The Effect of Variable Resistance Training on Lower Limb Strength and Power Development: A Training Study

By

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Use of Thesis

Note to Reader

This thesis is presented in two main parts, the first being made up of a literature review and methods section (chapters two and three) and the second consisting of an experimental investigation (chapter four) which has been written specifically for publication in a peer review journal. The experimental design has been written and formatted according to the publication guidelines of which this paper has been submitted. Some information may appear to be repeated as a result of this format. However, this thesis fulfils the Waikato Institute of Technology's Master of Science (Sport and Exercise Science) guidelines for thesis submission.

Abstract

The ability to develop high levels of muscular strength and power is considered to be a critical component in many, if not most, sports. Because of this, new training methods are constantly being sought in an attempt to improve strength and power development. One such method is variable resistance training (VRT). This research aims to determine the effect of VRT on back squat one repetition (1RM) strength, vertical jump height and 30m sprint time.

Twenty male high school athletes (mean age 17.5 ± 0.7 years) were pair matched based on 1RM scores (predicted from 4RM). Subjects completed a five-week within-group standardised training programme, with the control group completing fixed load back squats and the experimental group completing variable resistance back squats (with the use of elastic bands). Pre- and post-training vertical jump height, predicted 1RM squat strength and 10m, 20m and 30m sprint speeds were measured.

The VRT group had greater increases in strength and vertical jump than the fixed load training group, with a moderate difference in pre- to post-training predicted 1RM (mean; ± 90% confidence limit; 7.0; ±6.1%) and a small difference in the within-group changes in vertical jump height (4.6; ± 5.4%) from pre- to post-training. VRT also produced a small difference (4.8; ±5.3%) in pre- to mid-training 1RM changes. All other changes were trivial or unclear.

Eleven male semi-elite athletes (mean age 19.9 ± 2.0 years) also participated in this research as a case study. Findings in this case study supported the effectiveness of VRT over fixed load training in improving back squat predicted 1RM strength, but

not vertical jump height or 30m sprint time. However, no findings in the semi-elite case study were statistically clear due to a lack of statistical power. Further research is required into the effects of this training technique on mature athletes.

This study also aimed to determine the level of regression that occurs in resistance afforded by elastic resistance bands as a result of repeated use. In order to ascertain the reliability of training loads used throughout the study, the resistance of each band was also measured at the mid-point and completion of the training study. This determined the rate of degradation that occurred to variable resistance elastic bands with use. Due to minor changes in the amount of variable resistance afforded by the bands after use, loading protocols were modified at the midpoint of training to reflect these changes.

This study has found that variable resistance training is an effective training tool in improving 1RM back squat strength and vertical jump height in mature high-school athletes. Preliminary research into the effect of VRT on semi-elite athletes also points to greater improvements in lower limb strength and vertical jump height when compared to fixed load training, although these findings are subject to further research. These results suggest that VRT is a useful training technique in lower body strength and power development in the vertical plane of movement. As such, VRT may be implemented with confidence into training programmes desiring to improve lower limb strength and vertical jump height.

Declaration

I hereby declare that the information presented in this thesis is the work of the author except where acknowledged in the text. This work has not been submitted either in whole or in part for credit toward any other degree at this or any other institute.

Caleb W. Dobbs

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Operational Definitions

Load:	The weight or force used to oppose a training movement, made up of fixed and/or variable resistance.
Variable Resistance:	A load that changes throughout a range of motion. This is commonly achieved with the application of elastic bands to a barbell causing increased elastic tension through the concentric phase of a movement. Additionally variable resistance may be achieved with the application of chains to a barbell.
Repetition Maximum:	The maximum load that a subject is able to lift over a set number of repetitions.
Fixed Load Training:	Traditional weight training utilising loads that do not change throughout a range of motion.

Variable Resistance Training (VRT):

Training utilising loads that change throughout a range of motion, typically increasing throughout the concentric phase of a movement and decreasing during the eccentric phase.

Mechanical Advantage: The accumulation of muscular force throughout a concentric movement. Although force production tends to be greatest over the mid phase of a muscular range of motion, the accumulated force and torque about a joint is greatest towards the end of the range of motion. As such, mechanical advantage is greatest towards the end of a concentric contraction.

CHAPTER ONE: INTRODUCTION

Background

There is a strong relation between strength, power and dynamic athletic performance (Baker & Nance, 1999; Kawamori & Haff, 2004; Tan, 1999). Therefore, the ability to develop high levels of muscular strength and power are critical components in many sporting activities (Kilduff et al., 2007). As a result of this, new training techniques are continually being developed in an attempt to improve strength and power adaptations in vivo. Research into the effects of new training techniques is valuable in determining the effectiveness and value of these techniques. One such method that has recently become popular is VRT (Ghigiarelli et al., 2009; McCurdy, Langford, Jenkerson & Doscher., 2008).

Variable resistance is a broad term used to describe loading techniques that provide changing loads throughout a movement and traditionally involves an increasing load during the concentric phase and decreasing load during the eccentric phase. The concept of variable resistant training is not new. As early as the 1940's experimentation with counter balances and pulley systems was being used to produce progressive resistance exercise. In the 1980's, pulley machines with changing radii were utilised as a type of variable resistance training (Keohane, 1986). Variations on machine-based variable resistance, such as the BowFlex® exercise machine, have also been developed.

