is plotted on the y-axis (Jovanovic & Flanagan, 2014).

It must be highlighted that a load-velocity profile must be constructed for individual upper body and lower body exercises. The kinematics and kinetics associated with commonly prescribed multi-joint resistance exercises such as the bench press, prone bench pull and back squat provide key differences in the load-velocity and power-load relationships that may be attributed to the differing muscular architecture and strength curves (Pearson et al., 2009; Sanchez-Medina et al., 2014). As previously mentioned, the primary movers used in exercises such as the back squat and prone bench pull exercises are characterized by faster shortening velocities, whereas the primary movers for the bench press exercise generate greater muscular force capabilities (Lieber & Friden, 2000; Pearson, et al., 2009). A study conducted by Sanchez-Medina and colleagues (2014) demonstrated that the MPV ($p<0.001$) and absolute P_{max} values obtained for mean power output for the prone bench pull (495 ± 81 W) were always significantly higher when compared to the bench press exercise (400 ± 80 W) for loads performed between 30% – 100% 1RM with the differences between exercises becoming larger as the load approached 1RM. Similarly, Pearson et al., (2009) demonstrated that MV for the concentric phase of the prone bench pull to be 525% greater than the bench press at 100% 1RM and mean power being 442% greater at the equivalent load. Additionally, Izquierdo et al., (2006a) demonstrated that MV decreased at a greater rate during the bench press when compared to the back squat exercise. For example, the velocity that was attained during repetitions performed at 75, 70, 65 and 60% 1RM were significantly higher in the back squat when compared to the bench press exercise. It is likely that the differences in repetition velocity during the bench press, prone bench pull and back squat may vary between the different muscle groups due to functional differences in joint position and levers, fiber type distribution and biomechanical characteristics of the open and closed upper and lower body kinetic chains (Izquierdo et al., 2006a). Therefore, load-velocity profiles should be generated for individual exercises to account for the unique kinematic and kinetic differences between exercises.

The results of the aforementioned studies confirm previous research regarding the importance of considering the contribution of the propulsive and braking phases (Sanchez-Medina et al., 2010) when assessing upper body and lower body muscular strength and power during isoinertial resistance training. An important aspect to take into account when lifting loads in isoinertial conditions is there exists a considerable portion of the concentric phase that is allocated to decelerating a moving resistance especially when lifting light and moderate loads. Sanchez-Medina and colleagues (2010) demonstrated that the lighter the load and higher the movement velocity (<70% 1RM), the greater the duration of the braking phase. Similarly, Izquierdo and colleagues (2006a) demonstrated that high velocity repetitions performed at 60-75% 1RM provide extended deceleration phases that may induce shorter concentric efforts and reduce repetition intensity. However, it is demonstrated that when loads are sufficiently high (>80% 1RM) the braking phase disappears and the full concentric phase can be considered entirely propulsive (Sanchez-Medina et al., 2010). This further highlights the importance of evaluating the training effect by referring to mean mechanical values of the concentric propulsive phase of the bench press and back squat exercise, especially when moving loads <70% 1RM to avoid under-estimating an athletes neuromuscular ability.

The creation of a load-velocity profile for an individual upper body or lower body exercise may inform future decisions of the efficacy of a prescribed strength and power training stimulus. This may be of particular interest to strength and conditioning practitioners who are not solely concerned with developing maximal strength but may also be interested in velocity specific strength and power adaptations across different load spectrums. In addition, the load-velocity relationship has been shown to provide accurate predictions in dynamic 1RM strength and power values with submaximal loads. Such a prediction can be used as a guide in prescribing daily training loads and identifying the point on the load spectrum where power (P_{max}) is maximized in relation to an athlete's daily biological status. Consequently, this may replace the need for a traditional 1RM test and arbitrarily prescribing strength and power training loads based off an athlete's pre-training block 1RM value.

2.5.6 Monitoring fatigue and controlling exercise load with movement velocity

Recent research has demonstrated that by monitoring movement velocity during isoinertial resistance training conditions it may be possible to limit the amount of metabolic stress and neuromuscular fatigue accumulated during resistance training (Sanchez-Medina & Gonzalez-Badillo, 2011). It is demonstrated that for a given muscle action performed over a set of repetitions the velocity of each repetition slows naturally, (Mookerjee & Ratamess, 1999; Pasquet et al., 2000) and the continued performance becomes progressively more difficult as the production of metabolic by products and fatigue increases. In support of these findings, Sanchez-Medina and colleagues (2011) demonstrated a near perfect correlation between the decline in MPV over prescribed sets and post-exercise lactate concentrations for the bench press ($r = 0.95$, $p<0.001$) and back squat ($r = 0.97$, $p <0.001$) exercises. In addition, post-exercise ammonia concentrations followed a curvelinear trend in relation to velocity loss where an increase in blood ammonia levels above baseline values coincided with a ~30-35% of loss in velocity during the back squat and bench press, respectively. An increase in blood ammonia levels has been demonstrated to be indicative of accelerated purine nucleotide degradation that is associated with a slow and energy consuming process that can significantly reduce performance for up to 48-72 hours post-exercise, thereby necessitating longer recovery times (Hellsten-Westing, Norman, Balsom, & Sjodin, 1993).

In order to control the accumulation of metabolic by products and extent of neuromuscular fatigue it can be suggested to prescribe loading strategies using velocity zones and velocity stops. A velocity zone can be defined as specific velocity zone that an athlete must perform a resistance training movement within in order to develop a specific skeletal muscle performance trait (i.e. 0.20 – 0.25 $m.s^{-1}$ for absolute strength). Conversely, a velocity stop can be defined as a prescribed movement velocity for each repetition and a minimum velocity threshold (MVT) is set, in which the individual is not allowed to drop below, as a means to minimize neuromuscular fatigue (Jovanovic & Flanagan, 2014). This novel method can be used to control the total volume load lifted in a resistance training session by ensuring athletes remain within a target velocity zone or by not dropping below a MVT as opposed to arbitrarily prescribing loads based off pre-training block relative or absolute 1RM values (Jovanovic & Flanagan, 2014). It can be observed from Figure 2 that the daily estimated 1RM values that are based off the associated warm-up sets tend to be different from the pre-training block 1RM values. Therefore, applying velocity zones or velocity stops during training sets may provide a simple but effective means to control the extent of neuromuscular fatigue and allow athletes to maintain maximal velocities by taking into account the daily variability in maximum strength.

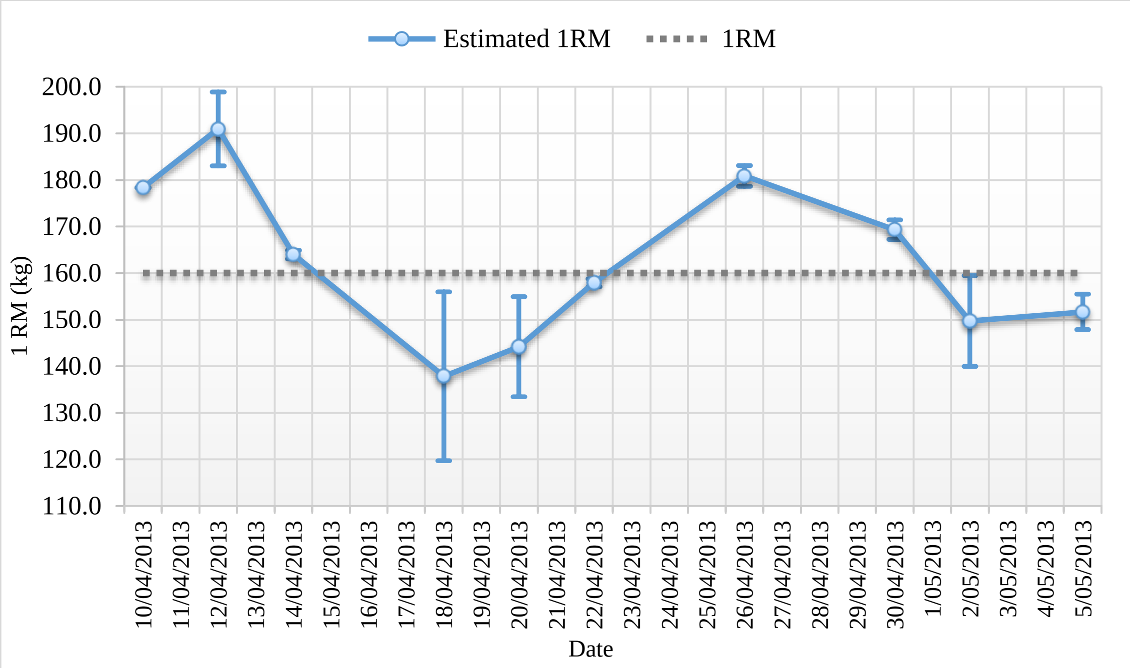


Figure 2: Estimation of 1RM from warm-up sets for the squat exercise during a training block. The dotted line represents pre-training block 1RM values with the blue line representing daily variation in maximum strength in relation to daily biological status (Jovanovic & Flanagan, 2014).

A study conducted by Padulo and colleagues (2012) investigated the effect of minimizing velocity loss during sets at fixed pushing speeds (FPS) and self-selected pushing speeds (SPS) to determine its influence of muscular strength improvements after a 3-week training intervention with the bench press exericse. The FPS group performed the bench press exercise at 85% 1RM within a starting velocity range of 0.36 – 0.45 m.s^{-1} with each set terminated when velocity decreased below a threshold of 20%. Conversely, the SPS group performed the bench press at 85% 1RM until volitional fatigue. The results demostrated that after three and five days post intervention, the FPS group significantly improved muscular strength by 10.20% and maximal speed by 2.22% whilst, the SPS group improved muscular strength by 0.17% and maximal speed by 0.11%. Additionally, the FPS group completed less repetitions and as a result, the total volume load was significantly less (-62%) when compared to the SPS group. The authors concluded that moving a load with maximal effort and minimizing velocity loss within sets may positively enhance neuromuscular strength adaptations.

Therefore, a decrease in repetition velocity both within sets and between sets may provide evidence of impaired neuromuscular function that may be controlled with setting velocity thresholds to limit the accumulation of metaboilc stress and neuromuscular fatigue. In addition, utilizing velocity zones or velocity stops may provide a novel approach in autoregulating and individualizing training volume and load that may be sensitive to changes in daily maximum strength and may optimize the training response. However, it is important to note that the velocity zones and velocity stops may differ between commonly prescribed multi-joint resistance exercises such as the bench press and back squat due to key differences in the load-velocity and power-load relationships that may be attributed to the differing muscular architecture and strength curves (Pearson et al., 2009; Sanchez-Medina et al., 2014). At present, the effect of utilizing velocity to monitor fatigue and control exercise volume load are currently not well understood and further research is warranted in this area.

2.5.7 Sport specific strength and power adaptations to velocity based resistance training

The majority of isoinertial resistance training studies have compared VBT to either half maximal velocity or high intensity strength training and its transference to sports performance. Isoinertial VBT studies have reported significant improvements in performance measures following training interventions that comprised of two to four supervised resistance training sessions per week across 4 – 10 week periods (Delecluse et al., 1995; Gonzalez-Badillo et al., 2014; Pareja-Blanco et al., 2014). A study conducted by Delecluse and colleagues (1995) investigated the effects of high intensity and high velocity training on different phases of 100-meter sprint performance. The results of the study demonstrated that high velocity training resulted in improved initial acceleration, maximum speed and significant improvements in total 100-meter sprint times. Conversely, high intensity training only resulted in improved acceleration during the initial phase of the 100-meter sprint (Delecluse et al., 1995). With regards to strength adaptation, Pareja-Blanco and colleagues (2014) demonstrated that maximal velocity vs. half maximal velocity training during a full squat in resistance trained men seemed to be of greater importance than time under tension (TUT) for inducing strength improvements. In addition, maximal velocity training improved maximum strength (Effect size: 0.94 vs. 0.54) and velocity development (ES: 1.76 vs. 0.75) to a greater extent across both light and heavy loads. Similarly, Gonzalez-Badillo and colleagues (2014) demonstrated that maximal concentric velocity efforts during the bench press exercise resulted in significantly greater gains in 1RM strength (18.2 vs. 9.7%), velocity developed against light (11.5 vs. 4.5%) and heavy (36.2 vs. 17.3%) loads when compared to half maximal concentric velocity efforts. In addition to significantly improving in all strength performance variables, the maximal concentric velocity group spent less total time under tension when compared to the half maximal concentric group (223 vs. 361 seconds) which supports the findings of Pareja-Blanco and colleagues (2014). However, the previous investigations of Pareja-Blanco et al., (2014) and Gonzalez-Badillo et al., (2014) provide limitations in that participants were instructed to perform a maximal intended lift during the warm up set and the velocity of this lift was then used to predict a percent of 1RM from the load-velocity relationship (e.g. 0.79 $m.s^{-1}$ = ~60% of 1RM). Each participant was then instructed to maintain a target velocity zone prescribed for each repetition with the predicted training load during each subsequent training week (e.g. week 1 = 0.90 $m.s^{-1}$). However, both studies failed to specify whether the training sessions performed were either strength or power training phases.

Velocity specificity in resistance training to improve sport specific strength and power adaptations are currently not well understood. There is evidence that suggests that sport specific movement patterns and high velocity training are associated with improvements in strength and power performance. However, there lacks evidence to support the use of high velocity resistance training to improve strength and power performance when compared to traditional heavy resistance training. Based on the available evidence it is difficult to recommend a movement velocity that will maximize sport specific strength and power performance and further research is warranted.

2.6 MONITORING TRAINING VOLUME AND LOAD

2.6.1 Autoregulatory and traditional prescribed training programmes

Periodization of a strength and power training stimulus is widely acknowledged as crucial to optimizing the training response. Central to the theory of periodization is the principle of progressive overload, which refers to the muscular and nervous system adapting to meet the needs of lifting an increasing load (Mann et al., 2010). This can be achieved by manipulating a number of resistance training variables that include; repetition speed, varying rest periods between sets and, altering training volume by changing the number of sets, reps and exercises performed throughout training blocks (Fleck & Kraemer, 2004). However, it is important to understand how the manipulation of these resistance training variables affects improvements not only in muscular strength and power performance but also the influence this has on internal load. Internal load can be defined as the physiological (i.e. heart rate and blood lactate) and psychological (i.e. RPE and mood monitoring) stress imposed on an athlete that is measured independently of external load (i.e. power output, speed and acceleration) (Halson, 2014). An on-going dilemma faced by strength and conditioning practitioners is how to accurately quantify and monitor resistance training volume and load throughout different training phases as there is no universally agreed upon best method. Thus, most traditional percentage based resistance training methods quantify a resistance training stimulus by calculating the sets x reps x load which equates to the total volume load lifted in a training session (Kraemer & Ratamess, 2004). In addition, a number of calculations have been utilized to determine daily, weekly, or monthly workload that include;

1) The volume index (VI) which determines workloads relative to body mass;

   VI = volume load (kg) ÷ Body mass (kg)

2) Training intensity (TI) determines the overall intensity of the training programme;

   TI = volume load (kg) ÷ repetitions and,

3) Training efficiency (TE) determines the change score from baseline measures in a specified exercise (i.e. bench press baseline score to 12 weeks) from the amount of absolute workload performed (i.e. volume load)

   TE = change score ÷ volume load (kg) (Haff, 2010; Painter et al., 2012; Harries et al., 2015).

These methods are used extensively by strength and conditioning practitioners due to its simplicity and the absence of expensive computer software and performance technology (Randell et al., 2010). However, when resistance training is periodized according to developing a specific skeletal muscle performance trait (i.e. speed-strength or strength-speed), monitoring becomes much more difficult as it is important to establish if the prescribed training stimulus is truly enhancing the intended development of a specific skeletal muscle performance trait. As previously mentioned, resistance training provides a complex model for monitoring training volume and load where factors such as repetition speed, sets, reps and rest periods continually change throughout strength and power training phases. Therefore, traditional percentage based quantification of training volume and load may be inadequate because of the prevailing importance of intensity and velocity of movement during strength and power resistance training (McGuigan & Foster, 2004a).

A less common and understudied form of monitoring training volume and load is autoregulation of resistance training (Mann et al., 2010). Autoregulation is a form of training that adjusts to the individual athlete's readiness to train on a day-to-day or week-to-week basis (Mann et al., 2010). This type of monitoring is based off allowing athlete's to increase strength and power at their own rate as individual athletes may respond differently to a given training stimulus and the training load required for adaptation may differ significantly from one athlete to another (Halson, 2014; Mann et al., 2010). Thus, the use of autoregulatory training may maximize strength and power adaptations over different training blocks by allowing athletes to progress at their own rate.

The rating of perceived exertion (RPE), autoregulatory progressive resistance exercise (APRE) and VBT have recently been investigated to quantify and monitor training volume and load. Several investigations have demonstrated the RPE to be a valid and reliable method ($r = 0.88$-0.95) of quantifying and monitoring training volume and load across different loading intensities (Day et al., 2004; McGuigan et al., 2004b; Singh et al., 2007). In addition, it is suggested that the use of a Borg CR-10 RPE scale can be utilized to prescribe weekly resistance training intensity (i.e. RPE 2 = easy, 5 = somewhat hard, 7 = hard, 10 = maximal) (Day et al., 2004) as opposed to percentages of 1RM. This is suggested to allow strength and conditioning practitioners to be confident that the athlete is working within the intended intensity range which is necessary for continued increases in strength and power performance (Fleck & Kraemer, 2004). However, prescribing resistance training intensity based off RPE values rather than percentages of 1RM has not previously been investigated. Conversely, Mann and colleagues (2010) investigated the effect of performing 6-weeks of APRE and traditional linear periodization on strength improvements in college athletes. This investigation demonstrated that APRE was more effective in improving bench press and back squat strength and upper body endurance when compared to traditional linear periodization. These findings provide evidence that RPE and APRE is effective in monitoring and regulating training volume and load. However, major shortcomings of these methods include requiring strength and conditioning practitioners to wait until a set has been performed or when a resistance training session has been completed before making adjustments in training volume and load. Alternatively, VBT allows adjustments to be made in training volume and load before the first set is performed. For example, due to the close relationship that exists between relative load and the movement velocity ($R^2 = 0.98$) (Gonzalez-Badillo & Sanchez-Medina, 2010), it is suggested that performing three to four warm-up sets with increasing loads (i.e. 40-85% 1RM) enables an estimation of a daily 1RM value. From this estimated value, adjustments can be made to training volume and load according to an athlete's daily variation in maximum strength and readiness to train (Jidovtseff et al., 2011; Jovanovic & Flanagan, 2014). Therefore, VBT may provide a superior approach in monitoring training volume and load when compared to other autoregulatory resistance training methods. In addition, the increasing availability of a variety of velocity monitoring technology such as linear position transducers (LPT) (i.e. Gymaware), accelerometer-based technology (i.e. Push Band) and free apps (i.e. Barsense) make VBT a easy and novel method of quantifying and monitoring resistance training volume and load in a practical setting for the strength and conditioning practitioner (Cronin et al., 2003; Gonzalez-Badillo & Sanchez-Medina, 2010; Jovanovic & Flanagan, 2014; Mann et al., 2015).

2.6.2 Session RPE and psychological wellness questionnaire monitoring

The session RPE and psychological wellness questionnaire monitoring have been proposed as non-invasive and inexpensive means of monitoring training load (Halson, 2014; McGuigan & Foster, 2004a). It is suggested that session RPE provides an accurate monitoring tool for the calculation of training load by simply obtaining the athlete's global intensity of a resistance training session and then multiplying by the duration or number of repetitions performed in a resistance training session (i.e. RPE = 7 x 60 mins = 420) to provide a session load (McGuigan & Foster, 2004a). This then provides the strength and conditioning practitioner with information regarding daily and weekly training loads where further simple calculations of training monotony and strain can also be made from session RPE values (Table 3). Training monotony can be defined as a measure of day-to-day training variability that has been shown to be related to the onset of overtraining when monotonous training is combined with high training loads (Foster, 1998). In addition, training strain can be defined as the overall training stress encountered during a training week that is calculated from training load and monotony scores (Foster, 1998). These monitoring strategies can be easily calculated with the formulas provided below;

Training monotony = *mean daily training load ÷ standard deviation of the daily training load*

Training strain = *weekly training load x monotony*

Table 3. Schematic weekly calculation of training load, monotony and strain (McGuigan & Foster, 2004a)

Day	Training Activity	Session RPE	Duration (mins or repetitions)	Load
Monday	Conditioning Resistance training	6 6	120 64	720 384
Tuesday	Team training	5	120	600
Wednesday	Match	7	180	1,260
Thursday	Team training Conditioning	3 3	60 40	180 120
Friday	Team training Resistance training	5 7	120 72	600 504
Saturday	Conditioning	6	120	720
Sunday	Team training	2	25	50
	Weekly Load (AU)			5,138
	Monotony (x SD)			1.43
	Strain (load x monotony)			3,200

A study conducted by Day and colleagues (2004) investigated the reliability of the session RPE scale to quantify resistance exercise intensity during low (50% 1RM), moderate (70% 1RM), and heavy (90% 1RM) intensity training. The results demonstrated that session RPE values were reported to be higher for heavy intensity resistance training (6.9 ± 1.4) when compared to moderate (5.2 ± 1.5) and low (3.3 ± 1.4) intensity resistance training. This indicates that performing less repetitions at high intensities were perceived to be more difficult than performing more repetitions and lower intensities. This is in agreement with Sweet and colleagues (2004) who demonstrated session RPE values decreased from 6.3 ± 1.4 to 5.7 ± 1.7 and 3.8 ± 1.6 that coincided with the decrease in percentage of 1RM from 90% to 70% and 50% respectively. In addition, McGuigan et al., (2004b) investigated the reliability of session RPE to determine physical effort during low intensity (30% 1RM) and high intensity (75% 1RM) resistance training. The results demonstrated a significant difference between session RPE values for the low (1.9) and high (7.1) resistance training intensities. It was concluded that session RPE provides a valid and reliable method (r = 0.88-0.95) of quantifying and monitoring training load across different loading intensities during resistance training. Therefore, session RPE appears to be a valid and reliable method for quantifying and monitoring resistance training load (Day et al., 2004; McGuigan & Foster, 2004b).