As well as using more traditional mechanisms, variable resistance can also be produced through the use of elastic bands. Variable resistance training of this nature has been used in rehabilitation to provide controlled stretch and strengthening and to increase range of motion after trauma (Patterson, Stegink, Hogan & Nassif, 2001; Wallace, Winchester & McGuigan, 2006). The addition of chains to fixed load has also been utilised as a mechanism for producing variable resistance and has received some attention in previous literature (Ghigiarelli et al., 2009; McCurdy, Langford, Ernest, Jenkersin & Doscher, 2009). Recently, variable resistance has been applied to strength and power training in an attempt to obtain improved training adaptations (Wallace et al., 2006).

Even in the early stages of the development of VRT, it was theorised that variable resistance may be a more effective training stimulus than fixed load training, as fixed load training results in a period of deceleration once the inertia of a load is overcome early in the concentric phase of a movement (Keohane 1986). This deceleration occurs as a necessity to slow the momentum of a load to prevent it from being thrown. In contrast, many other sports specific training techniques such as jumping and ballistic movements produce a continuing increase in force throughout the concentric phase until the load is released (Ebben, Flanagan & Jensen, 2007; Welter & Bobbert, 2002). Variable resistance was designed to more closely reflect the length-tension relationship during a movement than traditional fixed load training (Kauhansen, Hakkinen, & Komi, 1989). The linear increase in load afforded by variable resistance bands is thought to closely match the increase in accumulated muscular force and increased torque about a joint throughout a concentric movement, and may allow for a greater period of activation (Mcmasters, Cronin, McGuigan, 2009; Wallace et al., 2006). Variable resistance is thought to provide an optimal load to be maintained throughout a greater range of motion and thus cause greater strength and power adaptations (Ebben & Jensen 2002; Faron, 1985; Ghigiarelli et al., 2009; Wallace et al., 2006).

It has been purported that training eccentrically at loads which exceed normal training thresholds allows for greater muscular adaptation to be developed (Higbie, Cureton, Warren & Prior, 1996). It has also been suggested that VRT may cause greater eccentric loading to occur by increasing the eccentric velocity and therefore the force needed to decelerate the load during this phase (Conlin, 2002; Cronin, McNair, & Marshall., 2003). Theoretically, there may be an additional advantage in using elastic tension which may not be relevant to the use of chains as a mechanism to provide variable resistance (Conlin, 2002; Cronin et al, 2003). However, in contrast to the purported benefits of VRT, it has also been suggested that variable resistance may be ineffective in producing strength adaptations, as reduced load at the end of an eccentric movement may not be an adequate stimulus to cause improvements in this range of movement (McCurdy et al., 2009).

Rationale for Investigation

Despite the theoretical benefits of VRT, limited scientific research exists in this field. Furthermore, much of the research that does exist has been acute in duration (Ghigiarelli et al., 2009) and is not uniformly supportive of the effectiveness of VRT (Ebben & Jensen 2002; Wallace et al., 2006). This is due, at least in part, to variations in methodological procedures. Although the body of longitudinal research into the effect of variable resistance as a training technique is growing (Cronin et al., 2003;

Ghigiarelli et al., 2009; McCurdy et al., 2009), much of this research is statistically inconclusive and more research is required in this field.

There are a number of theoretical advantages of variable resistance training as a tool for power development, including increasing load through the concentric phase of a movement and more closely reflecting muscular force production through a range of motion. However limited research in this field of study and the longitudinal research that exists, to date, has focussed on upper body movements (Ghigiarelli et al., 2009; McCurdy et al., 2009). In light of this, there is a need for further longitudinal research into the effect of variable resistance training in lower limb strength and power development.

Aim of Research

The aim of this research was to determine the effect that lower body variable resistance training had on practical strength and power measures, namely predicted one repetition max (1RM) back squat (predicted from four repetition max (4RM) back squat), vertical jump height and 30m sprint time.

Hypotheses

Based on previous work in the area it was hypothesised that:

1. Variable resistance back squat training will produce greater strength gains in comparison to fixed load back squat training.

2. Variable resistance back squat training will produce greater gains in vertical jump height and 30m sprint speed in comparison to fixed load back squat training.

CHAPTER TWO: LITERATURE REVIEW

Introduction

Muscular strength is a foundational prerequisite of muscular power (Tan, 1999). Furthermore, the relationship between power and dynamic athletic performance has been well established in prior research (Baker & Nance, 1999; Kawamori & Haff, 2004). As such, the ability to develop high levels of muscular strength and power are considered to be a critical component in many sporting activities (Kilduff et al., 2007). This is considered to be important regardless of the sport or predominant energy system, as critical sporting movements are often executed forcefully and quickly (Cormie, Mccaulley, Triplett & Mcbridge, 2006; Elliot, Wagner, & Chiu, 2007; Kraemer & Newton, 2000).

The ability to produce muscular power is a multi-faceted process and integrates a number of factors including strength (Kraemer & Newton, 2000), the stretch shorten cycle (Newton et al., 1997), rate of force development (Kraemer & Newton, 2000; Newton & Kraemer, 1994) and force development at high velocity (Newton & Kraemer, 1994). In an attempt to better understand these factors and improve training protocols to optimise power adaptations, numerous training techniques have been utilised and subsequently studied. These include the effect of resistance training with both heavy and light loads (Newton & Kraemer, 1994); ballistic exercise performance (Crewther, Cronin & Keogh, 2005; Cronin et al ., 2003; Kraemer & Newton, 2000); plyometric training (Fatouros et al., 2000; Luebbers et al., 2003); Olympic style weight training (Garhammer, 1993; Newton & Kraemer, 1994); the effect of combining these exercises and methods (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000) and training energy systems concurrently (Baker, 2001b). Furthermore, because of the importance of strength and power to a wide range of sports, new methods for improving strength and power are continually being sought (Wallace et al., 2006). One such method that has been recently developed is VRT (Wallace et al., 2006).

Traditionally during weight training, load is afforded by fixed loads that remain constant throughout a range of motion. However, VRT is designed to vary the load throughout a movement as the force required to move a load increases during the concentric phase (Ebben & Jensen, 2002; Wallace et al, 2006). The most common method of achieving this is by utilising variable resistance elastic bands or chains which increase the load through the concentric movement by increased stretch or increasing the number of links lifted off the ground respectively. It has been suggested that this allows an optimal load to be maintained consistently throughout the range of motion by increasing the load as mechanical advantage increases (Ebben & Jensen, 2002; Faron, 1985; Ghigiarelli et al, 2009; Wallace et al, 2006).

There are a number of theoretical advantages of VRT as a tool for strength and power development. Increasing the load through the concentric phase is thought to combine the benefits afforded from the increased range of acceleration associated with ballistic type training, while including the higher loads normally utilised in traditional resistance training (Wallace et al., 2006). This may cause a training stimulus that more closely reflects muscular force production through a range of motion, allowing for a more optimal muscular stimulus (Faron, 1985; Wallace et al, 2006). Furthermore, it has been suggested that the use of elastic tension provides a more rapid descent phase causing greater eccentric muscular contraction and improved strength adaptations (Conlin, 2002).

This review aims to outline the physiological basis of muscular movement in vivo and to explore the areas of power development which may be relevant to the purported effects of variable resistance training. As such, this review will outline factors affecting strength and power development in vivo and critically discuss the effect that variable resistance training may have in these processes. From this, a review of the theoretical differences in training stimulus that VRT produces in comparison to traditional fixed load training, and the effects that these differences may have on strength and power development, will be undertaken to help to draw conclusions on the effectiveness of VRT as a training technique.

Physiology of the Working Muscle

The accepted theory to explain muscular force development is the cross bridge theory (Wu & Herzog, 1999). This theory was originally outlined by Huxley and Niedergerke (1954) and Huxley and Hanson (1954). Since this time, through the application of improved research techniques and technology, new insights have been added to the basic theory as outlined by Huxley and associates (Lecarpentier, Chemla, Pourny, Blanc, & Coirault, 2001). There are still elements of muscular movement which this model struggles to explain, e.g. force depression following muscle shortening and why myosin molecules have two heads (Huxley, 2000; Wu & Herzog, 1999), and attempts are being made to refine the model to more accurately express the nature of the working muscle in vivo (Cha & Donowitz, 2008; Dykes & Wright, 2007; Mijailovich, Fredberg & Butler 1996; Wu & Herzog, 1999). However, it seems that the challenges to the cross bridging model concern improving the theory's ability to represent human muscular movement rather than being challenges to the premises that underpin this theory. Furthermore, the primary concepts of this theory have remained unchanged since its inception (Kraemer & Spiering, 2006).

According to the cross bridge theory, muscular force is produced by myofilament proteins, predominantly actin and myosin cross bridges. Actin and myosin proteins are located throughout muscle fibre and are arranged into individual contractile units of overlapping actin and myosin fibres known as sacromeres (Huxley & Hanson, 1954). Muscular force is produced as actin and myosin cross bridging causes myosin to slide over actin causing the sacromere to reduce in size. This is known as the sliding filament theory (Kraemer & Spiering, 2006; Rassier, MacIntosh & Herzog, 1999).

Actin and myosin cross bridging occurs as a result of a biological cascade triggered by a neurological stimulus originating in the motor cortex. When this stimulus reaches the neuromuscular junction, the motor neuron releases acetylcholine which binds to receptors on the muscle causing the depolarisation of muscle cells. Depolarisation then travels down transverse tubules within the muscle, stimulating the sarcoplasmic reticulum to release stored $Ca^{2}+$. The $Ca^{2}+$ released from the sarcoplasmic reticulum then binds to, and changes the shape of, trypomyosin. This exposes actin active sites which myosin heads are able to bind to. They then pull the actin toward the centre of the sacromere, causing the sacromere to shorten in size and causing muscular contraction (Kraemer & Spiering, 2006; Wilmore & Costill, 2004).

The ability for actin and myosin cross bridging to occur is restricted by the limited cross bridge attachment range, only occuring when actin and myosin overlaps within the sacromere (Matsubara & Yagi 1987; Rassier et al., 1999). During muscular contractions, joint angles that allow for greater actin and myosin cross sectional area will produce the greatest muscular force (Huxley, 2000; Rassier et al., 1999). As such, the magnitude of muscular force production is affected by muscular length (Brughelli & Cronin, 2007; Herrel, Meyers, Timmermans & Nishikawa, 2002). This is known as the length-tension relationship (Brughelli & Cronin, 2007), the force-length relationship (Rassier et al., 1999) or, less commonly, the human strength curve (Kulig Andrews & Hay**,** 1984).