Changes in mood and affective psychological states have been described as consistent, sensitive and, early markers of overreaching and overtraining in competitive athletes (Meeusen et al., 2006; Urhausen & Kindermann, 2002). In particular, mood has been demonstrated to show a consistent dose-response relationship to training load (Bouget, Rouveix, Michaux, Pequignot, & Filaire, 2006). Psychological wellness questionnaires typically measure recovery with perceptions of wellbeing (i.e. fatigue), perceived stress, current mood, and behavioural symptoms (i.e. insomnia) that are influenced by both training and non-training stressors (Kellman, 2010; Main & Grove, 2009; Rushall, 1990; Shearer et al., 2015). A number of psychological wellness questionnaires are used in elite sporting environments to monitor training load that include the profile of mood states (POMS) (Morgan, Brown, Raglin, O'Connor, & Ellickson, 1987), the recovery-stress questionnaire (REST-Q-Sport) (Laux, Krumm, Diers, & Flor, 2015), daily analysis of life demands for athletes (DALDA) (Rushall, 1990), the total recovery scale (TQR) (Kentta & Hassmen, 1998) and, the brief assessment of mood (BAM) (Shearer et al., 2015). This form of monitoring provides practitioners with a great degree of certainty when prescribing and adjusting training loads with the intention of optimizing adaptation and performance (Coutts & Cormack, 2014; Halson, 2014; Taylor et al., 2012). In addition, recent research has suggested that psychological wellness questionnaire monitoring may be more sensitive and reliable than traditional physiological and biochemical monitoring measures (i.e. creatine kinase activity) (Buchheit et al., 2013; Halson, 2014; Meeusen et al., 2013; O'Connor et al., 1989; Urhausen & Kindermann, 2002). A recent survey conducted in high performance sports in Australia and New Zealand identified that 91% of elite/professional sporting programmes use a form of psychological wellness questionnaire monitoring (Taylor, Chapman, Cronin, Newton, & Gill, 2012).

A study conducted by Morgan and colleagues (1987) investigated administrating the POMS questionnaire in 16 male swimmers at the beginning, middle and end of a training season. The results demonstrated that the POMS questionnaire revealed significant changes in mood were due to a significant increase in fatigue ($p < 0.01$) and a significant decrease in vigor ($p < 0.01$). In other words, the POMS questionnaire indicates to have a dose-response relationship with periods of high training loads and periods where reductions in training load occur. In addition, McNair et al., (1992) demonstrated that the POMS questionnaire exhibits a test-retest reliability for measures of mood (0.56-0.74), psychological states (0.16-0.33) and traits (0.80-0.90) that can be detected following periods of increased training as brief as three days (O'Connor, Morgan, Raglin, Barksdale, & Kalin, 1989). Furthermore, Kellman and Kallus (2001) developed the REST-Q-Sport questionnaire that identifies the extent to which athletes are physically or mentally stressed and their capabilities towards recovery. The REST-Q-Sport questionnaire has been demonstrated to provide a valid and reliable ($p < 0.01$) (Davis, Orzeck, & Keelan, 2007) method to measure psychological and recovery states in athletes and has been reported to have a dose-response relationship with training load, creatine kinase activity, stress-recovery states, and the prediction of injuries (Kellman & Gunther, 2000; Kellman et al., 2001; Laux et al., 2015). However, major shortcomings of the aforementioned psychological wellness questionnaires is that they typically consist of 25-65 questions that take at least 10 minutes to complete. From a practical perspective, it is suggested that psychological wellness questionnaires take less than one minute to complete to ensure long term adherence and reduce bias of reporting unfavourable coping strategies (Saw et al., 2015; Shearer et al., 2015). Thus, the majority of elite/professional sporting programmes use custom-designed questionnaires that typically place emphasis on rating muscle soreness, fatigue, mood and sleep quality and consist of 4-12 questions that are measured on a 1-5 or 1-10 Likert point scale (Shearer et al., 2015). One such questionnaire that may be of interest to sports scientists and strength and conditioning practitioners in professional environments is the psychological wellness questionnaire implemented by McLean and colleagues (2010) that investigated the neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. The custom-made psychological wellness questionnaire was based on the recommendations of Hooper et al., (1995) that consisted of five questions and assessed fatigue, sleep quality, general muscle soreness, stress levels, and mood on a five point Likert scale (1 = “poor recovery”, 5 = “fully recovered”). The results demonstrated that the overall psychological wellness measure was sensitive to detect changes in fatigue and muscle soreness one to five days post a competition match. In addition, perceptions of fatigue and general muscle soreness provided important information regarding adaptation to training and the extent of muscle damage sustained during training and competition. Therefore, this custom-made questionnaire provides an inexpensive and non-invasive monitoring tool that can be considered a useful indicator to detect changes in psychological and physiological states in professional athletes. However, due to the short form of this questionnaire, other simple assessments of neuromuscular recovery such as the countermovement jump (CMJ) and hand grip test should be utilized alongside the questionnaire to provide a greater understanding of the responses to training volume and load to optimize performance in professional athletes.

2.6.3 Salivary cortisol

The measurement of salivary cortisol has been proposed as a non-invasive and time efficient means of monitoring the stress response to resistance training. Salivary cortisol collection provides benefits of the possibility of collecting multiple samples in a relatively time efficient manner, especially where serum collection is undesirable or difficult to obtain such as in professional sporting environments (Lewis, 2006; Vining, McGinley, & Symons, 1983). In addition, saliva measures the free bioavailable hormone levels in the body when compared to serum measures that only measure the protein bound non-bioavailable hormone levels (Aardal-Eriksson, Karlberg, & Holm, 1998). Furthermore, strong correlations ($r = 0.97$) have been reported between salivary and serum levels of cortisol (Vining et al., 1983). Therefore, salivary cortisol may actually provide a better measure than serum cortisol of the stress response to resistance training as it more accurately measures the unbound biological active cortisol hormone when compared to serum measures (McGuigan et al., 2004b; Vining et al., 1983).

The endocrine system is suggested to play an important role in strength and power adaptations by mediating the remodelling of skeletal muscle. Specifically, alterations in concentrations of the anabolic hormone testosterone and catabolic hormone cortisol may mediate acute and chronic changes in protein metabolism, muscle growth and force potential (Crewther et al., 2005). In addition, there is a consensus that hormonal responses to resistance training protocols are dependant on the amount of muscle mass activated, exercise order, training load, sets and reps and length of rest interval between sets (Kraemer et al., 1990). However, movement velocity is a parameter that may also affect the hormonal response to resistance training and thus, the resulting neuromuscular adaptation (Smilios et al., 2014). It has been demonstrated that an increase in movement velocity is associated with a higher heart rate, blood lactate concentrations, energy expenditure and augmented disruption of muscle ultra-structure (Hunter et al., 2003; Mazzetti et al., 2007). Furthermore, the execution of a movement with maximum velocity may augment the RFD and muscular electrical activity that may in turn induce a higher hormonal response through peripheral and neural mechanisms (Smilios et al., 2014).

A study conducted by Smilios and colleagues (2014) investigated the effect of maximum (V_{max}) and submaximum (70%V_{max}) movement velocities during hypertrophy type resistance exercise protocols on testosterone, human growth hormone, and cortisol responses in resistance trained men. The results demonstrated that performing resistance exercise with maximum movement velocities (V_{max}) increases testosterone and human growth hormone to a similar extent when compared to performing resistance exercise with submaximum movement velocities (70%V_{max}). In contrast, no significant difference was observed in cortisol responses to the maximum and submaximum movement lifting velocity conditions. Similarly, Goto et al., (2008) and Headley et al., (2011) demonstrated reduced or unchanged cortisol responses to submaximum movement velocities during hypertrophy type resistance exercise. However, the aforementioned studies provide numerous limitations that inlcude; 1) they employed fixed TPT movement velocities (e.g. 2 seconds for the eccentric and concentric phases) and, 2) failed to equate total volume load between maximum and submaximum movement velocity groups that may have influenced the differing hormonal responses.

Based on the available evidence, salivary cortisol provides a non-invasive and reliable measure of the stress response to resistance training. In addition, the influence that movement velocity has on elicitng salivary cortisol stress during strength and power training are yet to be determined and further investigation is warranted in this area.

2.7 Conclusions

Collectively, it is evident that the concept of velocity specific resistance training is an important consideration when designing and implementing resistance training programmes. It is demonstrated that a close relationship exists between relative load and the movement velocity that is attained during resistance training (R^2 = 0.98) (Gonzalez-Badillo & Sanchez-Medina, 2010). This relationship makes it possible to determine with great precision the real intensity of effort or work being incurred by an athlete at loads performed between 30% to 95% of 1RM. In addition, previous research has demonstrated the intention to move a load explosively and the actual movement velocity achieved as controlled by load are both vital stimuli for improving velocity specific neuromuscular performance capabilities and possible neural adaptations (Behm & Sale, 1993; McBride et al., 2002). Consequently, the velocity at which loads are lifted may determine the resulting training effect and its transference to sports performance (Gonzalez-Badillo et al., 2014). It is suggested the velocity specific adaptations to resistance training are mediated by a combination of muscular morphological, molecular and neural factors that may influence adaptation at the skeletal muscle (Kraemer & Ratamess., 2005). In addition, velocity specific adaptations to resistance training may include several factors including; enhanced coordination and specificity of movement, increased discharge of high threshold motor units, enhanced intramuscular and intermuscular coordination and increased stress placed on fast twitch muscle fibers (Cronin et al., 2002; Enoka, 1997; Tricoli et al., 2001). Therefore, it can be suggested that two possible neuromuscular adaptations to VBT include mechanisms of adaptations within the skeletal muscle itself (Duchateaus & Hainaut, 1984) and adaptations within the nervous system that may affect the muscle force-velocity curve and preferential recruitment of higher threshold motor units. However, the velocity specific neuromuscular adaptations to resistance training are currently not well understood and further research is warranted.

2.7.1 Practical applications of velocity based resistance training in strength and conditioning practices

When designing resistance training programmes, strength and conditioning practitioners should consider movement velocity as an important variable to optimize neuromuscular strength and power adaptations. LPT devices should be frequently used in sporting environments as a monitoring strategy that will allow for the prescription of individual and daily exercise specific loads from the load-velocity relationship which will lead to improved strength and power programming. With this in mind, a load-velocity profile should be created for specific upper body and lower body strength and whole body power exercises for individual athletes. Constructing an individual athlete load-velocity profile for a given exercise allows strength and conditioning practitioners to periodically assess an athlete’s velocity-specific strength and power adaptations across different loading spectrums that may inform future decisions of the efficacy of a prescribed strength and power training stimulus. In addition, by utilizing velocity zones or velocity stops this may provide a novel approach in prescribing daily training loads that are sensitive to daily fluctuations in biological status and readiness to train. This is achieved by ensuring athletes remain within a target velocity zone or do not drop below a MVT that allows for autoregulating and individualizing daily training volume and load. Consequently, applying velocity zones or velocity stops both within sets and between sets will control the excessive accumulation of metabolic-by-products and neuromuscular fatigue that will allow athletes to maintain maximal lifting velocities throughout strength and power training phases by taking into account athletes daily variability in maximum strength and readiness to train.

2.7.2 Future research

Currently, a paucity of literature exists in performing resistance training within specific VBT zones and its subsequent effect on neuromuscular strength and power adaptations. Longitudinal research investigating performing resistance training within specific VBT zones has yet to be undertaken. Therefore, future research should investigate the influence of performing resistance training within specific VBT zones and its effect on improving subsequent neuromuscular strength and power adaptations across different loading spectrums. During such interventions, the changes in neuromuscular strength and power performance should be habitually tracked throughout strength and power training phases to determine the velocity specific neuromuscular adaptations to VBT. Additionally, as it is suggested strength and power performance is enhanced at or near the optimal training velocity, determining the specific VBT zones that enhance neuromuscular strength and power adaptations is warranted.

CHAPTER THREE: THE VELOCITY PROFILING OF SEMI-PROFESSIONAL RUGBY UNION AND PROFESSIONAL RUGBY LEAGUE PLAYERS

3.1 Preface

Given the spectrum of strength and power demands encountered during rugby union and rugby league competition (i.e. tackling, pushing, lifting, jumping and scrummaging) it would be advantageous to determine which resistance training stimulus enhances skeletal muscle performance traits such as starting strength, speed-strength, strength-speed, accelerative strength, and absolute strength/power to a greater extent. From the review of literature it was evident that; 1) there is very limited research that has addressed the effects of optimizing VBT in improving neuromuscular strength and power adaptations and, 2) no study to date has investigated the optimal velocity training zones for the development of specific skeletal muscle performance traits in semi-professional rugby union and professional rugby league players. Therefore, the purpose of this chapter was to document the velocity profiles and identify specific velocity training zones across different load spectrums (%1RM) in the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players. The results of this investigation are used in the subsequent training intervention that is intended to maximize neuromuscular strength and power performance in professional rugby league players (Chapter four).

3.2 Introduction

It is common place that resistance training programmes utlilize traditional percentage based training (TPT) methods to improve measures of maximal strength and power performance in professional athletes (Mann et al., 2015). However, an ongoing dilemma faced by strength and conditioning practitioners is the issue of how to accurately quantify, assess and monitor a prescribed training stimulus in order to maximize strength and power adaptations. Several acute resistance training variables (i.e. exercise type, order, sets and repetitions, percentage of one repetition maximum and rest duration) have traditionally been associated with configuring and prescribing a strength and power training stimulus (Kraemer & Ratamess, 2004). In addition, exercise intensity is generally acknowledged as the most important stimulus related to enhancing strength and power adaptations and is commonly identified with relative loading intensities of an athlete's percentage of one repetition maximum (1RM) for a given exercise (Kraemer & Ratamess, 2004).

Manipulation of the aforementioned resistance training variables are suggested to shape the magnitude and type of physiological responses and ultimately the neuromuscular adaptations to strength and power training. This traditional TPT method often requires the direct assessment of an athlete's 1RM for a given exercise. However, major shortcomings of the direct assessment of 1RM includes a higher association with injury risk and this process can be time consuming and impractical for large groups such as team sports (Braith et al., 1993). In addition, it is observed that an athlete's actual 1RM can change quite rapidly after only a few training sessions and often the obtained value is not the athlete's true maximum that can be associated with daily fluctuations in biological status (Gonzalez-Badillo & Sanchez-Medina, 2010). For example, Jovanovic and colleagues (2014) demonstrated that an ~18% difference exists above or below a previously tested 1RM which suggests an ~36% difference exists around a pre-training block 1RM due to daily variability in biological status and readiness to train. Therefore, arbitrarily prescribing training loads (kg) based off a pre-training block 1RM and a pre-selected intensity (e.g. 80% 1RM) may not necessarily reflect the intended focus of a resistance training session as this will negatively accumulate higher fatigue (e.g. 80% + 18% = 98% 1RM) or under prepare an athlete (e.g. 80% - 18% = 62%) due to fluctuations in daily variability.

Thus, the aforementioned limitations suggest trying to find a better way of configuring and prescribing a resistance training stimulus to optimize the intended focus of resistance training session. Movement velocity is a variable that could be of great interest when designing resistance training programmes to optimize neuromuscular strength and power adaptations. It is suggested that how the load that is actually lifted or moved may be more significant in developing functional neuromuscular strength and power adaptations (Harris et al., 2007). However, the velocity component of a given exercise is often an overlooked and under-utilized performance measure. Previous research has demonstrated that the greatest muscular strength and power improvements occur when specific resistance training is performed at or near the optimal training velocity (Behm & Sale, 1993) and as velocity deviates from the trained velocity, the less effective training will be (Caiozzo et al., 1981). Additionally, it is demonstrated that a inextricable relationship exists between relative load and the movement velocity that is attained during resistance training with loads between 30% to 95% 1RM (R^2 = 0.98) (Gonzalez-Badillo & Sanchez-Medina, 2010). This relationship makes it possible to determine with great precision the real intensity of effort or work being incurred by an athlete as the mean velocity attained with each % of 1RM (30-95% 1RM) is a very stable indicator of the actual percentage of 1RM that each load (kg) represents (Gonzalez-Badillo & Sanchez-Medina, 2010). Furthermore, it is demonstrated that each percent of 1RM loading intensity has its own unique velocity training zone and although an athlete's 1RM value may increase after a period of strength training, the velocity that is obtained at each percentage of 1RM remains stable (Gonzalez-Badillo & Sanchez-Medina, 2010).

Given the spectrum of strength and power demands encountered during rugby union and rugby league competition (i.e. tackling, pushing, lifting, jumping and scrummaging) it would be advantageous to determine whether skeletal muscle performance traits such as starting strength, speed-strength, strength-speed, accelerative strength, and absolute strength/power that effect different portions of the force-velocity curve may be optimized within specific velocity training zones. The aforementioned skeletal muscle performance traits can be defined as;

1) Starting strength – The ability to overcome inertia rapidly and is developed using light loads that are moved at exceedingly high movement velocities (Bondarchuk, 2014, Mann et al., 2015)
2) Speed-strength – The ability to move light loads at high movement velocities with a specific focus on improving explosive strength (Siff, 2000)
3) Strength-speed – The ability to rapidly move moderately heavy loads at moderate movement velocities (Roman, 1986)

4) Accelerative strength – The ability to rapidly move a heavy load at low-moderate movement velocities (Mann et al., 2015)
5) Absolute strength – The ability to exert maximal force at low movement velocities that is approaching the athletes 1RM (Mann et al., 2015)

Previous research in rugby union and rugby league players have investigated enhancing acute strength and power performance with complex training methods (i.e. strength training coupled with heavy and light ballistic exercises) (Argus et al., 2012; Baker & Newton., 2005; Bevan et al., 2009; McMaster et al., 2014). In addition, previous authors have attempted to determine optimal training loads across a variety of loading spectrums to enhance power output with ballistic (i.e. bench press throw and squat jumps) (Baker et al., 2001a; Baker et al., 2001b; Bevan et al., 2010; Turner et al., 2015) and weightlifting type exercises (i.e. power clean) (De Villiers & Venter., 2015; Kilduff et al., 2007). However, the effectiveness of complex training methods and determining optimal loads to enhance power output for athletic performance in elite team sport athletes remain debateable, as these studies provide limitations that include prescribing training loads based off traditional percentage based methods that do not take into account an athlete's daily biological status and readiness to train. Thus, movement velocity may provide an alternative approach in prescribing strength and power training by utilizing velocity zones or velocity stops (Jovanovic & Flanagan, 2014). This novel approach may allow for accurate training loads to be prescribed for a pre-selected training intensity that may be sensitive to daily variability in maximum strength and readiness to train as opposed to prescribing training loads based off pre-training block 1RM values.

An interesting study conducted in youth soccer players demonstrated that using movement velocity as a reference to prescribe resistance training with relative loads between 45-70% 1RM significantly enhanced full squat strength ($p < 0.01$) and CMJ performance ($p < 0.05$) when compared to performing TPT maximum repetitions (Lopez-Segovia, Palao Andres, & Gonzalez-Badillo, 2010). However, no conclusive evidence has been reported from previous investigations that support performing resistance training within specific velocity zones and to the best of our knowledge, no studies have yet specifically examined this issue in semi-professional rugby union and professional rugby league players.

Therefore, the purpose of the present investigation was to document the velocity profiles and to identify specific velocity training zones across different load spectrums (%1RM) in the bench press, back squat and power clean exercises that may maximize neuromuscular strength and power performance in semi-professional rugby union and professional rugby league players.

3.3 Methods

3.3.1 Experimental approach to the problem

This empirical research study was designed to provide comprehensive descriptive information about the strength and power velocity profiles of semi-professional rugby union and professional rugby league players. In order to determine the velocity profiles of each participant across loading spectrums of 20-95% 1RM for the bench press, back squat and power clean exercises, participants were required to perform a prescribed number of sets and reps at each designated training intensity whilst a linear position transducer (LPT) was attached to the barbell. The bench press and back squat exercises were chosen for the purpose of assessing upper and lower body maximal strength, respectively, whilst the power clean was chosen as a measure of whole body power production (De Villiers & Venter, 2015; Hoffman et al., 2004; Seitz et al., 2014). These exercises are widely used in athletic training environments and all the participants in the present study were familiar with generating maximum effort and executing the exercises with efficient technique. The LPT device provided instantaneous feedback via its software platform for measures of force, power and velocity.

3.3.2 Participants

Forty-one semi-professional rugby union participants from two New Zealand premiership rugby union teams and eleven professional rugby league participants from a National Rugby League (NRL) competition team volunteered to take part in this study (Table 4). The following inclusion criteria was imposed for each participant for the purpose of this study; 1) a competitive male rugby league or a competitive rugby union athlete aged 18-30 years, 2) have no current acute or chronic injuries or medical conditions, 3) have been involved in a structured resistance training programme for ≥ 2 years, 4) possess appropriate joint mobility to perform the bench press, back squat and power clean movements with appropriate technique and, 5) are not using any performance enhancing or banned substances (World Anti-Doping Agency 2015). All testing procedures and risks were clearly and fully explained and written consent for each participant was obtained prior to the commencement of the study. The research study was approved by the AUT University Ethics Committee (AUTEC), Auckland, New Zealand.

Table 4. Anthropometric characteristics of the rugby union and rugby league participants (mean ± *SD*)

		Age (years)	Weight (kg)	Height (cm)
Rugby Union (n=41)	**Forwards** (n=29)	20.7 ± 2.1	107.3 ± 9.8	187.6 ± 7.4
	Backs (n=12)	20.3 ± 2.0	84.8 ± 7.9	181.1 ± 3.9
Rugby League (n=11)	**Forwards** (n=7)	22.9 ± 2.1	103.3 ± 7.8	183.4 ± 4.8
	Backs (n=4)	23.0 ± 2.2	88.8 ± 8.3	178.0 ± 6.5

3.3.3 Testing Procedures

Prior to the commencement of each testing session, all participants were required to complete a standardised warm up procedure as prescribed by their respective playing organization (Table 5). Additionally, a warm up set of the relevant exercise was performed with the barbell only prior to the commencement of the testing session. During the testing sessions, participants performed a prescribed number of sets and reps at each designated training load spectrum of 20, 30, 45, 60, 75, 80, 85, 90 and 95% 1RM for the bench press, back squat and power clean exercise (Table 6). A wire from a linear position transducer (LPT) (Gymaware PowerTool, Kinetic Performance PTY Ltd., ACT, Australia) was attached to the inside of the Olympic barbell with a Velcro strap during the exercises. The concentric maximum peak and mean velocities ($m.s^{-1}$) achieved were calculated and recorded instantaneously using the LPT software platform which has been reported to provide valid and reliable measures of strength and power movements (CV < 3%, $r = 0.59 – 1.00$, $p < 0.05 – 0.001$) (Drinkwater et al, 2007; Crewther et al., 2011b). The training load for each set spectrum was determined from the participants' previous

1RM obtained for each lift within a four-week period due to in-season competition constraints placed on the participants from coaching staff.

3.3.3.1 Bench press

The bench press exercise was performed on an adjustable power rack (Life Fitness, Hammer Strength, Auckland, New Zealand) with a loaded 20kg Olympic barbell placed horizontally at the chosen height of the participant. The bench press was performed with the participants lying with their back flat on a bench with arms fully extended and hands gripping the bar approximately shoulder width apart whilst the knees were bent at a 90-degree angle and feet fixed to the ground. The depth of the bench press was set to touch the chest without bouncing the bar. Additionally, participants were instructed to perform the bench press without the bar leaving the hands (i.e. not throwing it) and their back had to remain flat on the bench at all times. Each participant was instructed to descend the barbell during the eccentric phase (2 seconds) in a controlled motion. However, participants were instructed to execute the concentric phase with maximal dynamic effort. Three minutes rest was provided between sets.

3.3.3.2 Back squat

The back squat exercise was performed with participants starting in the upright position with knees and hips fully extended, feet placed approximately shoulder width apart and the Olympic barbell positioned approximately across the acromion joint. The depth for the back squat was set at a knee angle of 90-degrees (visually determined) before returning to the upright position. Each participant was instructed to descend the barbell during the eccentric phase (2 seconds) in a controlled motion. However, participants were instructed to execute the concentric phase with maximal dynamic effort. Additionally, participants were instructed to perform the back squat with feet fixed to the ground at all times. Three minutes rest was provided between sets.

3.3.3.3 Power clean

The power clean exercise was performed on a weightlifting platform (Life Fitness, Hammer Strength, Auckland, New Zealand) that consisted of a 20kg Olympic barbell that was loaded with bumper plates. All repetitions were performed from the ground with the participants' feet placed approximately shoulder width apart with their hands gripping the bar approximately outside shoulder width. Each participant was instructed to perform the first pull (i.e. lifting the bar from the ground to the knee) in a controlled motion whilst gaining momentum. However, participants were instructed to perform the second pull (i.e. transitioning from the double knee-bend and accelerating the bar to the hip whilst extending the trapezius) with maximal dynamic effort. The catch position of the power clean was set at or above a knee angle of 90 degrees in order to be recorded as a successful lift (visually determined). Three minutes rest was provided between sets.

Table 5. Rugby union and rugby league example warm-up routine

Exercise	**Sets**	**Reps**
1. Foam roller	1	10 (Lower back, gluteus maximus, hamstring, quadriceps)
2. Snatch grip overhead squat	1	10
3. Shoulder rotations	1	10
4. Bear crawls	1	3 x 10-meters
5. Hurdle walks (step over and under)	1	5 each leg

Table 6. Velocity profiling sets and reps protocol

%1RM	Sets	Reps	Rest	Bench Press and Back Squat Tempo	Power Clean Tempo
20%	1	3	3 mins	2:0:X	X:X:X
30%	1	3	3 mins	2:0:X	X:X:X
45%	1	3	3 mins	2:0:X	X:X:X
60%	1	3	3 mins	2:0:X	X:X:X
75%	1	2	3 mins	2:0:X	X:X:X
80%	1	2	3 mins	2:0:X	X:X:X
85%	1	1	3 mins	2:0:X	X:X:X
90%	1	1	3 mins	2:0:X	X:X:X
95%	1	1	3 mins	2:0:X	X:X:X
Tempo durations; 2 = 2 seconds down for the eccentric phase of the lift, 0 = no pause at the bottom of the lift and, X = maximal dynamic movement					

3.3.4 Statistical Analysis

Standard statistical methods of mean ± standard deviations (SD) were used to report the velocity profiling data. Initial checks of normality were conducted using the Shapiro-Wilks test to determine differences between groups. Independent sample t-tests were computed by means of t-test or its nonparametric equivalent utilizing the Mann-Whitney U Test. A significance level of $p < 0.05$ was selected to indicate statistical significance between groups.

3.4 Results

3.4.1 Rugby union velocity profiling

3.4.1.1 Bench Press

Significant differences were found between forwards and backs for peak velocity ($m.s^{-1}$) at 75% 1RM (17.8%). In addition, significant differences were found between forwards and backs for mean velocity ($m.s^{-1}$) at loading intensities of 85% 1RM (21.6%), and at 95% 1RM (36.4%) ($p < 0.05$) (refer to appendix Table 1). However, no significant differences between forwards and backs were found for peak velocity ($m.s^{-1}$) at 20, 30, 45, 60, 80, 85, 90 and 95% 1RM and mean velocity ($m.s^{-1}$) at 20, 30, 45, 60, 80 and 90% 1RM loading intensities ($p > 0.05$). Results for forwards and backs bench press mean velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 3.

3.4.1.2 Back squat

Significant differences were found between forwards and backs for peak velocity ($m.s^{-1}$) at 30% 1RM (18.7%) and 45% 1RM (23.9%). In addition, significant differences were found between forwards and backs for mean velocity ($m.s^{-1}$) at 45% 1RM (21.4%) ($p < 0.05$) (refer to appendix Table 2). However, no significant differences between forwards and backs were found for peak velocity ($m.s^{-1}$) at 20, 60, 75, 80, 85, 90 and 95% 1RM and mean velocity ($m.s^{-1}$) at 20, 30, 60, 75, 80, 85, 90 and 95% 1RM loading intensities ($p > 0.05$). Results for forwards and backs back squat mean velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 4.

3.4.1.3 Power clean

No significant differences exist between forwards and backs across loading intensities of 20-95% 1RM for peak and mean velocities ($m.s^{-1}$) ($p > 0.05$) (refer to appendix Table 3). Results for forwards and backs power clean peak velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 5.

3.4.2 Rugby league velocity profiling

3.4.2.1 Bench press

No significant differences exist between forwards and backs across loading intensities of 20-95% 1RM for peak and mean velocities ($m.s^{-1}$) ($p > 0.05$) (refer to appendix Table 4). Results for forwards and backs bench press mean velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 6.

3.4.2.2 Back squat

A significant difference between forwards and backs only existed for mean velocity ($m.s^{-1}$) at 75% 1RM loading intensity (17.9%) ($p < 0.05$) (refer to appendix Table 5). Results for forwards and backs back squat mean velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 7.

3.4.2.3 Power clean

Significant differences between forwards and backs were found for peak velocity ($m.s^{-1}$) at 20% 1RM (14.4%) and 75% (8.2%) 1RM loading intensities ($p < 0.05$) (refer to appendix Table 6). Results for forwards and backs power clean peak velocity ($m.s^{-1}$) analysis across loading intensities of 20-95% 1RM are illustrated in Figure 8.

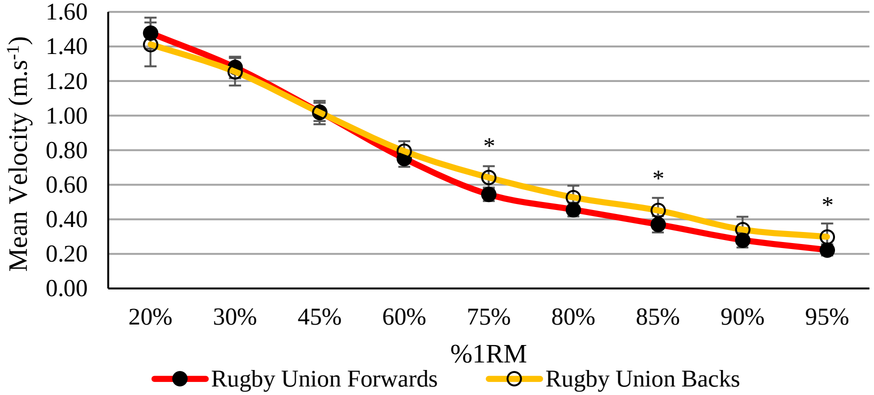


Figure 3. Rugby union forwards and backs mean velocity spectrum for the bench press exercise across loading intensities of 20-95% 1RM. The mean velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

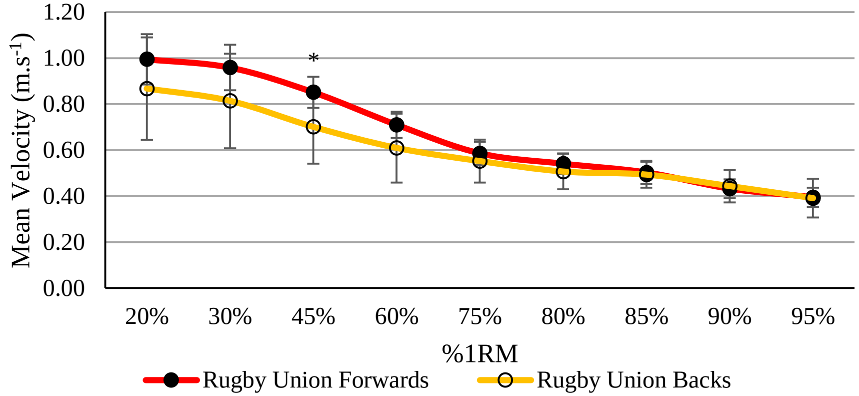


Figure 4. Rugby union forwards and backs mean velocity spectrum for the back squat exercise across loading intensities of 20-95% 1RM. The mean velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

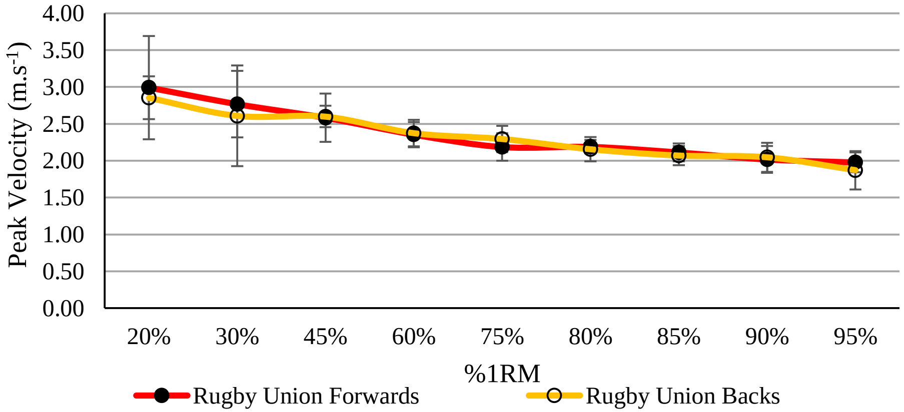


Figure 5. Rugby union forwards and backs peak velocity spectrum for the power clean exercise across loading intensities of 20-95% 1RM. The peak velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

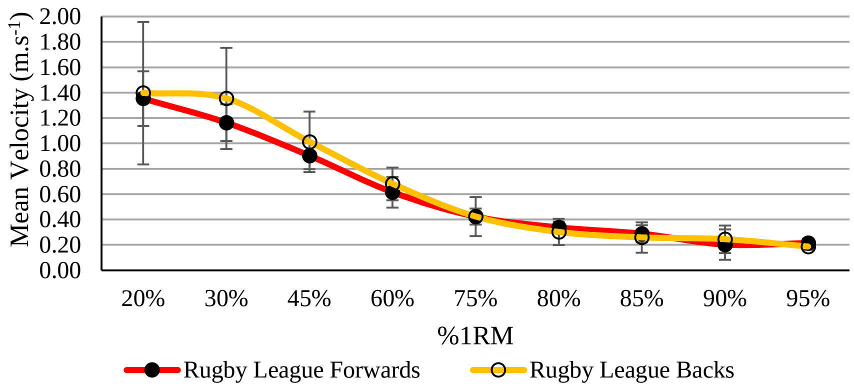


Figure 6. Rugby league forwards and backs mean velocity spectrum for the bench press exercise across loading intensities of 20-95% 1RM. The mean velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

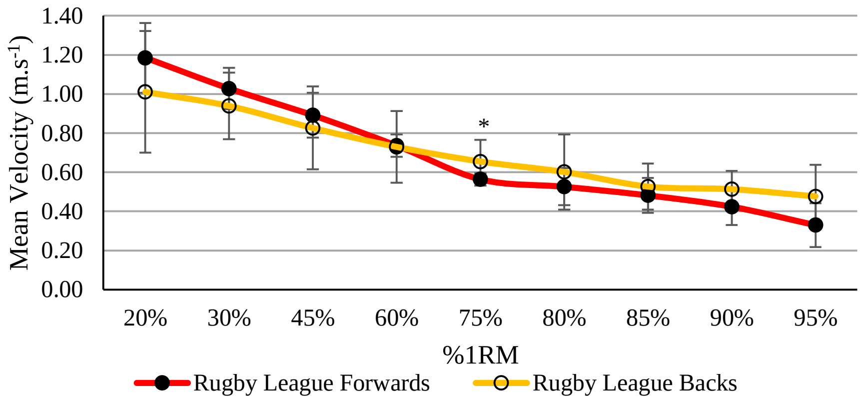


Figure 7. Rugby league forwards and backs mean velocity spectrum for the back squat exercise across loading intensities of 20-95% 1RM. The mean velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

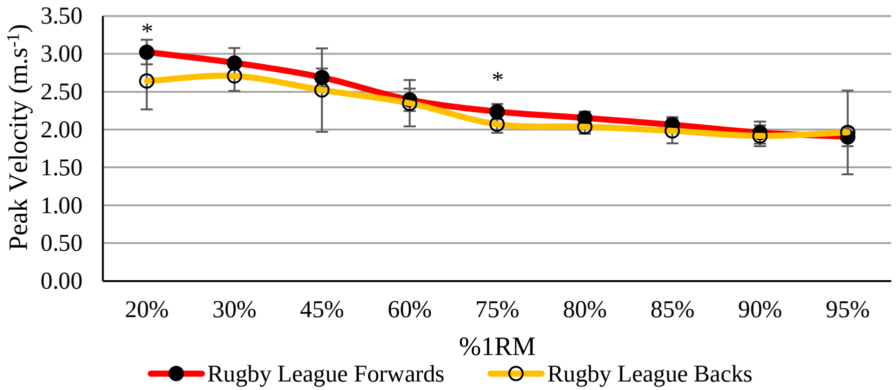


Figure 8. Rugby league forwards and backs peak velocity spectrum for the power clean exercise across loading intensities of 20-95% 1RM. The peak velocity achieved for each loading intensity is plotted from each positional groups mean with 95% confidence intervals. * = significant difference

3.5 Discussion

The purpose of this study was to develop a better understanding of the strength and power velocity profiles for the bench press, back squat, and power clean exercises across loading intensities of 20-95% 1RM in semi-professional rugby union and professional rugby league players. It was hypothesized that the strength and power velocity profiles for the bench press, back squat and power clean exercises would provide a large range of velocities at lighter loads when compared to heavier loads due to the propulsive and braking phases that occur at light and heavy loading intensities (%1RM). Additionally, it was hypothesized that multi-joint compound movements (i.e. power clean and back squat) that require greater activation and synchronization of agonist and antagonist muscle groups would result in a larger spread of velocity profiles when compared to the bench press exercise.

To the best of our knowledge, this is the first study that has analysed the velocity profiles of semi-professional rugby union and professional rugby league players across loading intensities of 20-95% 1RM in the bench press, back squat and power clean exercises. The main finding of this study was that unique VBT zones exist for loads lifted between 20-95% 1RM for the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players whereby subtle differences exist between each code with further investigation warranted.

On closer examination, it was identified that potential differences exist between positional groups within each code across loading intensities of 20-95% 1RM for each exercise that requires further investigation. In addition, it can be speculated that the observed unique VBT zones can be further broken down to focus specifically on enhancing specific skeletal muscle performance traits within a periodized strength and power resistance training programme that include starting strength, speed-strength, strength-speed, accelerative strength and absolute strength/power (Table 7 and 8). Thus, the present study adds to previous research by corroborating that each percent of 1RM (30-95% 1RM) loading intensity has its own unique VBT zone (Gonzalez-Badillo & Sanchez-Medina, 2010) and provides evidence for considering movement velocity in strength and power training programmes.

Specifically, the results of this study demonstrated that; 1) during the bench press exercise, rugby union backs produced higher peak and mean velocities at moderate to high intensity ranges (75-95% 1RM) when compared to rugby union forwards.

Conversely, rugby union forwards produced higher peak and mean velocities for the back squat exercise at low to moderate intensity ranges (20-60% 1RM) when compared to rugby union backs whilst no differences were observed for the power clean exercise, 2) rugby league backs produced higher peak and mean velocities for the bench press exercise at low intensity ranges (30-45% 1RM) when compared to rugby league forwards and, 3) rugby league forwards produced higher peak and mean velocities for the back squat at low intensity ranges (20-45% 1RM) when compared to rugby league backs who produced higher peak and mean velocities at mid to high intensity ranges (75-95% 1RM) whilst no differences were observed for the power clean exercise.

The observed differences in lifting velocities within each code may be partly explained by the different demands placed on rugby union forwards and backs and rugby league forwards and backs during competition. It is well established that the demands placed on rugby union and rugby league players vary according to specific positions played. High levels of muscular strength and power and the capacity to generate high levels of muscular force rapidly are considered to be critical attributes for performing the tackling, lifting, pushing and pulling tasks during match play (Gabbett, 2005b; Meir et al., 2001). Forwards typically have superior maximum upper and lower body absolute strength levels when compared to backs due to differences in body mass and the higher frequency of tackling, mauling and rucking activities (Crewther et al., 2009). In addition, previous investigations have demonstrated that rugby union players have superior upper (873 – 1,300 W vs. 340 – 610 W) and lower (4,750 – 5,755 W vs. 1,850 – 1,990 W) body muscular power outputs when compared to rugby league players with similar trends observed in maximal strength capabilities (Argus et al., 2009; Baker, 2001a; Baker, 2002; Baker et al., 2008; Bevan et al., 2010; Comfort et al., 2011; Crewther et al., 2009). These differences are likely due to rugby union players predominantly training and competing with relatively lower body orientations during tackles, rucks, scrums, and mauls. In addition, there is less space between attackers and defenders during match play whereby acceleration becomes vital (Cross et al., 2015). In comparison, rugby league players predominantly train and compete in more of an upright position with higher contact orientations in the resultant vertical-horizontal plane due to the main focus being on securing the ball and keeping an opposition player upright for as long as possible (Cross et al., 2015). However, rugby league players tend to be more homogenous in anthropometrical characteristics and muscular strength and power capabilities when compared to rugby union players due to the different demands, playing styles and tactics encountered between each respective code (Twist & Worsfold, 2015).