The length-tension relationship is an important component of muscular movement in affecting the magnitude of muscular force production (Brughelli & Cronin, 2007). In vivo, this relationship effectively stipulates that force production varies as a function of joint angle (Kulig et al., 1984). Although it has been demonstrated that the length-tension relationship can be influenced by training (Brughelli & Cronin, 2007), the underlying principle that peak muscular force production tends to the mid-point of muscular range of motion remains (Findley, 2004). As force is accumulated throughout a muscular movement, however, total force, or mechanical advantage, is greatest toward the end of a concentric movement **(**Rahmani, Dalleau, Viale, Hautier & Lacour, 2000**).** The length-tension relationship is one of the underlying theories behind using variable resistance techniques that more closely match the human strength curve (Kulig et al., 1984).

Factors Affecting the Development of Muscular Power

Strength

Strength can be defined as the ability of a muscle to exert force (Wilmore & Costill, 2004; Kulig et al., 1984). It is an essential component of power. Power can be defined as muscular force multiplied by velocity (Cronin & Sleivert, 2005). It is clear that maximal strength is a prerequisite to the development of power (Tan, 1999). As such, a strong relationship exists between maximal strength and power (Baker, 2001a; Baker & Nance, 1999). We can observe this relationship in numerous studies comparing strength status and power production (Baker, 2001a; Baker, 2002; Baker & Nance; Tan, 1999).

Despite the weight of evidence supporting the correlation between maximal strength and power, the literature is not consistent in supporting a linear relationship between these two variables. For example, Baker, Nance & Moore (2001a) found similar strength scores in professional and semi-professional rugby league players, although professional players produced greater power scores. Furthermore, research has found no significant relationship between lower limb strength and power or speed measures in professional and semi-professional rugby league players (Cronin & Hansen, 2005). In this research, however, both semi-professional and professional rugby league players were treated in the same statistical analysis. This may explain the lack of a significant relationship between strength and power measures. Therefore, this does not preclude the relationship between strength and power, but suggests that this relationship is complex and not fully understood (Baker, 2001a; Tan, 1999).

Although strength is a prerequisite to the development of power, athletes who are exposed to specific power training can become more powerful than non-power trained athletes of equal strength (Baker, 2001a). It has been hypothesised that the relationship between strength and power diminishes as the athlete gains strength closer to their genetic maximum (Kraemer & Newton, 2000). In light of this, it seems important that athletes train not only to gain strength but also to train specifically to improve power. This seems to be particularly important for highly trained athletes who are approaching their genetic ceiling in strength.

An interesting component of muscular strength is the concept of a 'biological sticking point', or the weakest point in a muscle's range of motion, and relates closely to the length-tension relationship. The biological sticking point has been shown to be at or near the beginning of the concentric phase of a movement in a number of training movements, including the back squat (Drinkwater, Galna, McKenna, Hunt & Pyne, 2007; Escamilla, Fleisig, Lowry, Barrentine & Andrews, 2001). This occurs due to a regression in actin myosin overlap during the eccentric phase of a movement, which normally results in a regression in muscular force development at the beginning of the concentric phase (Rassier et al., 1999). The biological sticking point as a component of muscular strength training is disadvantageous as it results in an optimal training load occurring only at this, the weakest point of a movement (Keohane, 1986).

Training Load

The load utilised during training is a factor that affects training stimulus and therefore contributes to training adaptations during power development (Kawamori & Haff, 2004). There is a consensus throughout the literature that training at the load which causes maximal power production (P-max) optimizes improvements in muscular power (Kawamori, Fuchimoto, Toji & Suei; cited in Cormie et al., 2006). In light of this, it seems important to determine, and train at, the load at which P-max is obtained.

A number of studies have been dedicated to determining the ideal training load for developing power (Baker et al., 2001a; Baker, Nance & Moore, 2001b; Cormie et al., 2006; Cronin, McNair & Marshall, 2001; Kawamori & Haff, 2004; Kilduff et al., 2007; Newton et al., 1997; Thomas et al., 2007). It has been postulated that a load between 30-45% of 1RM is generally required to produce maximal power production (Baker et al, 2001a; Baker et al, 2001b; Kawamori & Haff, 2004). Although these findings are supported in the literature (Baker et al, 2001a; Baker et al, 2001b; Kawamori & Haff, 2004), there are also number of studies that do not support this and continued controversy over the ideal load to provide maximal power remains (Cronin et al., 2001; Kraemer & Newton, 2000). It has been suggested that the variance in findings concerning the optimal load in developing P-max results from variations in training status (Cormie et al., 2006; Thomas et al., 2007), variations in methodological procedures (Baker et al., 2001b; Crewther et al., 2005; Cronin & Slievert, 2005), movement complexity (Kawamori & Haff, 2004) and gender differences (Thomas et al., 2007). The lack of a standardised protocol presents a major difficulty in comparing these findings and has lead to conflicting results (Crewther et al., 2005). Furthermore, the range at which P-max occurs may vary somewhat due to diversity in muscle architecture and subsequently unique power development within different muscle groups (Pearson, Hume, Cronin & Slyfield, 2009).

One of the primary disadvantages of traditional fixed load training is that a muscular movement is limited by the maximum load tolerable at the weakest point of a muscular movement (Faron, 1985; Keohane, 1986). As a result, optimal training load will only be achieved over a small range of motion (Keohane, 1986). A unique characteristic of variable resistance training is that load changes throughout a range of motion. With the addition of chains or bands to a barbell while performing traditional lifts, the load can be increased progressively throughout the concentric phase of motion (Ebben & Jensen, 2002; Wallace et al., 2006). This is thought to allow an optimal load to be achieved consistently throughout the range of motion by producing increasing load as mechanical advantage increases (Ebben & Jensen, 2002; Faron, 1985; Ghigiarelli et al., 2009; Wallace et al, 2006).