A unique finding of this investigation was that for a given exercise modality (i.e. upper body strength: bench press, lower body strength: back squat and whole body power: power clean) the pattern of decline in the MV and PV achieved across the same loading intensities of 20-95% 1RM decreased at a greater rate in the power clean than the bench press and back squat. Furthermore, with regards to velocity declines between upper and lower body strength movements, the MV and PV decreased at a greater rate in the bench press when compard to the back squat exercise. The observed decline in MV between the upper and lower body strength and whole body power movements may be attributed to the differing muscular constraints (i.e. as determined by skeletal muscle architecture) and strength curves that exist for each given exercise. For example, it is likely that the differences in repetition velocity during the bench press, back squat and power clean may vary between the different muscle groups due to functional differences in joint position and levers, fiber type distribution and biomechanical characteristics of the open and closed upper and lower body kinetic chains (Izquierdo et al., 2006a). Previous research has demonstrated that greater fiber lengths and longitudinal fiber arrangement of the primary movers used in the back squat and power clean exercises are characterized by faster shortening velocities, whereas the primary movers for the bench press exercise are characterized by shorter fiber lengths and greater pennation angles that subsequently generate greater muscular force capabilities (Lieber & Friden, 2000; Pearson et al., 2009). Furthermore, research has also highlighted the importance of considering the contribution of the propulsive and braking phases (Sanchez-Medina et al., 2010) when assessing upper body and lower body muscular strength and power during isoinertial resistance training.

During this study, participants were instructed to perform the concentric phase of the bench press and back squat movement with maximum dynamic effort whilst participants were instructed to perform the power clean with maximal dynamic effort throughout the entire lift. However, participants were also instructed to perform the bench press without the bar leaving the hands and back remaining flat on the bench at all times. Additionally, participants were instructed to perform the back squat without jumping and keeping their feet fixed to the ground at all times. Consequently, this may have influenced the current results as it is demonstrated that when lifting loads in isoinertial conditions there exists a considerable portion of the concentric phase that is allocated to decelerating a moving resistance especially when lifting light and moderate loads. Sanchez-Medina and colleagues (2010) demonstrated that the lighter the load and the higher the movement velocity (<70% 1RM), the greater the duration of the braking phase. Similiarly, Izquierdo and colleagues (2006a) demonstrated that high velocity repetitions performed at 60-75% 1RM provide extended deceleration phases that may induce shorter concentric efforts and reduce repetition intensity. However, it is demonstrated that when loads are sufficiently high (>80% 1RM) the braking phase disappears and the full concentric phase can be considered entirely propulsive (Sanchez-Medina et al., 2010). Therefore, when comparing results between studies it is important to consider adhering to similar methods employed in the current study.

As previously shown, the greatest muscular strength and power improvements occur when specific resistance training is performed at or near the optimal training velocity (Behm & Sale, 1993). Additionally, as velocity deviates from the optimal training velocity, the less effective training will be (Caiozzo et al., 1981). Thus, a critical component of VBT is that training at optimal velocities rather than at a % of 1RM will allow an athlete to perform resistance training with specific loads that will maximize training specificity. In addition, the inextricable relationship that exists between relative load and the movement velocity ($R^2 = 0.98$) makes it possible to enhance the quality of effort of work performed by an athlete for loads executed between 30% to 95% 1RM (Gonzalez-Badillo & Sanchez-Medina, 2010). Furthermore, if movement velocity is routinely measured for every repetition of a given exercise it is possible to determine whether the prescribed training load (kg) for a pre-selected training intensity (%1RM) truly represents the intended focus a resistance training session (Gonzalez-Badillo & Sanchez-Medina, 2010; Pareja-Blanco., 2014). Consequently, VBT becomes a type of autoregulatory training whereby training loads (kg) and volume (sets x reps x load) can be adjusted to account for daily fluctutations in biological status and an athlete's readiness to train (Kraemer & Fleck, 2007; Mann et al., 2010). For example, if an athlete is executing a given exercise at a slower velocity than usual, adjustments can be made in the form of decreasing training load (kg) in order for the athlete to execute loads within a specified VBT zone to maximize the intended focus of the resistance training session (i.e. strength-speed).

This novel method provides advantages in allowing strength and conditioning practitioners to accurately prescribe training loads based on an athlete's ability to maintain a prescribed movement velocity that may also aid in fatigue monitoring (Jidovtseff et al., 2011; Jovanovic & Flanagan, 2014). Recent research has demonstrated that velocity naturally declines during resistance training as fatigue develops (Izquierdo et al., 2006a; Jidovtseff et al., 2011; Sanchez-Medina & Gonzalez-Badillo, 2011) and the decline in movement velocity can be interpreted as evidence of impaired neuromuscular function (Sanchez-Medina & Gonzalez-Badillo, 2011). Therefore, by taking into account the daily biological status of an athlete and adjusting training loads accordingly, strength and power performance can be maximized by training within specific VBT zones as it is demonstrated the velocity at which loads are lifted may consequently influence the resulting training effect (Behm & Sale, 1993; Cormie et al., 2007; Kawamori et al., 2005; Pareja-Blanco et al., 2013).

It must be acknowledged that several key limitations exist in the current study. Firstly, due to in-season competition constraints, a limited number of rugby league participants (n = 11) were available for the study when compared to the availability of the rugby union players (n = 41) that consequently prevented cross code positional comparisons. Secondly, the loads prescribed for each exercise across the set loading intensities (20-95% 1RM) may have not necessarily reflected each participant's true maximum strength and power capabilities. This is due to in-season competition constraints which prevented pre-intervention 1RM testing. As a result, each participant's historical 1RM value obtained within a four-week period prior to the commencement of the study was used to assign the testing loads for each lift. Lastly, minor injuries sustained during training and competition may have hindered each athlete's ability to display maximal dynamic effort for each of the prescribed lifts across the set loading intensities of 20-95% 1RM.

3.6 Conclusions

The main finding of the present investigation was that unique VBT zones exist for the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players. This may provide key advantages in the design of resistance training programmes by focusing on enhancing specific skeletal muscle performance traits within a periodized strength and power resistance training programme that include starting strength, speed-strength, strength-speed, accelerative strength and absolute strength/power. Consequently, this provides strength and conditioning practitioners with a novel method to accurately prescribe training loads (kg) for a pre-selected intensity (%1RM) based on an athlete's ability to maintain a prescribed movement velocity.

3.7 Practical applications

For the strength and conditioning practitoner, VBT offers a novel and unique approach to maximizing strength and power performance in professional athletes. The findings of the present investigation provide important practical applications for the prescription of strength and power resistance training utilizing movement velocity. In addition, by utilizing the suggested VBT zones, strength and power performance can be maximized by allowing strength and conditioning practitioners to accurately prescribe training loads based on an athlete’s ability to maintain a prescribed movement velocity that will consequently optimize the development of the intended specific skeletal muscle performance trait. Furthermore, VBT may also serve as a useful tool for strength and conditioning practitioners to not only enhance strength and power performance, but it also aids in controlling the extent of neuromuscular fatigue and the accumulation of excessive metabolic by products that may influence adaptations to resistance training. This is achieved by adjusting daily training loads according to a athlete’s daily biological status and readiness to train and further research is warranted in this area.

Table 7. Rugby union velocity training zones for the bench press, back squat and power clean exercises

Rugby Union Velocity Training Zones									
Bench Press									
% 1RM	**20%**	**30%**	**45%**	**60%**	**75%**	**80%**	**85%**	**90%**	**95%**
	Starting Strength	**Speed-Strength**		**Strength-Speed**	**Accelerative Strength**		**Absolute Strength**		
Mean Velocity Zone ($m.s^{-1}$)	**> 1.40**	**1.25 - 1.30**	**1.00 - 1.05**	**0.75 - 0.80**	**0.55 - 0.65**	**0.45 - 0.55**	**0.35 - 0.45**	**0.25 - 0.35**	**< 0.30**
Back Squat									
% 1RM	**20%**	**30%**	**45%**	**60%**	**75%**	**80%**	**85%**	**90%**	**95%**
	Starting Strength	**Speed-Strength**		**Strength-Speed**	**Accelerative Strength**		**Absolute Strength**		
Mean Velocity Zone ($m.s^{-1}$)	**> 1.00**	**0.80 - 0.96**	**0.70 - 0.80**	**0.60 - 0.70**	**0.55 - 60**	**0.50 - 0.55**	**0.45 - 0.50**	**0.40 - 0.45**	**< 0.35**
Power Clean									
% 1RM	**20%**	**30%**	**45%**	**60%**	**75%**	**80%**	**85%**	**90%**	**95%**
	Starting Strength	**Speed-Strength**		**Strength-Speed**	**Accelerative Strength**		**Absolute Power**		
Peak Velocity Zone ($m.s^{-1}$)	**> 2.80**	**2.60 - 2.78**	**2.55 - 2.60**	**2.35 - 2.40**	**2.20 - 2.30**	**2.15 - 2.20**	**2.05 - 2.15**	**2.00 - 2.05**	**< 2.00**

Table 8. Rugby league velocity training zones for the bench press, back squat and power clean exercises

Rugby League Velocity Training Zones

Bench Press

% 1RM	20%	30%	45%	60%	75%	80%	85%	90%	95%
	Starting Strength	Speed-Strength		Strength-Speed	Accelerative Strength		Absolute Strength		
Mean Velocity Zone ($m.s^{-1}$)	> 1.40	1.15 - 1.35	0.90 - 1.05	0.60 - 0.70	0.38 - 0.45	0.30 - 0.35	0.25 - 0.30	0.20 - 0.25	< 0.20

Back Squat

% 1RM	20%	30%	45%	60%	75%	80%	85%	90%	95%
	Starting Strength	Speed-Strength		Strength-Speed	Accelerative Strength		Absolute Strength		
Mean Velocity Zone ($m.s^{-1}$)	> 1.20	0.95 - 1.05	0.85 - 0.90	0.70 - 0.75	0.55 - 0.70	0.50 - 0.60	0.45 - 0.50	0.40 - 0.50	< 0.35

Power Clean

% 1RM	20%	30%	45%	60%	75%	80%	85%	90%	95%
	Starting Strength	Speed-Strength		Strength-Speed	Accelerative Strength		Absolute Power		
Peak Velocity Zone ($m.s^{-1}$)	> 3.00	2.70 - 2.85	2.50 - 2.70	2.35 - 2.40	2.05 - 2.25	2.05 - 2.15	1.95 - 2.05	1.90 - 1.95	< 1.90

CHAPTER FOUR: THE INFLUENCE OF A 5-WEEK VELOCITY BASED RESISTANCE TRAINING PROGRAMME ON NEUROMUSCULAR STRENGTH AND POWER ADAPTATIONS IN PROFESSIONAL RUGBY LEAGUE PLAYERS: A CASE STUDY

4.1 Preface

In the previous chapter it was revealed that unique VBT zones exists for loads lifted between 20-95% 1RM for the bench press, back squat and power clean exercises in professional rugby league players. Specifically, it was demonstrated that skeletal muscle performance traits that include starting strength, speed-strength, strength-speed, accelerative strength and absolute strength/power can be maximized within specific VBT zones. This chapter implements the information presented in the previous chapter with a 5-week training intervention where participants performed isoinertial resistance training either within specific VBT zones or with TPT methods across different load spectrums. Therefore, the primary purpose of this chapter was to develop a better understanding of performing isoinertial resistance training within specific VBT zones across different load spectrums as a training stimulus to elicit subsequent strength and power adaptations when compared to TPT methods. The second purpose of this chapter was to compare and examine the psychological wellness and salivary cortisol stress response between VBT and TPT programmes to determine if VBT induces the same psychological and physiological stress response as TPT in professional rugby league players.

4.2 Introduction

Resistance training is widely recognized as an effective primary tool for improving or maintaining neuromuscular strength and power in athletes. The neuromuscular system specifically adapts to the stimulus applied, resulting in increases in muscle strength and functional performance (Ratamess et al., 2009). Traditional percentage based resistance training programmes often involve manipulating several acute variables (i.e. exercise intensity, exercise type, order, sets, repetitions and rest duration) simultaneously. In addition, the total volume load is often calculated (i.e. sets x reps x load) to achieve specific performance outcomes. However, this traditional method fails to take into account movement velocity that could be of great interest when designing resistance training programmes to optimize neuromuscular strength and power adaptations.

The training principle of specificity suggests that movement velocity is an important consideration when designing resistance training programmes as greater improvements in strength and power performance have been shown to occur at or near the optimal training velocity (Behm & Sale, 1993). The optimal training velocity can be defined as a prescribed movement velocity that influences both neural and muscular components that consequently maximizes functional strength and power performance (Behm & Sale, 1993). Research on movement velocity during resistance training is scarce with the majority of studies examining the effect of velocity specific neuromuscular adaptations on isokinetic dynamometry equipment (Coburn et al., 2006; Kaneko et al., 1983; Wilson et al., 1993). However, it is generally accepted that isokinetic muscle actions are considered to be less specific to actual sporting movements and the practical applications of the results from isokinetic research are somewhat questionable (Cronin et al., 2002).

Isoinertial resistance (i.e. constant mass) training is the most commonly available type of resistance training in sporting settings and is suggested to be more specific to actual sporting movements as it facilitates the nervous systems ability to activate agonist, antagonist and synergistic muscle activity that is essential to successful sporting performance (Cronin et al., 2002). The majority of isoinertial VBT studies have compared both maximal and half maximal lifting velocities of strength training and the associated transference to sports performance following two to four supervised resistance training sessions per week across 4–10 week periods (Delecluse et al., 1995; Gonzalez-Badillo et al., 2014; Pareja-Blanco et al., 2014). These studies have reported significant improvements when training with maximum concentric velocity efforts in 100-meter sprint times, maximum strength (18.2 vs. 9.7%) and velocity development with light (11.5 vs. 4.5%) and heavy (36.2 vs. 17.3%) loads when compared to half maximal concentric velocity efforts. On closer examination, the velocity specific adaptations to resistance training appear to be largely influenced by adaptations within the nervous system or by changes within the skeletal muscle itself. The velocity specific adaptations within the nervous system are suggested to provide unique improvements in the frequency at which motor units discharge that provide greater increases in maximal muscular shortening velocity, twitch and tetanic rate of tension development (Behm & Sale, 1993; Duchateaus & Hainaut, 1984). Consequently, this may result in a training induced enhancement of fast twitch fiber activation (Tricoli et al., 2001) and increased skeletal muscle contraction velocity, peak power (PP) and rate of force development (RFD) that may be associated with the enhancement of sport specific tasks (Ikegawa et al., 2008). In addition, skeletal muscle fiber type transitions or desirable morphological changes in muscle fascicle length and/or pennation angle may subsequently alter muscle force-velocity characteristics (Blazevich et al., 2003). Therefore, movement velocity may be considered a fundamental component of resistance training as the velocity at which loads are lifted may determine the resulting training effect and its transference to sports performance (Gonzalez-Badillo et al., 2014).

Numerous resistance training methods have been postulated to improve strength and power performance that include utilizing the power-load relationship to identify training loads that maximize P_{max} output. Progressing this contention, it is suggested that training with loads that maximize mechanical P_{max} output may improve 10-20-meter sprint times and elicit small-moderate improvements in lower body and upper body strength performance (Blazevich & Jenkins, 2002; Harris et al., 2008). However, previous research has demonstrated that this method may be no more effective than performing heavy resistance training (>80% 1RM) through improving the force component that plays an important role in training adaptations of maximal muscular power output (Hakkinen et al., 1985; Harris et al., 2008; Kaneko et al., 1983; McBride et al., 2002; Moss et al., 1997). Conversely, it is suggested that training at specific movement velocities may improve strength and power performance mainly at the trained velocity. In addition, as velocity begins to deviate from the intended training velocity, the less effective training will be (Caiozzo et al., 1981; Kanehisa & Miyashita, 1983). Furthermore, it is suggested that athletes should simulate the velocity and acceleration profiles associated with desired successful sporting performance and that resistance training loads should accommodate these profiles, whereby functional strength and power adaptations may be optimized (Cronin et al., 2002; Jones et al., 2001). This can be achieved by utilizing velocity zones or velocity stops that may provide a novel approach in autoregulating and individualizing training volume and load by being sensitive to changes in daily maximum strength. Velocity zones can be defined as specific velocity zones that an athlete must perform a resistance training movement within in order to develop a specific skeletal muscle performance trait (i.e. 0.20 – 0.25 $m.s^{-1}$ for absolute strength). Conversely, a velocity stop can be defined as a prescribed movement velocity for each repetition and a minimum velocity threshold (MVT) is set, in which the individual is not allowed to drop below, as a means to minimize neuromuscular fatigue (Jovanovic & Flanagan, 2014). Combining both velocity zones and velocity stops appropriately may allow for maximal velocities to be maintained throughout training blocks by prescribing optimal training loads in relation to daily biological status and limiting neuromuscular fatigue. Taking this into consideration, it can be suggested that utilizing movement velocity to monitor fatigue and to control exercise volume, may positively influence the enhancement of muscular strength and/or power across different load spectrums. However, despite these potential advantages, the majority of VBT isoinertial studies have emphasized maximal and half maximal lifting velocities and failed to equate the total volume load lifted between groups whilst manipulating several training variables simultaneously (Delecluse et al., 1995; Gonzalez-Badillo et al., 2014; Pareja-Blanco et al., 2014). Therefore, the mechanisms responsible for the muscle morphological and strength and power adaptations to VBT are difficult to interpret due to studies not focusing on movement velocity as the independent variable and failing to equate the total volume load lifted between groups.

It is well established that the acute and chronic biological alterations of the anabolic hormones testosterone and catabolic hormone cortisol contribute to positive adaptations in muscle growth, strength and power performance (Crewther, Lowe, Weatherby, Gill, & Keogh, 2009). Various studies have investigated the hormonal response to TPT and have demonstrated that protocols that are high in volume, moderate to high in intensity, incorporate short rest intervals and target large muscle groups are associated with the greatest acute increases in testosterone and cortisol (Kraemer & Ratamess, 2005). Additionally, altering one of the aforementioned parameters or their configuration (i.e. increasing number of sets or reduction in rest interval), creates a unique stimulus that modifies the hormonal response to resistance training (Smilios, Tsoukos, Zafeiridis, Spassis, & Tokmakidis, 2014). In contrast, movement velocity is also an important parameter that may greatly influence the biological stress arising from resistance training. Movement velocity is demonstrated to be associated with a higher heart rate, energy expenditure and an augmented disruption of muscle ultra-structure (Hunter et al., 2003; Mazzetti et al., 2007; Shepstone et al., 2005). Additionally, the execution of a resistance training movement with intended maximum velocity during light intensity (0-30% 1RM) explosive movements (McBride et al., 2002) and heavy strength training loads (Behm & Sale, 1993), may increase the recruitment of higher threshold motor units along with activating a greater muscle mass which may consequently induce a greater hormonal response (Carpentier et al., 1996; Smilios et al., 2014). Previous research examining the effect of movement velocity on cortisol repsonse have reported reduced (Goto, Takahashi, Yamamoto, & Takamatsu, 2008) or unchanged (Headley et al., 2011) cortisol concentrations when performing the bench press and knee extension exercises with fast movement velocities when compared with slow movement velocities. However, these studies provide limitations as they prescribed movement velocities based off traditional fixed lifting tempos (2:2 and 2:4 or 1:1 and 3:3) for the concentric and eccentric phases and only utilized low to moderate loads (40-75% 1RM). The use of cortisol as a method to monitor catabolic states in athletes, and to predict athletic performance and the overtraining syndrome has gained interest among strength and conditioning professionals. Additionally, salivary cortisol has been shown to respond promptly to bouts of both high and low intensity resistance exercise and power-based interventions in rugby league and rugby union players. Thus, cortisol is deemed to be a reliable and valid measurement tool of strength and power resistance exercise load (Crewther et al., 2009; Crewther et al., 2011a; McGuigan et al., 2004b; McLellan et al., 2010). In addition, psychological wellness questionnaire monitoring provides an efficient and non-invasive monitoring strategy that exhibits a dose-response relationship with training load and provides an early marker of overreaching and/or overtraining in athletes (Gastin et al., 2013; Main & Grove, 2009; Raglin, 2001; Urhausen & Kindermann, 2002).

The primary purpose of the present investigation was to develop a better understanding of performing resistance training within specific VBT zones across different load spectrums as a training stimulus to elicit subsequent strength and power adaptations when compared to TPT methods in professional rugby league players. The second purpose of the present investigation was to compare and examine the psychological wellness and salivary cortisol stress response between VBT and TPT programmes to determine if VBT induces the same psychological and physiological stress response as TPT in professional rugby league players.

4.3 Methods

4.3.1 Experimental approach to the problem

To investigate whether VBT performed with isoinertial external loads across different load spectrums elicited subsequent improvements in neuromuscular strength and power performance, a single subject case study pre-intervention and post-intervention design was employed. Neuromuscular strength and power performance measures of 3RM bench press, back squat, power clean, countermovement jump (CMJ) and squat jump (SJ) were determined and measures of force, power, velocity and displacement were considered for analysis for the CMJ and SJ. This approach allowed us to assess the unique effect of performing VBT within specific velocity zones across different load spectrums as an ecologically valid training stimulus to elicit improvements in strength and power performance in professional rugby league players.

4.3.2 Participants

Ten participants from a National Rugby League (NRL) competition team volunteered to take part in this study. The participants competed in both the NRL competition and New South Wales (NSW) cup competition from March 2015 to September 2015. However, five participants were removed from the study due to failure to complete physical assessments and their assigned resistance training programmes due to unforeseen match related injuries and/or availability constraints placed upon the athletes from the senior coaching staff. Subsequently, five professional rugby league athletes (mean ± *SD*, age 22.2 ± 1.3 years, height 182.6 ± 4.16 cm, mass 98.4 ± 7.8 kg) participated in the case study. The following inclusion criteria was imposed for each participant for the purpose of this study; 1) a competitive male rugby league athlete aged 18-30 years, 2) no current acute or chronic injuries or medical conditions, 3) have been involved in a high performance resistance training programme for ≥ 2 years, 4) possess an appropriate level of joint mobility to perform the bench press, back squat and power clean movements with correct technique, 5) not using any performance enhancing or banned substances (World Anti-Doping Agency 2015) and, 6) free from saliva borne infectious disease. Informed written consent was collected from all athletes prior to commencing the investigation. Study procedures were approved by the AUT University Ethics Committee (AUTEC), Auckland, New Zealand.

4.3.3 Resistance training programme

This study employed a 5-week training intervention where participants performed two supervised resistance training sessions per week (10 total training sessions) during the in-season competition phase. In addition, training weeks were periodized with low, moderate and heavy intensity training weeks with the addition of a taper week to allow for neuromuscular recovery. Participants were randomly assigned to either the VBT group (n = 3) or TPT group (n = 2). Training sessions took place at the participant's usual training base under the direct supervision of the investigator at the same time of day (13:30 ± 1 hour) for each participant. All participants were required to refrain from performing additional resistance training exercise outside of the prescribed training programme but continued with their coach specific skills and cardiovascular conditioning sessions.

The magnitude of training volume (i.e. sets, reps, intended training intensity and rest) between the TPT vs. VBT groups were kept identical within each training session. The training loads performed by the TPT group were prescribed from each participant's previous 1RM for the bench press, back squat and power clean that was obtained within a four-week period prior to the commencement of the study. In-season competition constraints placed on the participants from coaching staff prevented the researchers from obtaining immediate pre-intervention 1RM values. Conversely, the VBT group performed an autoregulatory type programme whereby the training loads were determined by a target mean velocity zone ($m.s^{-1}$) that was associated with each particular training intensity for the bench press and back squat exercises and a target peak velocity zone ($m.s^{-1}$) for the power clean exercise. The target velocity zones were determined following a velocity strength and power profiling session for the bench press, back squat and power clean exercises across a load spectrum of 20-95% 1RM (refer to study one). Descriptive characteristics of the resistance training programme for the VBT group and TPT group are presented in Table 9. During each training session, the VBT group attached a linear position transducer (LPT) (GymAware PowerTool, Kinetic Performance PTY Ltd., ACT, Australia) to the inside of an Olympic barbell that registered the kinematics of every repetition in real time whereby the LPT software calculated an estimation of the kinetics of each exercise. The immediate feedback allowed participants to adjust their subsequent training load (following consultation with the primary investigator) according to the concentric velocity that was achieved for the preceding set to ensure they were training within the required velocity zone ($m.s^{-1}$). The VBT group were instructed to perform the concentric phase for each repetition of the bench press and back squat with maximal dynamic effort whilst, participants were instructed to perform the power clean with maximal dynamic effort throughout the entire movement. Participants were instructed to perform the bench press without the bar leaving the hands and back remaining flat on the bench at all times. Additionally, participants were instructed to perform the back squat with feet fixed to the ground at all times. The depth of the bench press was set to touch the chest without bouncing the bar. The depth for the back squat was set at a knee angle of 90 degrees and the power clean catch was set at or above a knee angle of 90 degrees. The depth of the bench press and back squat and catch position of the power clean were visually determined and the participants were provided with one warning if the required movement depth was not achieved. The TPT group were also instructed to perform each exercise with maximum dynamic effort. However, the TPT participants did not receive any quantitative feedback for their movement velocity (i.e. a LPT was not attached to the bar) in order to replicate the participant's regular training environment.

4.3.4 Saliva, psychological wellness questionnaire and session RPE monitoring collection

Psychological wellness questionnaire monitoring and pre and post saliva collection was performed for each of the two resistance training sessions completed on assigned light (Week 1, 70-75% 1RM), moderate (Week 2, 75-80% 1RM) and heavy (Week 5, 80-85% 1RM) intensity training weeks. All participants were required to refrain from performing additional resistance training exercise outside of the prescribed training programme. Additionally, session RPE was collected for all prescribed resistance training sessions throughout the 5-week training intervention. The psychological wellness questionnaire was derived from a previous study conducted in professional rugby league players by McLean and colleagues (2010). The psychological wellness questionnaire monitoring collection was performed 30 minutes prior to the commencement of a resistance training session that consisted of 8 questions relating to perceived fatigue, sleep quality, stress, mood and muscle soreness which were rated on a 1-5 scale (refer to appendix 4). In addition, a wellness threshold of 25 points was set out of a possible 50 points to determine; 1) an athlete's readiness to train and, 2) their degree of neuromuscular recovery from a previous training session (McLean et al., 2010). A wellness score below 25 points indicates that an athlete may not have recovered effectively from a previous training session and may have accumulated excessive fatigue. Conversely, a wellness score above 25 points indicates an athlete has recovered effectively from a previous training session and has not accumulated excessive fatigue. Saliva collection was performed 15 minutes pre training and within 15 minutes post training. A 2-mL saliva sample was collected via passive drool, with saliva samples stored at -80 degrees before assay analysis for salivary cortisol (Sal-C) concentrations following the conclusion of the 5-week training intervention (Crewther et al., 2009). The salivary collection timeline was set for low, moderate and high intensity weeks to account for in-season competition matches and logistical reasons. The analysis of salivary cortisol concentrations involved three steps; 1) sample centrifugation, 2) extraction of the clear supernatant and, 3) Elecsys cortisol assay analysis performed at the AUT Roche Diagnostics Laboratory. Salivary collection was specifically chosen due to its ability to measure the free bioavailable hormone levels in the body (Aardal-Eriksson et al., 1998). Conversely, other methods such as serum collection only measures the protein bound non-available hormone levels (Aardal-Eriksson et al., 1998). Therefore, saliva collection provides a non-invasive and accurate measurement of hormone levels in dynamic endocrine tests ($r = 0.76$-0.85, $p < 0.001$) (Aardal-Eriksson et al., 1998; Duplessis et al., 2010). Session-RPE was collected within 30 minutes following the cessation of each training session utilizing the Borg CR-10 RPE scale which has been shown to be a reliable and valid method of quantifying resistance exercise load (McGuigan et al., 2004b).

Table 9. Descriptive characteristics of the training programme performed by the velocity based training group and traditional percentage based training group

VBT Group					
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Training week intensity	**Light**	**Moderate**	**Light**	**Moderate**	**Heavy**
Bench Press					
Sets x Reps	4 x 5	4 x 5	3 x 5	4 x 5	4 x 6,6,4,4
Mean VBT Zone ($m.s^{-1}$)	0.35 – 0.50	0.29 – 0.35	0.35 – 0.50	0.29 – 0.35	0.24 – 0.35
% 1RM	75%	80%	75%	80%	85%
Back Squat					
Sets x Reps	4 x 5	5 x 5	3 x 8	4 x 6,6,5,5	4 x 5,5,4,4
Mean VBT Zone ($m.s^{-1}$)	0.55 – 0.60	0.50 – 0.55	0.55 – 0.60	0.50 – 0.55	0.35 – 0.55
% 1RM	75%	80%	75%	80%	85%
Power Clean					
Sets x Reps	4 x 5	3 x 5	*	3 x 6	3 x 6,5,4
Peak VBT Zone ($m.s^{-1}$)	2.25 – 2.60	2.13 – 2.35	*	2.13 – 2.35	2.08 – 2.30
% 1RM	70%	75%	*	75%	80%
Traditional Percentage Based Group					
Bench Press					
Sets x Reps	4 x 5	4 x 5	3 x 5	4 x 5	4 x 6,6,4,4
% 1RM	75%	80%	75%	80%	85%
Back Squat					
Sets x Reps	4 x 5	5 x 5	3 x 8	4 x 6,6,5,5	4 x 5,5,4,4
% 1RM	75%	80%	75%	80%	85%
Power Clean					
Sets x Reps	4 x 5	3 x 5	*	3 x 6	3 x 6,5,4
% 1RM	70%	75%	*	75%	80%

*** =** the power clean exercise was not performed during the third week of the intervention due to the in-season competition constraints requiring senior coaching staff to modify the prescribed training programme

4.3.5 Testing procedures

Pre and post-intervention neuromuscular strength and power assessments were performed one week before and one week after the cessation of the study. The following tests were performed in a single session in the following order; 1) countermovement jump (CMJ), 2) squat jump (SJ), 3) 3RM power clean, 4) 3RM back squat, and 5) 3RM bench press.

4.3.5.1 CMJ and SJ

Lower body power was measured pre and post-intervention using an explosive bodyweight CMJ and SJ performed on a portable AMTI force plate (AMTI Force and Motion, Watertown, MA, USA). Participants lowered their body position to a self-selected depth for both the CMJ and SJ. Each participant was instructed to execute the entire motion of the CMJ including arm swing with maximal dynamic effort. Conversely, participants were instructed to hold the SJ position with hands on hips at a self-selected hip and knee angle for two seconds before the verbal instruction of "jump" was given to execute the SJ motion with maximal dynamic effort (Gutierrez-Davila et al., 2014; Markovic et al., 2014; Morrissey et al., 1998; Pareja-Blanco et al., 2014). Four maximal CMJs, separated by a 5-10 second rest period were executed whilst, a three-minute rest period was provided before executing four maximal SJs, separated by a 5-10 second rest period. CMJ and SJ peak force (PF), peak power (PP), peak velocity (PV) and displacement were registered and considered for analysis. The test-retest reliability for CMJ and SJ performance measures of force, power, velocity and displacement were not possible to assess in the current study. However, previous research has reported AMTI force plate reliability for measures of force (ICC = 0.80 - 0.97; CV = 2.1% - 6.4%) (Buckthorpe et al., 2012; Cronin et al., 2004), power (ICC = 0.94; CV = 10.4%) and velocity (ICC = 0.94; CV = 9.7%) (Hansen, Cronin, & Newton, 2011).

4.3.5.2 Bench press and back squat

The bench press and back squat exercises were performed on an adjustable power rack (Life Fitness, Hammer Strength, Auckland, New Zealand) with a loaded 20kg Olympic barbell placed horizontally at the chosen height of the participant. The bench press and back squat were chosen for the purpose of assessing upper and lower body maximal strength, respectively, in this study as they are exercises that are widely used in athletic training environments. In addition, all the participants in the present study were familiar with generating maximum force and executing the exercises with efficient technique. The bench press was performed with the participants lying with their back flat on a bench with arms fully extended and hands gripping the bar approximately shoulder width apart whilst the knees were bent at a 90-degree angle and feet fixed to the ground. The depth of the bench press was set to touch the chest without bouncing the bar. The back squat was performed with participants starting in the upright position with knees and hips fully extended, feet placed approximately shoulder width apart and the Olympic barbell positioned approximately across the acromion joint. The depth for the back squat was set at a knee angle of 90-degrees (visually determined) before returning to the upright position. Each participant was instructed to descend the barbell during the eccentric phase for the bench press and back squat in a controlled motion. However, participants were instructed to execute the concentric phase of the bench press and back squat with maximal dynamic effort. Participants were also instructed to perform the bench press without the bar leaving the hands and back remaining flat on the bench at all times. Additionally, participants were instructed to perform the back squat with feet fixed to the ground at all times. As previously mentioned, the pre-intervention 1RM bench press and back squat maximum strength values for each participant were obtained from historical data that were assessed within a four-week period of the participants commencing the study. The post-intervention bench press and back squat maximum strength characteristics of participants were assessed with a 3RM as it was not possible to perform 1RM assessment due to in-season competition constraints placed on participants from coaching staff. Therefore, a predicted 1RM value was generated from the Brzycki (1993) formula that is shown to be a reliable method for predicting 1RM ($r^2 = 0.98$).

Predicted 1RM = Load (kg)/1.0278 - (0.0278 x number of reps)

The post-intervention loading intensities were individually adjusted for each participant with 2.5 to 5kg load increments for both the bench press and back squat so that a maximum 3RM could be precisely determined. A warm-up set for both the bench press and back squat was executed with five repetitions on the 20kg Olympic barbell only, three repetitions executed at light loads (< 60% 1RM), three repetitions executed at moderate loads (70 – 80% 1RM), before loads were executed at above 80% 1RM to determine maximal 3RM dynamic strength. Strong verbal encouragement was provided to motivate participants to execute maximal effort. Inter-set rest periods ranging between three to five minutes were provided for each participant.

4.3.5.3 Power clean

The power clean exercise was performed on a weightlifting platform (Life Fitness, Hammer Strength, Auckland, New Zealand) that consisted of a 20kg Olympic barbell that was loaded with bumper plates. The power clean was chosen for the purpose of assessing whole body power in this study as it is an exercise that is widely used in athletic training environments (De Villiers & Venter, 2015; Hoffman et al., 2004; Seitz et al., 2014). In addition, all participants in the present study were familiar with generating whole body power and executing the power clean exercise with efficient technique. All repetitions were performed from the ground with the participants' feet placed approximately shoulder width apart with their hands gripping the bar approximately outside shoulder width. Each participant was instructed to perform the first pull (i.e. lifting the bar from the ground to the knee) in a controlled motion whilst gaining momentum. However, participants were instructed to perform the second pull (i.e. transitioning from the double knee-bend and accelerating the bar to the hip whilst extending the trapezius) with maximal dynamic effort. The catch position of the power clean was set at or above a knee angle of 90-degrees in order to be recorded as a successful lift. As noted above, it was not possible to perform a post-intervention 1RM assessment due to in-season competition constraints placed on participants from coaching staff. Therefore, the post-intervention power clean maximum for each participant were assessed with a 3RM and a predicted 1RM value was generated from the Brzycki (1993) formula. Strong verbal encouragement was provided to motivate participants to execute maximal effort. Inter-set rest periods ranging between three to five minutes were provided for each participant.

4.3.6 Statistical analysis

The proposed statistical analysis methods for the present investigation included reporting means and standard deviations to describe all data variables. Analysis of the efficacy of the training programme included computing independent t-tests to compare the percent change in the variables of interest using IBM SPSS software version 22. Cohen's effect statistics were to be used to describe the differences in pre and post testing between groups. The effect size magnitude were to be calculated according to the Cohen scale where $d = 0.2$ is considered a small effect, $d = 0.5$ is moderate and $d = 0.8$ is a large effect size (Cohen, 1992). A significance level of $p < 0.05$ was to be selected to indicate statistical significance. However, due to the large drop out of participants prior to the commencement of the research study, it was only possible to describe all data variables as means and standard deviations and differences in pre and post testing between groups as percentage changes.

4.4 Results

4.4.1 Intended vs actual total tonnage lifted and session RPE

The VBT group's actual total tonnage that was lifted for the bench press, back squat and power clean exercises was higher than the intended loads throughout the intervention period (Table 10). Interestingly, the VBT group and TPT group did not report major dissimilarities in perceived internal load (Figures 9 – 11).

4.4.2 Saliva collection and wellness questionnaire monitoring

During the low intensity training week, the TPT group on average elicited a greater increase in Sal-C (+52.3%) when compared to the VBT group (+12.8%). In addition, a greater increase in Sal-C was observed for the TPT group (+472.6%) during the heavy intensity training week whilst the VBT group elicited less Sal-C (+99.0%). However, Sal-C response for the moderate intensity training week are indefinite with the VBT group showing a decrease in Sal-C (-1.1%) whilst a greater decrease was observed in TPT group (-30.0%) (Table 11). In relation to the weekly psychological wellness questionnaire monitoring data, the VBT group reported higher weekly psychological wellness scores for light (37.7 ± 1.4 vs 35.5 ± 3.1), moderate (35.5 ± 2.7 vs 29.5 ± 0.7) and heavy (35.0 ± 1.6 vs 29.0 ± 3.5) intensity training weeks when compared to the TPT group. The higher psychological wellness questionnaire scores reported by the VBT group indicated that the participants recovered more effectively from previous resistance training sessions and did not accumulate excessive fatigue.

4.4.3 Countermovement jump (CMJ)

Analysis between initial pre and post intervention testing showed substantial changes in CMJ and SJ force, power, velocity and displacement between participants in the VBT group and TPT group (Table 12). Participants 1-2 in the VBT group showed substantial improvements in CMJ force (N) (+15.9 and +66.8%), power (W) (+31.8 and +76.3%), velocity ($m.s^{-1}$) (+2.9 and +36.9%) and displacement ($m.s^{-1}$) (+2.8 and +67.9%). In addition, participant 3 in the VBT group showed similar improvements in CMJ force (N) (+30.9%), power (W) (+9.3%) and displacement ($m.s^{-1}$) (+32.7%) however, showed a decrease in velocity ($m.s^{-1}$) (-11.3%). Participant 4 in the TPT group showed decreases across all CMJ performance variables of force (N) (-28.2%), power (W) (-9.8%), velocity ($m.s^{-1}$) (-19.0%) and displacement ($m.s^{-1}$) (-51.6%) (Table 12).

4.4.4 Squat jump (SJ)

Participant 2 in the VBT group improved across all performance variables of force (N) (+105.7%), power (W) (+35.0%), velocity ($m.s^{-1}$) (+12.8%) and displacement ($m.s^{-1}$) (+131.6%). Similar improvements were observed for participant 1 and 3 in the VBT group for force (N) (+32.2% and +41.5%), power (N) (+6.8% and +5.5%) and displacement ($m.s^{-1}$) (+7.4% and +62.1%). However, both participants showed decreases in velocity ($m.s^{-1}$) (-11.6% and -16.3%). Participant 4 in the TPT group showed improvements in only power (W) (+8.8%) and velocity ($m.s^{-1}$) (+3.9%) however, showed decreases in force (N) (-6.4%) and displacement ($m.s^{-1}$) (-5.6%) (Table 13).

4.4.5 Strength and power assessments

4.4.5.1 Bench press

Analysis between initial pre and post intervention testing showed only participant 1 in the VBT group improved bench press maximal strength with an increase of +1.5%. Participant 2 in the VBT group showed a decrease in maximal bench press strength by -2.3% whilst, participant 4 and 5 in the TPT group showed a greater decrease in maximal bench press strength by -3.7% and 10.4% (Table 14).

4.4.5.2 Back squat

Analysis between initial pre and post intervention testing showed only participant 1 in the VBT group improved maximal back squat strength with an increase of +5.9%. Participant 2 in the VBT group showed a decrease in maximal back squat strength by -7.7% whilst, participant 4 in the TPT group showed a greater decrease in maximal back squat strength by -17.6% (Table 14).

4.4.5.3 Power clean

Analysis between initial pre and post intervention testing showed only participant 2 in the VBT group improved power clean maximal power with an increase of +1.5%. Participant 1 in the VBT group showed a decrease in power clean maximal power by -7.3% whilst, participant 4 in the TPT group showed no change in power clean maximal power (Table 14).