The concept of mechanical advantage is closely related to the length-tension relationship in skeletal muscle and reflects the ability of a muscle to obtain greater accumulative force and torque around a moving joint throughout a concentric contraction. According to the sliding filament theory of muscular force development, there is a need for overlap between actin and myosin filaments (Herrel et al., 2002; Rassier, 1999). Because the amount of overlap varies with muscular length, a relationship exists between the length of a muscle and the amount of isometric force it is able to generate (Herrel et al., 2002). Presuming uniform distribution of myosin cross bridges and that each cross bridge exerts, on average, equal force production, then muscular force generation will be greatest when the greatest actin myosin overlap occurs (Rassier et al., 1999). This principle has been used both as an argument for (Ebben & Jensen, 2002; Wallace et al., 2006) and against (Findley, 2004) the use of variable resistance training as an effective training tool. Findley argues that the linear increase in variable resistance tension during the eccentric phase of a movement works in contrast to the muscular length-tension relationship, which, in single joint movements, produces force most effectively at a mid range of movement (Mcmasters ert al, 2009). Similarly, some variable resistance machines have been designed to produce peak load at the mid range of a movement with reducing loads at the beginning and final phase of movements (Kauhanen et al., 1989). As such, variable resistance provided by bands or chains is thought to provide a low intensity over the muscle’s optimal contractile range in order to accommodate the greater load and reduced ability to produce muscular force at the upper extremities of the movement (Findley, 2004). However, this does not take into account the accumulation of force throughout a muscular contraction.

Force produced throughout the concentric phase of a movement is cumulative. Although a muscle may be less effective at producing force as it nears full extension, total force and torque about joints involved in force production is greatest toward the end of a full concentric contraction in dynamic squat movements (McmAsters et al, 2009; Rahmani et al, 2000). While traditional weight training does result in deceleration toward the end of the concentric phase (Cronin et al., 2003), this is not resultant of progressive accumulative muscular weakness, but occurs as a necessity to slow the momentum of a load to prevent it from being thrown. In contrast, many other sports-specific training techniques, such as jumping and ballistic movements, produce a continuing increase in force throughout the concentric phase until the load is released (Ebben et al., 2007; Welter & Bobbert, 2002). As such, the linear increase in load afforded by variable resistance seems to be appropriate to match muscular mechanical advantage.

It has also been suggested that training eccentrically at loads which exceed normal training thresholds allows for greater strength adaptation to be developed (Higbie et al., 1996). Traditionally this has been achieved by loading the eccentric phase at a load greater than an athlete’s 1RM, and completing the eccentric phase only (Cronin et al., 2003). A similar training stimulus may be obtained through increasing the velocity of the eccentric phase and therefore the force needed to decelerate the load during the eccentric phase during variable resistance training (Conlin, 2002; Cronin et al., 2003). As such this may cause greater strength adaptation and be an additional advantage of the use of elastic tension to provide variable resistance (Conlin, 2002; Cronin et al., 2003). However, this concept is still theoretical with limited evidence to support the idea that the use of elastic tension results in greater eccentric loading.

In contrast to the theoretical advantages of VRT it has also been argued that variable resistance may in fact be ineffective in producing strength adaptations, as the reduced load at the beginning of a concentric movement may not provide an adequate stimulus to cause adaptations in this range of movement (McCurdy et al., 2009). As the biological sticking point in most movements is at or near the bottom of a muscular movement (Drinkwater et al., 2007; Escamilla et al., 2001; McCurdy et al, 2009) this may reduce the training stimulus over this range of motion and reduce the ability of fixed loads to be moved over this, the weakest point of a movement. This may result in less strength gains as a result of VRT compared to fixed load training, as strength adaptations may not be as great at the point of failure i.e. the biological sticking point (McCurdy et al., 2009). However, this theoretical disadvantage presumes that loading will be less at the beginning of a concentric training movement in VRT compared to fixed load training, rather than being unchanged at this point and increasing throughout the concentric phase.

An additional disadvantage of variable resistance is that the force required to stretch the elastic bands used during variable resistance training has not been quantified. This makes determining the load afforded by variable resistance bands difficult (Paterson et al, 2001). This problem is compounded by variations in limb length causing differences in the stretch of variable resistance bands and therefore variations in the force afforded by elastic bands even if the property of a band is unchanged.

Training Velocity

Power is the product of both force and velocity. Furthermore, an important factor in the process of power development is the kinetics and kinematics associated with the load used to provide resistance. Specifically, variations in the force, contractile duration, power and work done in a training movement are dependent on the training load (Crewther et al., 2005). It is not just the load that affects training adaptation, but also the ability of the load to be moved at velocities specific to the desired sporting movement (Cronin et al., 2003; Kawanori & Haff, 2004; Kraemer & Newton, 2000). Because of this, greater performance gains will be achieved at or near the training velocity (Behm & Sale, 1993b). Therefore, when developing strength and power, it is recommended that athletes should perform resistance training that simulates the contraction characteristics of their specific sporting event (Cronin et al., 2003).

In order to develop power at high velocity, training must be performed at high velocity (Hatfield et al., 2006). However, the force-velocity relationship is such that the speed of muscular contraction is inversely proportionate to the load (Peterson, Alvar & Rhea, 2006). Therefore, as load increases, the velocity at which it can be moved decreases (Newton & Kraemer, 1994). As many sporting disciplines require explosive movements under low loads, it may be speculated that training with light loads would provide superior stimulus for the development of muscular power (Baker et al., 2001a). This is in contrast to traditional strength training which relies on high load with a prolonged period of contraction, producing greater total work output, resulting in greater muscular strength adaptation (Crewther et al., 2005; Tan, 1999). However, as increases in power are specific to the training velocity, variation in training load and subsequently training velocity affect the training adaptation (Newton & Kraemer, 1994). In light of this, it seems that the ability of the load to be moved at velocities and load similar to sports specific movements is indeed a significant factor in training (Cronin et al., 2003; Kawanori & Haff, 2004; Kraemer et al., 2000).

One of the limitations of traditional weight training is that it produces a significant deceleration phase at the end of the concentric motion (Cronin et al., 2003; Wallace et al., 2006). During ballistic training, the load is projected allowing acceleration of the load for greater periods of time (Crewther et al., 2005; Cronin et al., 2003; Kraemer & Newton, 2000). This type of training seems to be more closely related to sport specific movements, such as jumping and throwing, than traditional weight training (Cronin & Sleivert, 2005; Cronin et al., 2003). Furthermore, ballistic training has been shown to increase power output to a greater extent than traditional weight training (Cronin & Sleivert, 2005; Cronin et al., 2003) and has been shown to improve functional performance (Cronin et al., 2003; Kraemer and Newton, 2000). However, these improvements would be limited to the use of light loads, as projection cannot be achieved with heavier loads (Crewther et al., 2005; Wallace et al., 2006). One potential benefit of variable resistance training is that it combines the benefits achieved from the increased range of acceleration afforded by ballistic training, while at the same time including the higher loads normally afforded from traditional resistance training (Wallace et al., 2006). This theory is supported by research that found both peak power and peak force to increase under certain loads when utilising variable resistance (Wallace et al., 2006). As power is a combination of force and velocity, and peak power occurs towards the end of a concentric phase in dynamic squat movements (Rahmani et al., 2000), this suggests that variable resistance loads allow either greater load to be lifted at similar velocities or similar loads to be lifted at greater velocities as compared to fixed load movements due to a greater range of acceleration. However, no specific research exists supporting the physiological cause of increased peak power due to variable resistance training.

A factor to be considered in training for power adaptations is the load at which training should occur in order to produce P-max (Cormie et al., 2006). During variable resistance movements, the resistance progressively increases throughout the concentric contraction allowing for greater muscle activation (Ebben & Jensen, 2002; Wallace et al., 2006). It seems that this allows for velocity to be maintained at greater loads at the top of concentric contractions (Conlin, 2002). As variable resistance allows for high velocity movements to occur under greater loads, variable resistance may be able to produce greater maximal force than traditional fixed load weight training. The literature is in agreement that training at loads which produces maximal power production optimises improvements in muscular power (Cormie et al., 2006). As such, if variable resistance actually produces increased maximal power outputs during training movements, it may well be effective in improving muscular power.

Rate of Force Development

The ability of the muscle to produce a high force over a short period is another factor which affects the development of muscular power (Kraemer & Newton, 2000; Newton & Kraemer, 1994). Although training for maximal strength has been shown to improve power (Baker, 2001a; Tan, 1999), it may in fact reduce the rate of force development at sports specific loads (Newton & Kaemer, 1994). As such, it seems that training at sports specific velocities and loads that allow sports specific velocity to be achieved is required to effectively develop the rate of force development (Newton & Kaemer, 1994).

However, training with heavy loads has also been suggested to improve the rate of force development as it requires the activation of fast twitch fibres, increased muscle size and increased concentration of contractile enzymes. In theory this may increase the ability to produce force at an increased rate (Kraemer & Newton, 2000). In contrast to this, as improvements in strength have been shown to be specific to training velocity, and training velocity reduces as load increases, this theory does not seem logical (Newton & Kraemer, 1994).

Rate of force development at high speeds or the muscle's ability to continue to produce high levels of force as velocity increases toward the end of the concentric phase has also been suggested to be an important factor in developing explosive power (Newton & Kraemer, 1994). The progressive increases in resistance throughout the concentric contraction during variable resistance training may provide a greater training effect at the later stages of concentric contraction and, as such, may be beneficial in increasing the rate of force development at high speeds. However, no research has been found exploring the effect of VRT on this area of force development.

It has also been postulated that the intent of movement may be an important factor in determining training effect (Behm & Sale, 1993a). Young and Bilby (1993) demonstrated that training the back squat under heavy loads with explosive intent over a seven week period resulted in a significantly greater improvement in power measures when compared to movements without explosive intent. As such it may not be necessary to perform an actual high velocity movement to obtain the explosive training adaptation typically associated with velocity specific training (Behm & Sale, 1993a).

Age

Another factor affecting the development of strength, and consequently power, is the age of athletes. Due to the progression of growth during adolescence, strength will increase naturally during this period. However gains in strength and power achieved through resistance training of sufficient intensity, volume and duration are significantly greater than those produced through natural adolescent development (Faigenbaum et al, 2010).