Table 10. Total intervention intended vs actual tonnage lifted for the velocity based training group and traditional percentage based training group

Velocity Based Training Group									
	Bench Press			Back Squat			Power Clean		
	Intended	Actual	% Change	Intended	Actual	% Change	Intended	Actual	% Change
Participant 1	1160kg	1235kg	+6.8%	1805kg	1860kg	+3.1%	835kg	930kg	+11.4%
Participant 2	1660kg	1720kg	+3.6%	1805kg	1865kg	+3.3%	885kg	930kg	+5.9%
Participant 3	1885kg	1985kg	+5.3%	1855kg	1910kg	+3.0%	945kg	990kg	+4.8%
Traditional Percentage Based Training Group									
Participant 4	1425kg	1425kg	0%	1785kg	1785kg	0%	625kg	625kg	0%
Participant 5	1325kg	1325kg	0%	1336kg	1336kg	0%	790kg	790kg	0%

Table 11. Salivary cortisol concentrations pre and post light, moderate and heavy intensity training weeks and mean weekly endocrine and neuromuscular psychological wellness questionnaire monitoring scores for the velocity based training group and traditional percentage based training group

	Velocity Based Training Group				Traditional Percentage Based Training Group			
Intensity %1RM	**Pre Sal-C**	**Post Sal-C**	**% Change**	**Wellness Score**	**Pre Sal-C**	**Post Sal-C**	**% Change**	**Wellness Score**
Light (70-75%)	13.7 ± 11.7	15.4 ± 12.1	+12.8%	37.7 ± 1.4	8.1 ± 3.9	12.3 ± 3.8	+52.3%	35.5 ± 3.1
Moderate (75-80%)	5.7 ± 3.8	5.4 ± 1.8	-1.1%	35.5 ± 2.7	10.8 ± 4.6	7.6 ± 3.6	-30.0%	29.5 ± 0.7
Heavy (80-85%)	8.5 ± 2.6	16.8 ± 26.1	+98.9%	35.0 ± 1.6	6.5 ± 1.1	37.4 ± 46.0	+472.6%	29.0 ± 3.5

Mean ± SD, 1RM = one repetition maximum

Table 12. Pre and post intervention countermovement jump results for the velocity based training group and traditional percentage based training group

Velocity Based Training Group												
	Force (N)			Power (W)			Velocity ($m.s^{-1}$)			Displacement ($m.s^{-1}$)		
	Pre	**Post**	**% Change**	**Pre**	**Post**	**% Change**	**Pre**	**Post**	**% Change**	**Pre**	**Post**	**% Change**
Participant 1	1341 ± 204	1554 ± 92	+15.9%	4692 ± 488	6186 ± 644	+31.8%	2.96 ± 0.31	3.04 ± 0.17	+2.9%	0.46 ± 0.06	0.47 ± 0.16	+2.8%
Participant 2	1487 ± 507	2480 ± 90	+66.8%	5378 ± 1100	9482 ± 356	+76.3%	3.23 ± 0.12	4.43 ± 0.05	+36.9%	0.55 ± 0.02	0.93 ± 0.02	+67.9%
Participant 3	1691 ± 414	2214 ± 514	+30.8%	5669 ± 199	6199 ± 430	+9.3%	3.37 ± 0.29	2.99 ± 0.18	-11.3%	0.55 ± 0.06	0.73 ± 0.04	+32.7%
Traditional Percentage Based Training Group												
Participant 4	1932 ± 436	1388 ± 44	-28.2%	6523 ± 1549	5886 ± 252	-9.8%	3.89 ± 0.88	3.15 ± 0.12	-19.0%	1.30 ± 1.23	0.63 ± 0.14	-51.6%
Participant 5	1752 ± 568	*	*	5241 ± 380	*	*	2.74 ± 0.14	*	*	0.47 ± 0.08	*	*

***** = did not complete post testing due to injury sustained during competition in the final week of the intervention

Table 13. Pre and post intervention squat jump results for the velocity based training group and traditional percentage based training group

	Force (N)			Power (W)			Velocity (m.s^{-1})			Displacement (m.s^{-1})		
Velocity Based Training Group												
	Pre	**Post**	**% Change**	**Pre**	**Post**	**% Change**	**Pre**	**Post**	**% Change**	**Pre**	**Post**	**% Change**
Participant 1	1598 ± 519	2112 ± 536	+32.2%	4713 ± 238	5033 ± 101	+6.8%	3.01 ± 0.03	2.66 ± 0.05	-11.6%	0.61 ± 0.45	0.66 ± 0.06	+7.4%
Participant 2	1230 ± 48	2530 ± 35	+105.7%	5852 ± 715	7899 ± 1567	+35.0%	3.28 ± 0.23	3.70 ± 0.70	+12.8%	0.44 ± 0.02	1.03 ± 0.19	+131.6%
Participant 3	1752 ± 923	2479 ± 56	+41.5%	5991 ± 401	6318 ± 344	+5.5%	3.54 ± 0.14	2.96 ± 0.14	-16.3%	0.52 ± 0.04	0.84 ± 0.14	+62.1%
Traditional Percentage Based Training Group												
Participant 4	1976 ± 87	1850 ± 488	-6.4%	5071 ± 931	5514 ± 1511	+8.8%	3.01 ± 0.57	3.13 ± 0.77	+3.9%	0.81 ± 0.30	0.76 ± 0.24	-5.6%
Participant 5	1872 ± 492	*	*	4522 ± 111	*	*	2.51 ± 0.06	*	*	0.63 ± 0.11	*	*

*** =** did not complete post testing due to injury sustained during competition in the final week of the intervention

Table 14. Pre and post intervention strength and power results for the velocity based training group and traditional percentage based training group

Velocity Based Training Group									
	Bench Press			Back Squat			Power Clean		
	Pre 1RM	**Post 1RM**	**% Change**	**Pre 1RM**	**Post 1RM**	**% Change**	**Pre 1RM**	**Post 1RM**	**% Change**
Participant 1	120kg	122kg	+1.5%	170kg	180kg	+5.9%	120kg	111kg	-7.3%
Participant 2	130kg	127kg	-2.3%	195kg	180kg	-7.7%	120kg	122kg	+1.5%
Participant 3	180kg	*	*	180kg	*	*	125kg	*	*
Traditional Percentage Based Training Group									
Participant 4	110kg	106kg	-3.7%	180kg	148kg	-17.6%	90kg	90kg	0%
Participant 5	130kg	116kg	-10.4%	150kg	*	*	100kg	*	*

***** = did not complete post testing due to injury sustained during competition in the final week of the intervention

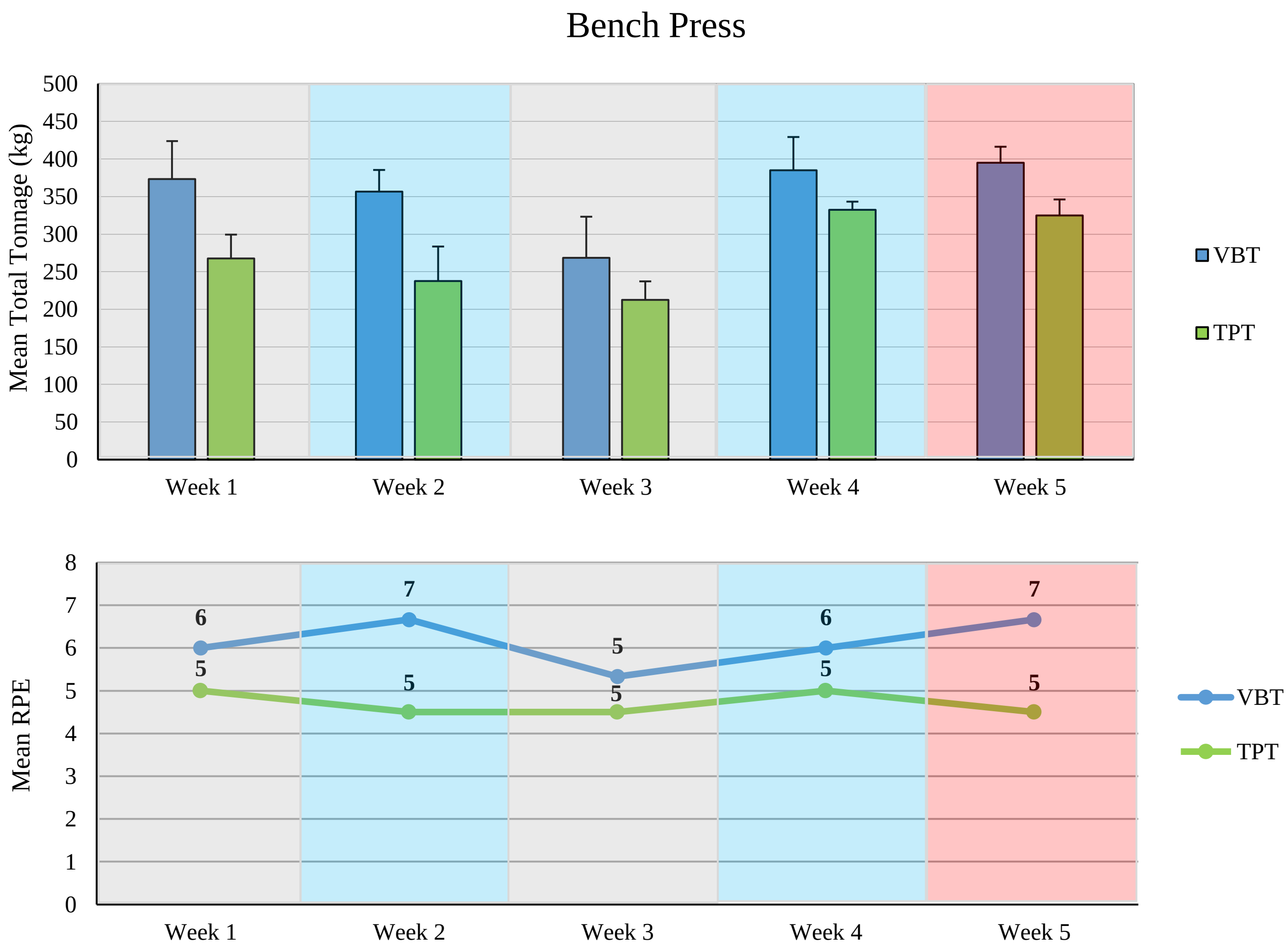


Figure 9. Velocity based training group and traditional percentage based training group actual mean bench press (±SD) weekly tonnage and mean session RPE. Week 1 = Light week (70-75%), Week 2 = Moderate week (75-80%), Week 3 = Light week (70-75%), Week 4 = Moderate week (75-80%), Week 5 = Heavy week (80-85%).

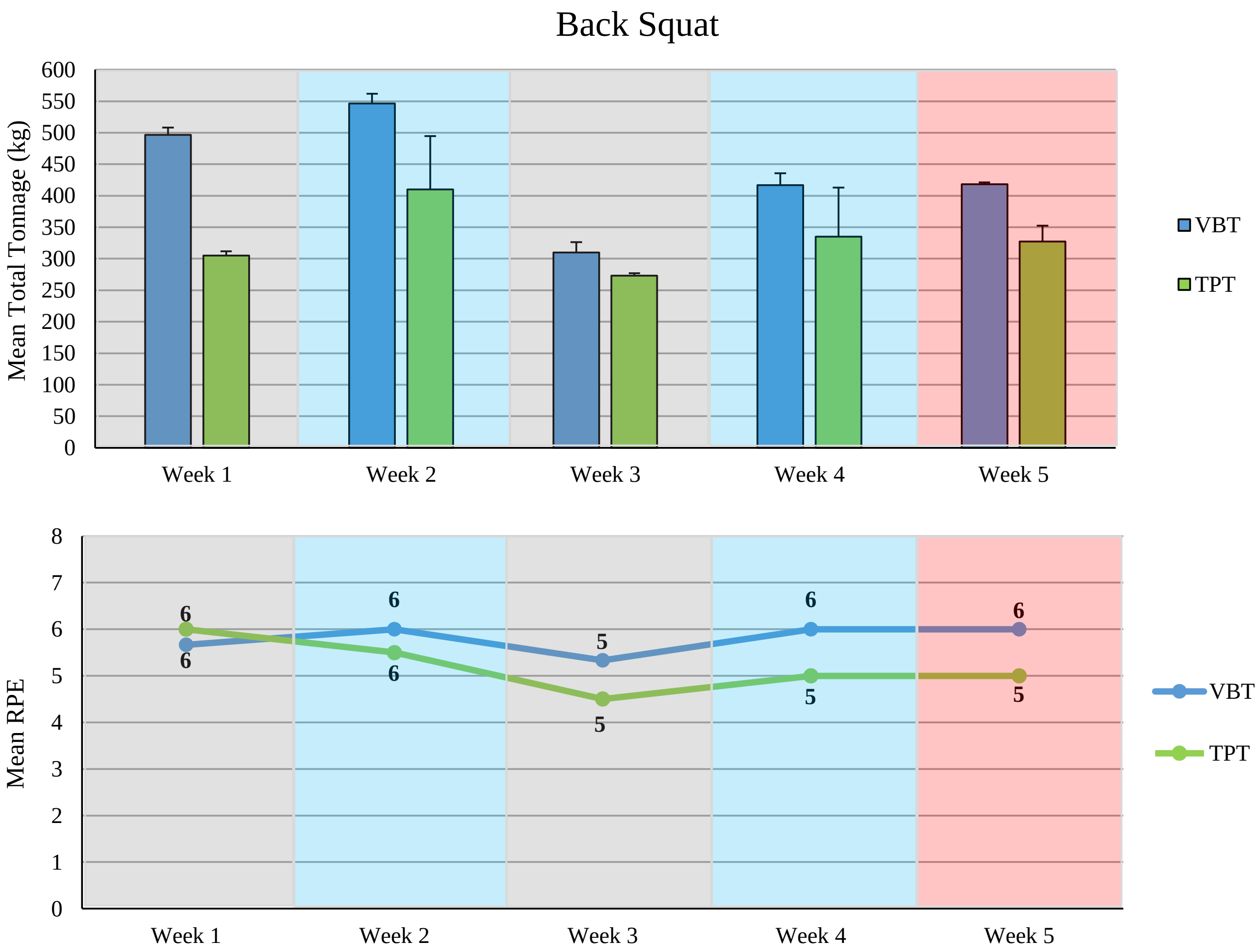


Figure 10. Velocity based training group and traditional percentage based training group actual mean back squat (±SD) weekly tonnage and mean session RPE. Week 1 = Light week (70-75%), Week 2 = Moderate week (75-80%), Week 3 = Light week (70-75%), Week 4 = Moderate week (75-80%), Week 5 = Heavy week (80-85%).

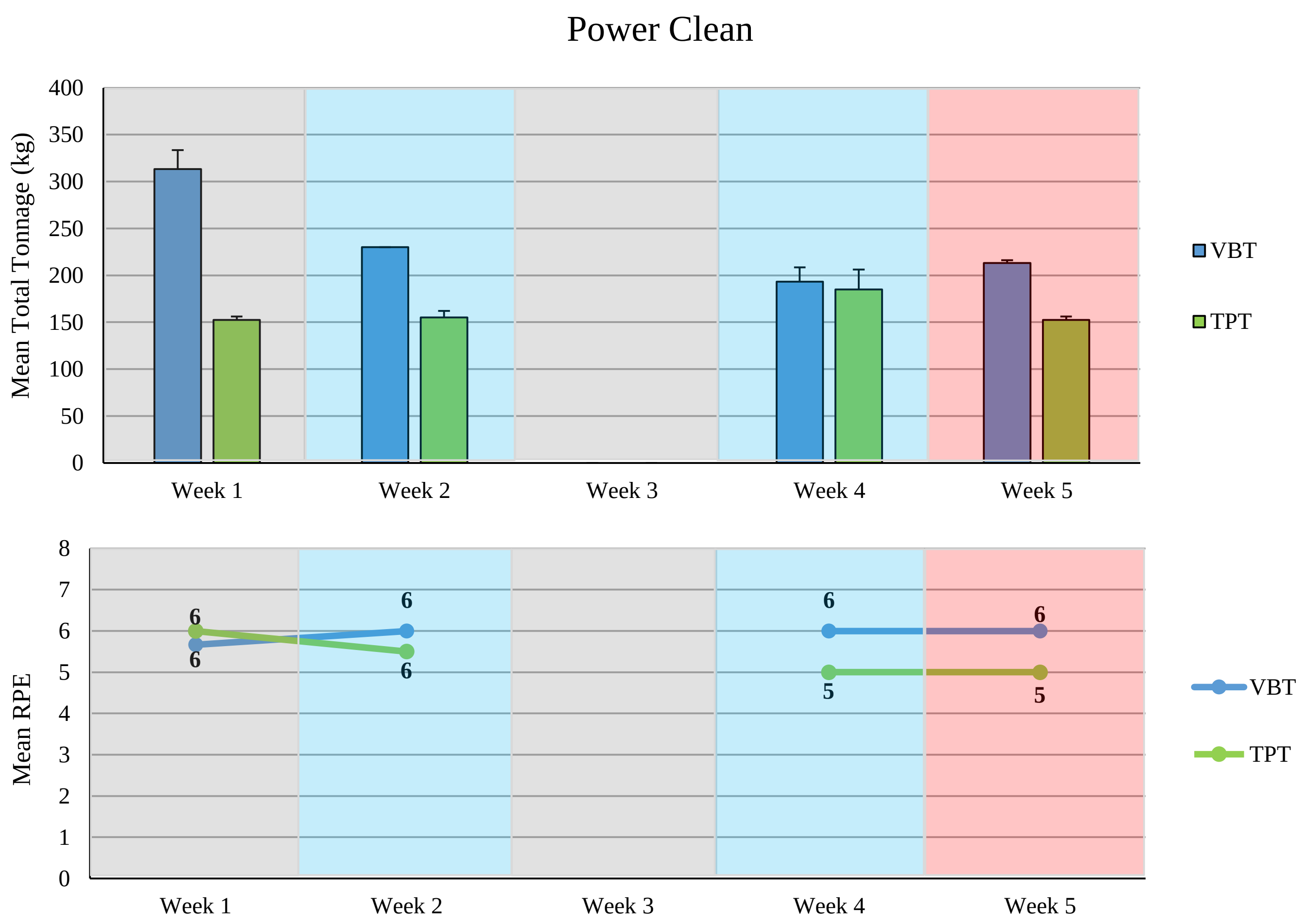
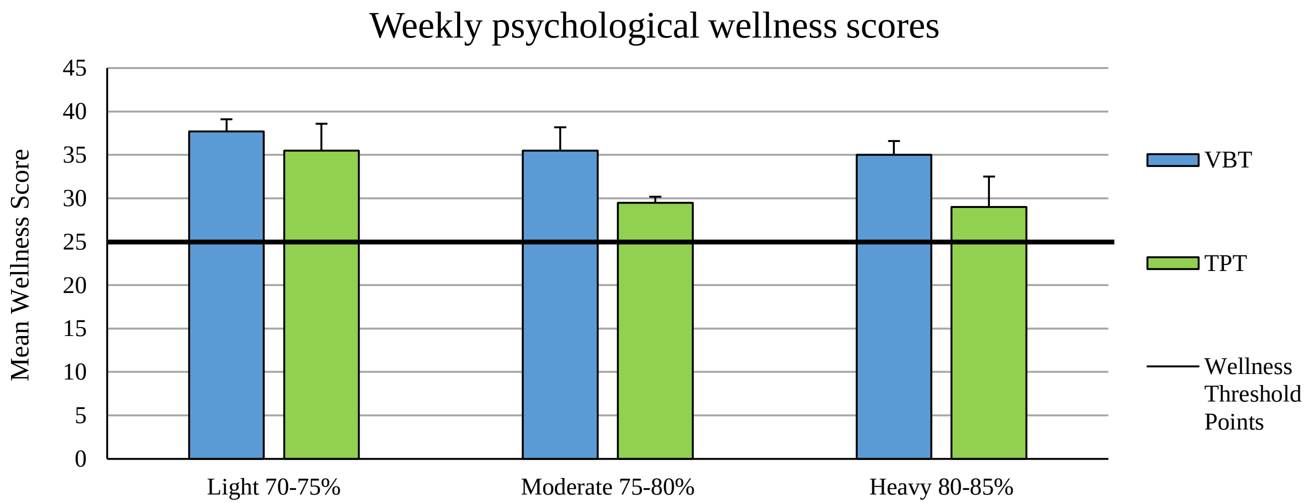
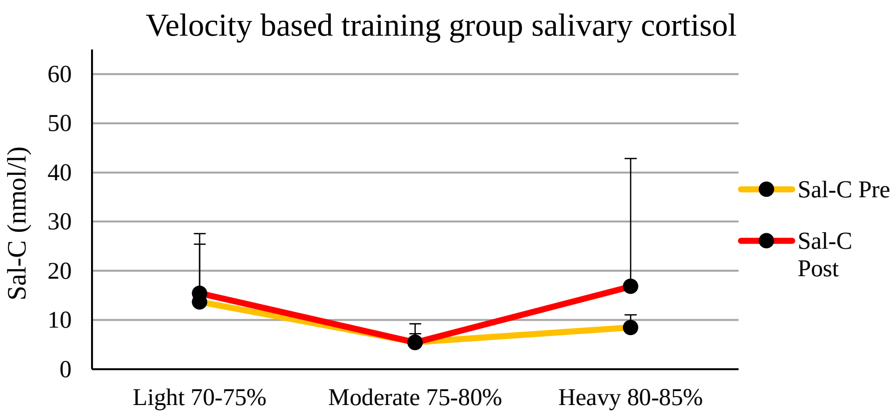


Figure 11. Velocity based training group and traditional percentage based training group actual mean power clean (±SD) weekly tonnage and mean session RPE. Week 1 = Light week (70-75%), Week 2 = Moderate week (75-80%), Week 3 = Light week (70-75%), Week 4 = Moderate week (75-80%), Week 5 = Heavy week (80-85%). *Week 3 - the power clean exercise was not performed during the third week of the intervention due to the in-season competition constraints requiring senior coaching staff to modify the prescribed training programme.