In males it has been shown that strength and power increases quickly during the adolescent years, and peaks in the adult years (Balmer, Potter, Bird & Davison, 2005; Jagiello, Kalina & Tkaczuk, 2004). Greater muscular improvements in pubescent boys, compared with pre-pubescent and elderly males in response to resistance training, are primarily due to an increase in anabolic hormones, specifically testosterone and GH (Crewther, Keogh, Cronin, & Cook, 2006). It is common for strength gains of approximately 30% to be obtained in adolescents over short, 8-20 week, training periods (Faigenbaum et al, 2009) with the greatest rate of improvement occurring early in training periods (Falk & Tenenbaum, 1996). This accelerated rate of improvement has been shown to slow by the age of 16-17, particularly in population groups that have trained throughout their early pubescent years (Jagiello et al., 2004). However, the relationship between physical maturity and VRT has not been addressed in prior research.

An Overview of Variable Resistance Training

Variable resistance training is not a new concept. As early as 1948 counter balances and pulley systems were being experimented with to produce "progressive resistance exercise" (Keohane, 1986). In the 1980s, pulley machines with changing radii were utilised as a type of variable resistance training (Keohane, 1986). This was designed to reflect the length-tension relationship during a movement (Kauhanses et al., 1989). There are also modern examples of machine-based variable resistance products such as the BowFlex® exercise machine.

It has been suggested that machine based variable resistance may be effective in producing a greater fatigue response as compared to equivalent fixed load movements (Kauhanen et al., 1989). This is supported by research that has shown greater neural activation in response to VRT as compared to fixed load training (Kauhanen et al., 1989). However, the reliability of this research is questionable as it seems that no attempt was made to standardise the mean load lifted across the two training variables.

Variable resistance can also be afforded through the addition of elastic bands. Variable resistance training of this nature has been used in rehabilitation to provide controlled stretch and strengthening and to increase range of motion after muscular trauma (Patterson et al., 2001; Wallace et al., 2006). Recently, variable resistance has also been applied to strength and power training in an attempt to obtain improved training adaptations (Wallace et al., 2006). Despite the theoretical benefits of variable resistance training, very little scientific research exists in this field. Furthermore, the research that does exist has been acute in duration (Ghigiarelli et al., 2009) and does not uniformly support the effectiveness of VRT. Ebben and Jensen (2002) found no significant difference in peak or mean ground reaction force between variable resistance squats while using chains or elastic bands as compared to traditional fixed load squat. However, the loading procedure for variable resistance in this test was calculated with the total resistance of the chain or bands (the full weight of the chain or the peak tension of the band) being subtracted from the fixed load (Ebben & Jensen, 2002). This gave a lower load when using bands or chains, as the total load was only equal to that of the free weight at full extension when the full force of the band or chain was active.

In contrast to this study, Wallace et al (2006) found that both peak power and peak force were increased under certain loads when utilising elastic bands to produce variable resistance during a squat movement when compared to a fixed load squat of a comparable load. The loading procedure in this test was different from that of Ebben and Jensen (2002), as only half of the total resistance of the chain or bands was subtracted from the traditional load (Wallace et al, 2006). This was done to produce an equal average total resistance so that the weight would truly reflect the percentage of one repetition maximum. This procedure, however, has not been tested with the use of chains as a means of producing variable resistance and more research into the kinetic effects VRT has been recommended (Wallace et al, 2006). Further research into the kinetic effect of variable resistance may also help in understanding the training effect of variable resistance loads more accurately.

Cronin et al (2003) also investigated the effect of ten weeks of VRT on a ballistic supine squat machine on muscular development. This research found that ballistic fixed load training and ballistic variable resistance training caused significantly greater changes in strength and power measures than non-ballistic fixed load training. However, no significant difference was found between the ballistic fixed load training and the ballistic variable resistance training groups. This research also found similar electromyographic results in fixed load and variable resistance training groups. However, the use of a supine squat machine in this research reduces the validity of these findings when compared to functional movements which are generally performed while standing. Furthermore, the utilisation of variable resistance training in ballistic movements is not compatible with the suggestion that VRT may combine the benefits afforded from the increased range of acceleration associated with ballistic training while utilising heavy loads normally utilised in traditional resistance training (Wallace et al., 2006).

Recently, research into the training effect of chains and elastic tension on bench press strength and power adaptations has been undertaken (Ghigarelli et al., 2009; McCurdy et al., 2009). A study by Ghigarelli et al. (2009) found no significant difference between the use of elastic bands, chains and fixed load training in strength and power development when training on the bench press over a seven-week period. However, both training with elastic bands and the addition of chains to fixed loads did increase strength and some power measures to a greater extent than fixed load training. Although this suggests that VRT provides greater strength and power adaptations, this research was inconclusive due to a lack of statistical power. A limitation to this research is that the experimental loading procedure was used only once a week, with all subjects also participating in fixed load bench press training. This may have reduced the magnitude of difference between these training procedures compared to a training intervention with a more regular and exclusive use of VRT. Furthermore, it was not stated if an attempt to standardise loads across training groups was undertaken in this research (Ghigarelli et al., 2009).

McCurdy et al. (2009) also found no significant difference in improvement in bench press 1RM strength over nine weeks of training between a fixed load training group and an experimental training group utilising chains to produce variable resistance. Loads were standardised between the variable resistance and fixed load training groups by measuring both the fixed load and variable resistance 1RMs. Loads were then prescribed based on percentage of 1RM derived from the test equivalent to the training stimulus. However, the VRT group in this research utilised chains to make up the entire training load with the exception of a barbell. This may be disadvantageous as the regression in load towards the end of the concentric phase may have been to great to produce a training stimulus and may not have been specific enough to fixed load testing protocols to provide a significant improvement in fixed load 1RM (McCurdy et al., 2009). No research to date has compared mean force development to a load made up completely of a variable load to fixed load training, although previous research has shown mean force and power values can be greater with mixed variable resistance and fixed load as compared to fixed load training (Wallace et al, 2006).