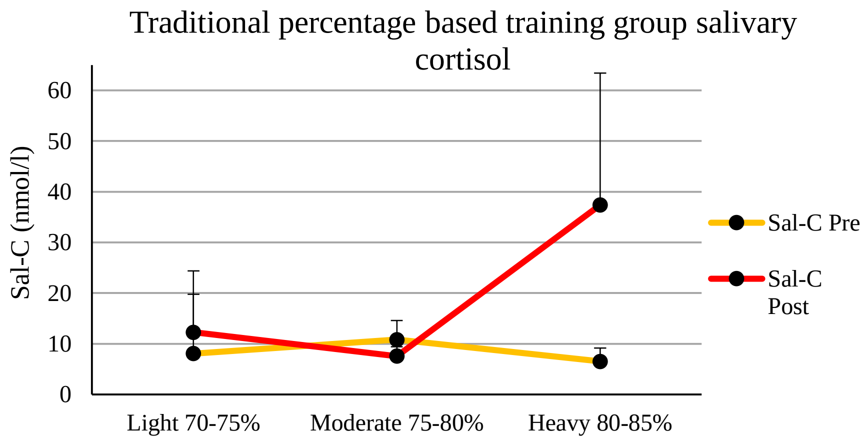


Figure 12. Velocity based training group and traditional percentage based training group mean weekly psychological wellness questionnaire scores (±SD) and mean salivary cortisol (±SD) response for light (70-75%), moderate (75-80%) and, heavy intensity training weeks (80-85%).

4.5 Discussion

The primary purpose of this study was to determine the influence of performing resistance training within specific VBT zones on subsequent strength and power adaptations when compared to TPT methods in professional rugby league players. It must be highlighted that a major limitation of this study was that a small sample size was used due to in-season competition constraints placed on potential participants. The authors acknowledge this limitation and the findings of this study will be discussed with this in mind.

The main findings of this investigation were that a substantial increase in CMJ and SJ performance was observed after the 5-week intervention in the VBT group. In addition, greater increases in training load were performed by the VBT group when compared to the intended values based off TPT methods (i.e. prescribing loads based off a pre-intervention 1RM value), whilst no change was observed in the TPT group. A novel finding of this investigation was that although the VBT group performed greater weekly tonnages, no substantial variance in reported session RPE values were observed between both groups. Additionally, the VBT group reported higher weekly wellness questionnaire scores and remained considerably above the set wellness threshold of 25 points when compared to the TPT group. Furthermore, the VBT group elicited less Sal-C training stress for light and heavy intensity training weeks when compared to the TPT group.

These results demonstrate that VBT allows greater training volumes to be performed without incurring excessive perceived internal load. In addition, the VBT participants were able to enhance neuromuscular recovery between training sessions to a greater extent which corresponded with greater perceived psychological wellness scores and optimized participant's readiness to train. However, it must be acknowledged that the limitations of the current findings include; 1) participant 5 from the TPT group did not complete the CMJ, SJ, back squat and power clean testing due to injury. In addition, participant 3 from the VBT group did not complete the final bench press, back squat and power clean testing due to injury sustained during competition in the final week of the intervention and, 2) the power clean exercise was not performed during the third week of the intervention due to the in-season competition constraints requiring senior coaching staff to modify the prescribed training programme.

Despite these limitations, this study provides evidence to suggest that performing isoinertial resistance training within specific VBT zones across different loading spectrums may be an effective training stimulus to improve the neuromuscular strength and power characteristics in professional rugby league players when compared to TPT methods. Whilst further research is needed, with a greater sample size, the results observed for the VBT group are in agreement with previous research that have suggested VBT may be an effective complementary resistance training method for improving neuromuscular strength and power performance (Gonzalez-Badillo et al., 2014; Padulo et al., 2012; Pareja-Blanco et al., 2014). In addition, the present findings are similar to those reported by Pareja-Blanco and colleagues (2014) who demonstrated a significant improvement in measures of CMJ height (+8.9%, ES: 0.63, $p < 0.001$) and 1RM back squat dynamic performance (+18%, ES: 0.94, $p < 0.001$) following 6-weeks of maximal intended concentric velocity training utilizing the back squat exercise.

The tangible improvements in neuromuscular strength and power performance after the 5-week VBT protocol may be attributed to a combination of muscular morphological, molecular and neural factors that may influence adaptation at the skeletal muscle level and further investigation is warranted in this area. However, it cannot be discounted that the observed improvements in strength and power performance may have been influenced by the greater total training loads performed by the VBT group as greater training loads affect the mechanical and metabolic stresses that are believed to influence and shape the magnitude of strength and power adaptations (Mangine et al., 2015; Moritani, 1993; Ratamess et al., 2009). A unique and important aspect of this investigation was that the magnitude of training volume (sets, reps, intended intensity and rest) were kept identical for both the VBT group and TPT group (Table 9). In contrast, the training loads executed per session differed between groups as the TPT group performed loads based off their previous 1RM whilst the VBT group performed an autoregulatory type programme whereby the performed loads were determined by a target velocity zone prescribed for each load spectrum.

Despite all participants being exposed to the same training volume in terms of sets and reps, the actual total tonnage of the VBT group for the bench press (+5.1%), back squat (+3.1%) and power clean (+7.1%) exercises were higher when compared to intended values based off TPT methods. Interestingly, although the VBT group performed greater total actual tonnage for the bench press, back squat and power clean exercises, no substantial variances were reported in session RPE values between both groups (Figures 9 – 11). This is in agreement with Hatfield and colleagues (2006) who demonstrated that performing the shoulder press and back squat exercises at higher movement velocities elicited more repetitions, higher peak power and volume load between 60-80% 1RM whilst no significant differences were reported in session RPE when compared to the slow velocity training group. Based on these findings it can be suggested that VBT may provide an alternative strategy in autoregulating training volume and load when compared to the autoregulatory progressive resistance exercise (APRE) and RPE methods (Day et al., 2004; Mann et al., 2010; McGuigan et al., 2004b; Singh et al., 2007). That is, performing resistance training within specific VBT zones can be used to individualize daily training volume and load both within and between sets when compared to the APRE and RPE methods that require practitioners to wait until a training set or session has been completed before making necessary adjustments. This means that performing resistance training within specific VBT zones may aid in identifying daily optimal training loads for a pre-selected training intensity that is sensitive to an athlete's daily fluctuations in maximum strength and readiness to train. In addition, it appears that the VBT group were able to train closer to the intended focus of the assigned light, moderate and, heavy intensity training weeks (i.e. their RPE's were higher in the heavy intensity training weeks and lower in the light intensity training weeks) when compared to the TPT group. Therefore, VBT may improve the quality of work or effort performed in each training session and may provide advantages in allowing athlete's to improve strength and power performance at their own rate.

Consequently, VBT may provide strength and conditioning practitioners with an efficient strength and power training periodization model that will allow athlete's to maintain maximal lifting velocities throughout strength and power training phases. Furthermore, the observations of the researcher during the training period in the VBT group revealed an enhanced level of competitiveness and motivation as a result of the immediate feedback regarding movement velocity. Thus, the competitive training environment may have also influenced the improvements in strength and power performance observed in the present study. The observations of the researcher are in agreement with Randell and colleagues (2011) who demonstrated that the immediate knowledge of velocity achieved for every repetition during the jump squat exercise significantly improved CMJ (4.6%), horizontal jump (2.6%) and 10-30-meter sprint performance (0.9–1.4%) in professional rugby players. In addition, Mann and colleagues (2015) also corroborate the researchers' observations with their own experiences.

It has been suggested that optimal adaptation to a prescribed resistance training stimulus depends on the appropriate selection of an overload stimulus based on the neuromuscular systems susceptibility to change (Cormie et al., 2011). However, the control of the actual training volume (i.e. sets x reps x intended intensity) performed by the two groups enabled us to isolate the influence movement velocity has on the observed neuromuscular strength and power changes. With this in mind, the present results indicate that the actual movement velocity achieved, as controlled by load, across different loading spectrums is a vital stimulus for improving velocity specific neuromuscular performance capabilities and possible neural adaptations (Behm & Sale, 1993; McBride et al., 2002). Previous research has found similar findings whereby performing high velocity movements provided velocity specific adaptations in improved peak force, peak power, peak velocity, muscular electrical activity, RFD and rate of neural activation (Anderson et al., 2006; de Oliveira et al., 2013; Hakkinen et al., 1985; Jones et al., 2001; McBride et al., 2002; Tillin et al., 2012). Additionally, placing emphasis on producing high velocity movements across a range of loading intensities, rather than producing maximal force has been suggested to induce greater improvements in neuromuscular strength and power performance (Jones et al., 2001).

In terms of Sal-C responses, performing resistance training within specific VBT zones elicited less Sal-C training stress during light (+12.8 vs. +52.3%) and heavy (+98.9 vs. +472.6%) intensity training weeks when compared to the TPT group. However, Sal-C training stress elicited between each resistance training method during moderate intensity training weeks remains indefinite with decreases in Sal-C response observed post training. In addition, although the VBT group performed greater total tonnage during light, moderate and heavy intensity training weeks, Sal-C response remained lower than the TPT group who performed less total tonnage across all training weeks (Figures 9 - 12). These results are in contrast to previous research that have suggested Sal-C, as a stress hormone increases more after the execution of greater volume protocols that are associated with higher metabolic stress when compared with lower volume protocols (Crewther et al., 2011a; McCaulley et al., 2009; Smilios et al., 2003).

When tracking Sal-C response during light, moderate and heavy intensity training weeks alongside psychological wellness questionnaire monitoring, the VBT group reported higher weekly psychological wellness questionnaire scores and remained 12.7 points above the set threshold of 25 points for the light intensity training week, 10.5 points for the moderate intensity training week and 10 points for the heavy intensity training week. This is greater than the TPT group who reported lower wellness points above the set threshold of 10.5 points for the light intensity week, 4.5 points for the moderate intensity training week and 4 points for the heavy intensity training week. With this in mind, the present results suggest that the VBT protocol may have been effective in enhancing neuromuscular recovery between training sessions and may have limited the accumulation of metabolic by products and controlled the extent of neuromuscular fatigue by taking into account participants daily biological status and readiness to train (Jovanovic et al., 2014; Sanchez-Medina et al., 2011). In addition, by using movement velocity as a type of autoregulatory training control, the physiological stress responses to resistance training appears to be attenutaed (i.e. decreased Sal-C stress response and greater psychological wellness questionnaire scores).

4.6 Conclusions

The present investigation provides preliminary data that supports further research into performing isoinertial resistance training within specific VBT zones across different loading spectrums in enhancing neuromuscular strength and power adaptations in professional rugby league players. This form of resistance training appears to facilitate tangible improvements in neuromuscular strength and power performance over a five-week concurrent training and competition period. Thus, the use of specific VBT zones for upper and lower body strength and whole body power exercises appear to provide advantages in optimizing the development of specific skeletal muscle performance traits that include starting strength, speed-strength, strength-speed, accelerative strength, and absolute strength/power that effect different portions of the force-velocity curve. In addition, movement velocity may provide a novel method in autoregulating the total volume load lifted in a resistance training session by ensuring athletes remain within a target velocity zone. Consequently, this will allow strength and conditioning practitioners to accurately prescribe daily training loads whilst improving training efficiency by determining whether the prescribed intensity (%1RM) and load (kg) for a given exercise truly represents the intended focus of a resistance training session. Finally, the acute Sal-C responses pre and post training and its relation to weekly psychological wellness questionnaire scores, suggests VBT elicits less training stress and limits the accumulation of metabolic by products and controls the extent of neuromuscular fatigue. Therefore, VBT may provide strength and conditioning practitioners with a novel and effective complementary resistance training method to improve strength and power adaptations whilst enhancing training efficiency in professional athletes with further investigation warranted. In addition, monitoring movement velocity alongside psychological wellness questionnaires provides a simple and non-invasive method to determine the extent of psychological and neuromuscular fatigue incurred during the in-season competition phase.

When interpreting the current results, it is important to acknowledge the limitations that are associated with the single subject case study research design. Firstly, as only professional rugby league players participated in the current investigation the results cannot be generalized to amateur players. In addition, due to the fact the study was conducted in a contact sport, competition and field-based training induced minor injuries may have hindered strength and power improvements. Furthermore, as the conclusions are based on standard statistical methods of means ± SD and percentage change, we acknowledge that the current results have a high degree of variability based on individual and group interpretation. Therefore, it is important that future research use traditional null hypothesis testing (t-tests), statistical correlation testing, effect sizes and larger sample sizes.

Due to in-season competition constraints, the training loads performed by the TPT group were prescribed off previous 1RM values for the bench press, back squat and power clean exercises that was obtained within a four-week period prior to the commencement of the study. Ideally, pre-intervention 1RM testing would have been completed immediately prior to the commencement of the study to ensure an accurate prescription of the training loads. However, as previously mentioned, the degree of variability in an athlete's daily maximum strength and readiness to train (Gonzalez-Badillo & Sanchez-Medina, 2010) may have not necessarily represented each participant's true maximum strength and power capabilities.

It must be recognised that any mechanisms driving the observed improvements in neuromuscular strength and power adaptations can only be theorized since alterations in muscular morphology and nervous system adaptations were not assessed and is consequently a limitation of the present investigation. However, the current investigation did manage to identify the efficacy of VBT as a simple and effective training method in an applied practical setting and the duration of the training cycle is a representation of a realistic strength and power cycle in which professional athletes are exposed to during in-season competition phases. Future VBT studies should look to analyse the muscular morphological and nervous system adaptations associated with this modality of training over extended training periods to determine its influence on enhancing neuromuscular strength and power adaptations in elite sport settings.

Whilst the use of saliva collection for subsequent analysis of cortisol is a non-invasive and practical method to determine resistance training stress in the current population, it must also be recognised that the concurrent training methods employed in the current investigation may have produced variations in Sal-C concentrations and induced measurement error. In addition, it is possible that the cortisol responses may have been influenced by the high impact nature of rugby league training and competition. Therefore, future studies should look to investigate the hormonal responses to VBT under controlled conditions to determine the influence VBT has on both anabolic and catabolic hormone responses and its role in neuromuscular strength and power adaptations.

4.7 Practical applications

VBT may provide strength and conditioning practitioners with an effective complementary resistance training modality in enhancing neuromuscular strength and power adaptations in professional athletes. This training modality may be suited to both pre-season and in-season competition training phases and may be of particular interest to strength and conditioning practitioners who are not solely concerned with developing maximal strength but may also be interested in velocity specific strength and power adaptations across different load spectrums. Consequently, VBT may complement TPT methods by overcoming its shortcomings by ensuring the accurate prescription of daily strength and power training loads as opposed to arbitrarily prescribing training loads based off an athlete's pre-training block 1RM value. This approach will optimize the intended focus of a resistance training session and may also provide motivational and competitive advantages within elite sport settings which research has suggested to be associated with positive strength and power adaptations (Randell et al., 2011). In addition, performing isoinertial resistance training within specific VBT zones is a novel approach that allows the autoregulation and individualization of both training volume and intensity both within and between sets that is sensitive to daily fluctuations in biological status and readiness to train. Therefore, VBT may aid in fatigue monitoring and reduce hormonal training stress typically associated with resistance training. However, a limitation of incorporating VBT in a practical setting is the expense of a LPT (i.e. Gymaware) that may make VBT impractical for some athletes and practitioners. Therefore, alternatives such as free mobile phone applications (e.g. Barsense and Bar Sensei) may make VBT easier and more affordable to apply in practical settings.

CHAPTER FIVE: GENERAL SUMMARY

5.1 Summary

The design and implementation of resistance training programmes in semi-professional rugby union and professional rugby league players have for decades utilized TPT methods to improve neuromuscular strength and power performance at various percentages of 1RM. However, movement velocity is a variable that is gaining great interest among strength and conditioning practitioners to achieve specific strength and power performance outcomes. To the best of our knowledge, no study to date has investigated the velocity profiles of semi-professional rugby union and professional rugby league players across different loading spectrums for the bench press, back squat and power clean exercises. In addition, no studies have investigated the influence of performing resistance training within specific VBT zones and its subsequent effect on neuromuscular strength and power adaptations. Therefore, this Master's thesis sought to investigate the overarching question of, "what is the influence of utilizing specific VBT zones across different load spectrums as a means to optimize the development of strength and power adaptations in semi-professional rugby union and professional rugby league players?"

The major conclusions of this thesis are that unique VBT zones exist for the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players. In addition, utilizing specific VBT zones for upper body and lower body strength and whole body power exercises across different load spectrums is an effective training modality to enhance neuromuscular strength and power performance whilst limiting the psychological and physiological stress response in professional rugby league players.

The first aim of this thesis was formulated due to the paucity of literature that currently exists in examining the velocity profiles of semi-professional rugby union and professional rugby league players across various loading spectrums. In addition, there was limited literature regarding the identification of optimal velocity training zones to enhance the development of neuromusuclar strength and power performance. As such, the first experimental study in this thesis (Chapter three) sought to examine the velocity profiles of semi-professional rugby union and professional rugby league players during the bench press, back squat and power clean exercises across different loading spectrums between 20-95% 1RM. The findings of this investigation revealed that unique VBT zones exist for loads lifted between 20-95% 1RM for the bench press, back squat and power clean exercises in semi-professional rugby union and professional rugby league players.

Specifically, rugby union and rugby league players are able to maximize bench press starting strength > 1.40 $m.s^{-1}$, speed-strength between 0.90-1.35 $m.s^{-1}$, strength-speed between 0.60-0.80 $m.s^{-1}$, accelerative strength between 0.30-0.65 $m.s^{-1}$ and, absolute strength < 0.20 $m.s^{-1}$. Additionally, back squat performance can be maximized for starting strength > 1.00-1.20 $m.s^{-1}$, speed-strength between 0.70-1.05 $m.s^{-1}$, strength-speed between 0.60-0.75 $m.s^{-1}$, accelerative strength between 0.50-0.70 $m.s^{-1}$ and, absolute strength < 0.35 $m.s^{-1}$. Furthermore, power clean performance can be maximized for starting strength > 2.80-3.00 $m.s^{-1}$, speed-strength between 2.50-2.85 $m.s^{-1}$, strength-speed between 2.35-2.40 $m.s^{-1}$, accelerative strength between 2.05-2.30 $m.s^{-1}$ and, absolute power < 1.90 $m.s^{-1}$. These results support the findings of Gonzalez-Badillo and Sanchez-Medina (2010) who demonstrate that that an inextricable relationship exists between relative load and the movement velocity that is attained during resistance training with loads performed between 30% to 95% 1RM and that each percent of 1RM loading intensity has it own unique velocity training zone (Gonzalez-Badillo & Sanchez-Medina, 2010). In addition, it was identified that subtle differences in velocities achieved for each exercise exist between each code and that potential differences exist between positional groups within each code. However, further investigation is needed with a larger sample size in order to make comparisons between and within codes possible. The proposed VBT zones may provide key advantages in the design of resistance training programmes by focusing on enhancing specific skeletal muscle performance traits within a periodized strength and power resistance training programme. Subsequently, it was concluded that by utilizing the suggested VBT zones, strength and power performance can be maximized by allowing strength and conditioning practitioners to accurately prescribe training loads based on an athlete's ability to maintain a prescribed movement velocity.

The second aims of this thesis was to; 1) develop a better understanding of the specific VBT zones identified in Study one as a training stimulus to elicit subsequent strength and power adaptations in professional rugby league players and, 2) examine and compare the psychological wellbeing and salivary cortisol stress response between VBT and TPT programmes to determine if VBT induces the same psychological and physiological stress response as TPT methods in professional rugby league players. As such, the second experimental study in this thesis (Chapter four) employed a 5-week training intervention and utilized a single subject case study design where five professional rugby league players were randomly assigned to the either the VBT group (n = 3) or TPT group (n = 2). Substantial improvements in CMJ and SJ performance were observed in the VBT group participant’s. In addition, greater increases in training load were performed by the VBT group when compared to the intended values based off traditional percentage based methods whilst no change was observed in the TPT group. Furthermore, although the VBT group performed greater training loads, no substantial variance in reported session RPE values were observed between both groups. A novel finding of this investigation was that the VBT group reported higher weekly wellness questionnaire scores and elicited less Sal-C training stress during light (+12.8 vs. +52.3%) and heavy (+98.9 vs. +472.6%) intensity training weeks when compared to the TPT group. These results suggest that VBT allows greater training volumes to be performed without incurring excessive perceived internal load. In addition, VBT allows for enhanced neuromuscular recovery between training sessions as determined by the VBT participants’ greater perceived psychological wellness scores and optimized readiness to train. Thus, it is supported that performing isoinertial resistance training within specific VBT zones across different loading spectrums is an effective training stimulus to enhance neuromuscular strength and power adaptations whilst enhancing training efficiency in professional rugby league players during the in-season competition phase.

5.2 Future research

The studies in this thesis have provided a deeper insight into VBT facilitating greater improvements in strength and power performance when compared to TPT methods during the in-season competition phase in professional rugby league players. These findings have also highlighted potential avenues for future research that may continue to develop our understanding of how VBT may be an effective complementary resistance training method to enhance neuromuscular strength and power performance in semi-professional rugby union and professional rugby league environments.

Future research into the influence VBT has on enhancing neuromuscular strength and power adaptations in semi-professional rugby union and professional rugby league players should include the effect of this training modality during the pre-season preparation period. This period usually lasts four months during which time the greatest training volumes and loads are incurred which typically results in the greatest improvements in strength and power capabilities. Knowledge of the magnitude VBT has on not only enhancing neuromuscular strength and power performance but also limiting the accumulation of excessive metabolic by products and neuromuscular fatigue during both pre-season and in-season phases in semi-professional rugby union and professional rugby league players may have important practical applications to ensure strength and power capabilities are maintained or enhanced throughout pre-season and in-season training phases.

Future research should also employ similar methods of testing and training to the current interventional studies along with examining the velocity profiles of additional key lifts such as the push press and bent over row and/or derivatives of Olympic lifts such as clean pulls and snatch pulls. In addition, future research should look to examine and compare the velocity profiles between rugby union and rugby league positional groups with larger sample sizes. It is recommended that rugby union and rugby league players have a sound degree of the technical skill and knowledge of the prescribed exercises before employing the recommended testing and training protocols. In addition, the technical ability of the rugby union and rugby league players should be similar to those used in this thesis to allow for a comparsion of the results.

Tracking the velocity specific intrinsic skeletal muscle adaptations of rugby union and rugby league players should include habitual assessment over training blocks that will provide advantages in assessing an athlete's progress over a spectrum of velocity demands and determine the efficacy of a prescribed strength and power training stimulus. For example, although an athlete's 1RM value may have not improved following a period of strength and power training, skeletal muscle velocity capabilities may have improved at various submaximal loads. Finally, by examining the muscle architectural responses and adaptations to VBT a better understanding of the specific neuromuscular strength and power adaptations to VBT will be gained.

5.3 Practical applications

The interventional studies in this thesis were designed to enhance resistance training prescription and to provide strength and conditioning practitioners with alternative resistance training strategies to improve neuromuscular strength and power performance in semi-professional rugby union and professional rugby league environments.

The velocity profiling information presented in Chapter three has provided a unique understanding of the specific VBT zones that may optimize neuromusuclar strength and power performance for the bench press, back squat and power clean exercises across different load spectrums of 20-95% 1RM in semi-professional rugby union and professional rugby league players. The findings of this investigation provide strength and conditioning practitioners with important information to enhance the quality of work or effort performed by an athlete during a resistance training session. In addition, the suggested VBT zones allow strength and conditioning practitioners to prescribe accurate training loads based on an athlete's ability to maintain a prescribed movement velocity that will consequently optimize the development of the intended skeletal muscle performance trait that includes; starting strength, speed-strength, strength-speed, accelerative strength and absolute strength/power.

Chapter four demonstrates that performing isoinertial resistance training within specific VBT zones across different loading spectrums is an effective training stimulus to enhance neuromuscular strength and power adaptations in professional rugby league players. Strength and conditioning practitioners can utilize a VBT approach that includes utilizing velocity zones or velocity stops rather than percentages of 1RM. This method provides numerous advantages, such as prescribing training loads that are sensitive to daily fluctuations in maximum strength and readiness to train during in-season strength and power training blocks. Combining both velocity zones and velocity stops allows for the autoregulation of daily training volume and load both within sets and between sets which may limit excessive neuromuscular fatigue. Consequently, this will allow maximal lifting velocities to be maintained throughout training blocks where subsequent neuromuscular strength and power performance can be enhanced during short in-season strength and power training phases. Furthermore, a VBT approach will enhance training efficiency and the immediate knowledge of movement velocities achieved for a given exercise will provide motivational and competitive advantages which research has suggested to be associated with positive strength and power adaptations.

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APPENDICES

Appendix 1: Study one velocity profiling tables

Table 1: Rugby union forwards and backs bench press peak and mean velocity ($m.s^{-1}$) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	**PV**	2.32 ± 0.29	1.91 ± 0.18	1.46 ± 0.17	1.03 ± 0.17	0.73 ± 0.11*	0.65 ± 0.13	0.57 ± 0.13	0.52 ± 0.12	0.46 ± 0.10
	MV	1.48 ± 0.19	1.28 ± 0.13	1.02 ± 0.11	0.75 ± 0.10	0.54 ± 0.08*	0.46 ± 0.08	0.37 ± 0.10*	0.28 ± 0.09	0.22 ± 0.07*
Backs	**PV**	2.17 ± 0.25	1.88 ± 0.13	1.44 ± 0.12	1.05 ± 0.10	0.86 ± 0.13*	0.73 ± 0.13	0.65 ± 0.13	0.58 ± 0.16	0.53 ± 0.11
	MV	1.41 ± 0.19	1.25 ± 0.12	1.02 ± 0.10	0.79 ± 0.09	0.64 ± 0.10*	0.53 ± 0.10	0.45 ± 0.11*	0.34 ± 0.11	0.30 ± 0.11*

PV = Peak Velocity ($m.s^{-1}$), MV = Mean Velocity ($m.s^{-1}$), * = $p < 0.05$

Table 2: Rugby union forwards and backs back squat peak and mean velocity ($m.s^{-1}$) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	**PV**	1.64 ± 0.45	1.59 ± 0.43*	1.45 ± 0.33*	1.27 ± 0.30	1.12 ± 0.28	1.07 ± 0.25	1.03 ± 0.25	0.97 ± 0.23	0.93 ± 0.25
	MV	1.00 ± 0.26	0.96 ± 0.23	0.85 ± 0.16*	0.71 ± 0.14	0.59 ± 0.12	0.54 ± 0.11	0.50 ± 0.12	0.43 ± 0.10	0.40 ± 0.10
Backs	**PV**	1.47 ± 0.43	1.34 ± 0.39*	1.17 ± 0.37*	1.02 ± 0.38	0.97 ± 0.25	0.92 ± 0.26	0.90 ± 0.17	0.87 ± 0.26	0.84 ± 0.22
	MV	0.87 ± 0.29	0.81 ± 0.27	0.70 ± 0.21*	0.61 ± 0.19	0.55 ± 0.12	0.51 ± 0.10	0.49 ± 0.07	0.44 ± 0.09	0.39 ± 0.11

PV = Peak Velocity ($m.s^{-1}$), MV = Mean Velocity ($m.s^{-1}$), * = $p < 0.05$

Table 3: Rugby union forwards and backs power clean peak and mean velocity ($m.s^{-1}$) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	PV	2.99 ± 0.67	2.77 ± 0.43	2.58 ± 0.31	2.35 ± 0.16	2.19 ± 0.18	2.19 ± 0.09	2.11 ± 0.11	2.02 ± 0.17	1.98 ± 0.13
	MV	1.44 ± 0.49	1.36 ± 0.51	1.29 ± 0.25	1.23 ± 0.24	1.15 ± 0.25	1.11 ± 0.22	1.16 ± 0.19	0.90 ± 0.43	1.05 ± 0.18
Backs	PV	2.85 ± 0.28	2.61 ± 0.65	2.60 ± 0.14	2.37 ± 0.17	2.30 ± 0.17	2.16 ± 0.16	2.07 ± 0.12	2.05 ± 0.19	1.87 ± 0.25
	MV	1.22 ± 0.32	1.19 ± 0.33	1.21 ± 0.25	1.13 ± 0.25	1.09 ± 0.25	0.99 ± 0.23	0.95 ± 0.21	0.95 ± 0.20	0.87 ± 0.21

PV = Peak Velocity ($m.s^{-1}$), MV = Mean Velocity ($m.s^{-1}$), * = $p < 0.05$

Table 4: Rugby league forwards and backs bench press peak and mean velocity ($m.s^{-1}$) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	PV	2.08 ± 0.24	1.73 ± 0.22	1.25 ± 0.90	0.78 ± 0.11	0.60 ± 0.03	0.53 ± 0.09	0.49 ± 0.15	0.41 ± 0.19	0.48 ± 0.17
	MV	1.35 ± 0.17	1.16 ± 0.12	0.90 ± 0.09	0.62 ± 0.10	0.42 ± 0.05	0.34 ± 0.04	0.29 ± 0.05	0.20 ± 0.10	0.21 ± 0.03
Backs	PV	2.03 ± 0.52	1.92 ± 0.41	1.63 ± 0.44	0.92 ± 0.15	0.69 ± 0.42	0.42 ± 0.08	0.43 ± 0.17	0.43 ± 0.17	0.32 ± 0.07
	MV	1.40 ± 0.45	1.35 ± 0.32	1.01 ± 0.19	0.68 ± 0.10	0.38 ± 0.12	0.30 ± 0.08	0.24 ± 0.09	0.24 ± 0.09	0.19 ± 0.02

PV = Peak Velocity ($m.s^{-1}$), MV = Mean Velocity ($m.s^{-1}$), * = $p < 0.05$

Table 5: Rugby league forwards and backs back squat peak and mean velocity (m.s^{-1}) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	**PV**	1.98 ± 0.27	1.72 ± 0.18	1.51 ± 0.12	1.27 ± 0.08	1.02 ± 0.10	1.00 ± 0.15	0.97 ± 0.15	0.91 ± 0.16	0.87 ± 0.13
	MV	1.19 ± 0.14	1.03 ± 0.08	0.89 ± 0.09	0.74 ± 0.05	0.56 ± 0.03*	0.53 ± 0.08	0.48 ± 0.07	0.42 ± 0.08	0.33 ± 0.09
Backs	**PV**	1.65 ± 0.18	1.55 ± 0.17	1.45 ± 0.17	1.29 ± 0.14	1.19 ± 0.14	1.06 ± 0.13	1.01 ± 0.10	0.98 ± 0.11	0.94 ± 0.15
	MV	1.01 ± 0.13	0.94 ± 0.07	0.83 ± 0.09	0.73 ± 0.07	0.66 ± 0.04*	0.60 ± 0.08	0.53 ± 0.05	0.51 ± 0.04	0.48 ± 0.07

PV = Peak Velocity (m.s^{-1}), MV = Mean Velocity (m.s^{-1}), * = $p < 0.05$

Table 6: Rugby league forwards and backs power clean peak and mean velocity (m.s^{-1}) for each % of 1RM

%1RM		20%	30%	45%	60%	75%	80%	85%	90%	95%
Forwards	**PV**	3.02 ± 0.15*	2.88 ± 0.19	2.69 ± 0.11	2.39 ± 0.14	2.24 ± 0.10*	2.15 ± 0.08	2.06 ± 0.10	1.96 ± 0.14	1.91 ± 0.12
	MV	1.73 ± 0.14	1.44 ± 0.24	1.24 ± 0.29	1.08 ± 0.31	1.02 ± 0.21	0.96 ± 0.22	0.98 ± 0.20	1.05 ± 0.17	1.02 ± 0.16
Backs	**PV**	2.64 ± 0.15*	2.71 ± 0.08	2.52 ± 0.22	2.35 ± 0.12	2.07 ± 0.04*	2.04 ± 0.04	1.98 ± 0.07	1.92 ± 0.06	1.96 ± 0.22
	MV	1.52 ± 0.13	1.57 ± 0.18	1.37 ± 0.12	1.30 ± 0.06	1.13 ± 0.04	1.09 ± 0.04	1.06 ± 0.18	1.03 ± 0.15	1.02 ± 0.24

PV = Peak Velocity (m.s^{-1}), MV = Mean Velocity (m.s^{-1}), * = $p < 0.05$

Appendix 2: Participant information sheet

Participant Information Sheet

Date Information Sheet Produced: 20.01.15

Project Title

The influence of velocity based resistance training on neuromuscular strength and power adaptations in semi-professional rugby union and professional rugby league players.

An invitation to participate:

Hi, my name is Gurdeep Singh and I am currently a strength and conditioning intern with the New Zealand Vodafone Warriors franchise. I am also 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. Gurdeep Singh and supervised by Dr. Adam Storey and Associate Professor Nic Gill. Participation in this study is completely voluntary and any decision to participate or not participate it is entirely your own decision. If you decide you no longer want to participate in the study you are free to withdraw yourself or any information that you have provided for this research study at any time prior to the completion of the data collection process without being disadvantaged in anyway. 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.

What is the purpose of this research:

Traditional percentage-based training is commonly used to prescribe the total load and intensity of the load lifted in a set or session which is based off an athlete's percentage of maximum (1RM). However, this method often overlooks the velocity component of an exercise which is a critical factor in developing functional strength and power performance.

Significant improvements in sport specific sprinting and jumping performance have been shown to occur following velocity based training (VBT) as well as improvements in strength and power production capabilities. The enhancements in performance are likely due to resistance training being performed at velocities that provide increased selective activation of fast twitch muscle fibres. Consequently, this may lead to increased muscle contraction velocities and peak power outputs which can have a positive influence on sport specific tasks such as sprinting and jumping. Additionally, velocity based training may enhance the anabolic response for strength and power adaptation by creating a desirable hormonal environmental response.

At present, there is a lack of specific research that has investigated the influence of VBT in providing subsequent improvements in strength and power performance Therefore, the primary purpose of this study is to develop a better understanding of specific VBT zones performed across different load spectrums as a training stimulus to elicit subsequent strength and power adaptations in professional rugby union and rugby league players. The secondary aim is to examine and compare the hormonal responses between VBT and traditional percentage-based training programmes in professional rugby league and union players.

These findings will contribute towards a Master's degree and will be presented in a thesis and journal-article format which may also include conference presentations.

Am I eligible to participate?

You are eligible to participate in this study if you are; 1) a professional male rugby league or rugby union player aged 18-30 years, 2) have no current acute or chronic injuries or medical conditions, 3) involved in a high performance resistance training programme for ≥ 2 years, 4) appropriate joint mobility to perform the bench press, back squat and power clean movements with appropriate technique, 5) are not using any performance enhancing or banned substances as per the World Anti-Doping Agency Code (2015) and 6) free from any saliva borne infectious diseases.

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 training session. During the familiarisation session all participants will perform a series of submaximal lifts for the bench press, back squat and power clean exercises 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. Adequate familiarisation will be provided prior to the commencement of the first training session with the total familiarisation session lasting approximately 30 minutes for each participant.

Testing Session:

The pre and post testing sessions will include quantitative measures of strength and power including the assessment of a one repetition maximum (1RM) for the bench press, back squat and power clean exercises along with a maximal countermovement jump test and a 40m sprint test. The pre testing will be conducted one week prior to the commencement of the first training session and post testing will be conducted three days after the cessation of the 6-week training intervention. All testing sessions will take approximately 1 hour.

Training

Once you have completed the familiarisation and testing session, you will be randomly assigned (verbally and in written form) to a traditional percentage-based training (TPB) group (control) or a velocity based training (VBT) group (experimental). All participants will be required to perform 4 supervised training sessions of approximately 90min duration per week across the 6-week intervention period. Both the TPB and VBT groups will perform movement-matched upper and lower body strength exercises (i.e. bench press and back squat) and a whole body power exercise (i.e. power clean) throughout the 6-week intervention. Furthermore, both groups will be volume (i.e. sets, reps and rest period) matched. However, the training loads lifted per session between groups may differ as the TPB group will perform prescribed loads based off a percentage of their 1RM (i.e. 85-95% 1RM for strength movements and 45-75% 1RM for power movements). Conversely, the training loads that are prescribed for the VBT group will be determined by the target velocity zone ($m.s^{-1}$) that will be prescribed for each load spectrum (i.e. velocity at 85% 1RM for strength movements and velocity at 60% 1RM for power movements). Each training week will be characterized by a linear increase in intensity whilst a decrease in volume (sets and reps) will differentiate light, moderate and heavy training weeks. Additionally, you will be required to provide a salivary sample 15 minutes pre training and within 15 minutes post training. Pre training salivary collection will require you to; 1) refrain from eating, drinking or using oral hygiene products for at least 30 minutes prior to the collection, 2) rinse your mouth out well with distilled water for at least one minute and will then spit out or swallow the water, 3) wait five minutes following the oral rinse, and 5) drool into a 50mL sterile tube until a 2mL sample is provided. The post training salivary collection will be performed in the same fashion as the pre testing sample collection procedure. Between training sessions, you may continue with your coach specific skills and cardiovascular conditioning sessions. However, you must refrain from performing any other resistance training outside the prescribed programme.

What are the discomforts and risks?

You will be asked to perform submaximal (light to moderate intensity) and maximal (heavy intensity) resistance training during the 6-week intervention data collection period and therefore may experience some discomfort for a short period of time during each training session. However, the intensity of the resistance training will be similar to what is experienced during your usual training programme.

How will these discomforts and risks be alleviated?

Being an professional athlete who regularly performs resistance training and is familiar with the high training intensities performed on a daily basis, the resistance exercise intensities prescribed will be similar to what you experience in a typical training day and week. If you are experiencing discomfort at any stage during the training intervention you are encouraged to inform the researcher supervising the session at the time in order 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 feel comfortable at all times throughout the process.

What are the benefits?

Participants will gain a personalised athletic profile regarding their 1RM, peak power and peak velocity performance for the bench press, back squat and power clean exercises as well as their individual hormonal response to resistance training. New knowledge for researchers and practitioners will be gained as we look to determine if velocity based training can influence improvements in strength and power performance to a greater extent when compared to traditional percentage-based training. The wider professional sporting community will be educated as to the differences between traditional percentage-based training and velocity based-training. This could lead to education regarding exercise prescription for athletes during strength and power training phases in New Zealand.

The results of this research are intended for publication and will contribute to part of my master's thesis and will also be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence

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

How will my privacy be protected

Your privacy will be protected at all times by the data being de-identified (i.e. coded numbers 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. However, following the cessation of the research study, the data collected throughout the study maybe passed onto coaches within your organisation, only once the research study is completed. The future use of the data collected from the research 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 (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 anonymity will be up held 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 2 hours towards pre and post testing and familiarisation sessions and 6 hours per week for 6 weeks for the training intervention.

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 up until the completion of data collection.

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 Gurdeep Singh.

Will I receive feedback on the results of this research?

Yes, participants will gain a personalised athletic profile regarding their 1RM, peak power and peak velocity performance for the bench press, back squat and power clean exercise. In addition, all participants will receive information regarding their individual hormonal response to resistance training. It is your choice whether you share this information with your coach or other people.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Primary Project Supervisor: Dr. Adam Storey, adam.storey@aut.ac.nz, 021 2124200.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher	**Gurdeep Singh** AUT-Millennium, 17 Antares Place, Mairangi Bay 02102878507 singh_g@hotmail.co.nz
Project supervisor	**Dr. Adam Storey** AUT-Millennium, 17 Antares Place, Mairangi Bay 0212124200 adam.storey@aut.ac.nz
Second research supervisor	**Associate Professor Nic Gill** AUT-Millennium, 17 Antares Place, Mairangi Bay nic.gill@aut.co.nz

Approved by the Auckland University of Technology Ethics Committee on 25/03/2015
AUTEC Reference number 15/15

Appendix 3: Consent form

Consent Form For use when laboratory or field-testing is involved.	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: The influence of velocity based resistance training on neuromuscular strength and power adaptations in semi-professional rugby union and professional rugby league players.

Project Supervisor: Dr. Adam Storey

Researcher: ***Gurdeep Singh***

Please tick each statement as they apply to you;

○ I have read and understood the information provided about this research project in the Information Sheet dated 20th January 2015.

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

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am a professional male rugby union or rugby league player aged 18-30 years.

○ I am not suffering from any current acute or chronic injuries and medical conditions.

○ I have been involved in a high performance resistance training programme for >2 years.

○ I am not using any performance enhancing or banned substances as per the 2015 World Anti-Doping Code.

○ I am aware that data collected throughout the research study maybe passed onto coaches within
my organisation, only once the research study is completed.

○ I am free from any saliva borne infectious disease.

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

○ I agree to take part in this research.

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

Participant's signature:

....

Participant's name:

....……………………………………………………………

Participant's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 25/03/2015 AUTEC Reference number 15/15

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

Appendix 4: Athlete psychological wellness monitoring form

Participant Wellness Questionnaire

Daily Neuromuscular, Endocrine and Mood States Questionnaire

Name: ______________________________ Date: ______________

	5	**4**	**3**	**2**	**1**
Fatigue	Very Fresh	Fresh	Average	More Tired Than Usual	Always Tired
Sleep Quality	Very Good	Good	Average	Poor	Very Poor
Muscle Soreness	Feeling Great	Feeling Good	Average	Change In Soreness Tightness	Very Sore and Tight
Stress Levels	Very Relaxed	Relaxed	Average	Feeling Stressed	Highly Stressed
Mood	Hard To Aggravate	Less Irritable Than Usual	Average	Fairly Easily Aggravated	Highly Irritable
Perceived Training/Playing Performance	Very Happy Performing Well	Satisfied With Performance	Average	Not Satisfied With Performance	Very Dissatisfied With Performance

Rate Any Muscle Soreness or Tightness

10	9	8	7	6	5	4	3	2	1	0

Fresh No Problems	Normal	More Symptoms Than Usual	Sudden Increase in Symptoms Over Past Week	Restricted By Tightness Or Soreness	Pain Interrupting Training or Playing

Rate Your Sleep Quality OVER THE PAST WEEK

10	9	8	7	6	5	4	3	2	1

Better Than Usual	Normal	Some Sleep Irregularity but Waking Refreshed	Poor Sleep and NOT Refreshed	Very Poor Overall Sleep

Total: …………/50

Approved by the Auckland University of Technology Ethics Committee on 25/03/2015 AUTEC Reference number 15/15