Conlin (2002) claims that the use of bands in conjunction with force training improves maximal strength, starting strength, speed strength and acceleration needed for power events. However, there seems to be limited specific scientific evidence to reinforce these claims (Ghigiarelli, et al., 2009; Wallace et al., 2006). Without supporting scientific research, these are subjective views and a greater body of evidence is required to prove such claims. Furthermore, variations in methodological procedures and conflicting results within the existing research have complicated understanding in this field. This does not necessarily discount the effectiveness of variable resistance training in developing power, but highlights the need for a greater body of scientific research into the effect of this training technique.

As such, a more complete understanding of how variable resistance movement affects the training stimulus would be beneficial (Ebben & Jensen, 2002; Wallace et al., 2006). Further research into the effect of variable resistance on peak force, peak power and velocity, particularly in the late phases of concentric action, has also been recommended, to determine the exact mode of musculo-skeletal adaptation that VRT causes (Wallace et al, 2006). Additionally, a greater number of training studies into the long-term effect of variable resistance training on athletes' strength and power development may be of benefit to provide a better understanding of the effect of VRT under different loading procedures and the effect of VRT in a greater number of muscle groups.

As previously stated, there are some difficulties in utilising variable resistance as a training tool and as a focus of research. These problems stem from difficulties in standardising training loads from 1RM (Newsman, Leese & Fernandez-Silva, 2005). Exercise intensity has traditionally been based on training recommendations calculated from a percentage of 1RM lifts (Newsman et al., 2005). This is demonstrated by the extensive debate concerning ideal loading for power development in terms of the most appropriate percentage of 1RM to lift (see *Training Load* above). Determining loads based on percentages of 1RM is relatively simple when dealing with traditional fixed loads. However, because of the nature of variable resistance training, accurately determining load is much more complex and poses serious complications in measuring and recommending variable resistance loads. Although some evidence exists that variable resistance training load can be effectively managed based on rate of perceived exertion (Colado & Tripplet, 2008), this can be particularly problematic when precise measurements are required during scientific testing and may be a contributing factor to the lack of research in this field.

Despite the methodological difficulties in studying VRT and the relative lack of research into the effect of VRT as a training technique, there is a growing body of research dedicated to this subject. Research findings to date are inconsistent regarding whether VRT produces greater force during muscular movements, and inconclusive as to whether variable resistance produces greater strength and power adaptations when compared to fixed load training. Due to the nature of these findings, further research is required in determining the usefulness of VRT as a training technique and to clarify what VRT loading and training protocols may produce greater strength and power adaptations as compared to fixed load training.

Conclusion

Although VRT has been utilised since the 1940's, VRT has only recently been applied to free weight training in an attempt to obtain muscular strength and power adaptations by varying the load throughout a training movement as tension increases during the concentric phase. This can be achieved with the addition of bands and/or chains to a fixed load.

There are a number of theoretical advantages of variable resistance training as a tool for power development and some subjective proof exists to support its effectiveness as a training method. Although some of these theories seem rational, there is limited scientific research to support the purported benefits of VRT. The lack of such research is further confounded by difficulties is measuring and standardising training loads when utilising variable resistance. Furthermore, due to variations in procedural protocols, scientific research in this field is somewhat contradictory and inconclusive. This, however, does not discount variable resistance training as an effective tool for strength and power development, but points to a need for a greater body of research into the kinetics and kinematics involved, as well as the implications of this form of training in the field.

CHAPTER THREE: METHODS

Experimental Design

This study was primarily designed to test the effect of variable resistance training on strength and power development compared to the strength and power gains achieved through fixed load resistance training. A pair matched training study was implemented over five weeks to compare the mean changes in strength and power measures between a variable resistance training group and a fixed load training group.

All subjects who participated in this research were involved in pre-existing training environments. Training practices between these groups was not standardised. However training within the pre-existing environments was standardised. Because of this, a within-group pair match system was used to match subjects from within the same training environments. The variable resistance and fixed load training groups were pair matched based on the pre intervention predicted 1RM.

Strength and power tests consisted of a back squat 1RM, predicted from a four repetition maximum lift (4RM), vertical jump height and 30m sprint speed. Vertical jump height and 30m sprint speed were tested both at the beginning and the end of the training period, while the 4RM test was implemented at the beginning, mid-point and end of the five-week training period.

A secondary aim of this research was to measure the rate of relaxation in elastic tension in variable resistance bands with repeated use. This was achieved by measuring and comparing the force produced by variable resistance elastic bands prior to, at the mid-point and post use in the training study. This was done in order to help to insure the reliability of this research by provided a more precise understanding of the load that variable resistance afforded subjects throughout the training study.

Subjects

A group of male rugby players (n = 31) participated in this study (see Table 1). Subjects were involved in pre-existing training environments, with training levels ranging from semi-professional and elite age group academy players (n = 11) to high level high school players (n = 20). However statistical analysis by skill level was not performed due to the low numbers in each group. More detailed subject information is included in chapters four and five for the high school and semi-elite players respectively.

Subjects were provided with a participant information sheet outlining their rights and expectations during the training study (Appendix A) and were required to sign a participant consent form (Appendix B). Subjects were also required to complete a questionnaire outlining their physical preparedness for participation in the training study (Appendix C). Because all subjects were involved in high intensity weight training, the pre-exercise screening questionnaire focused on each subject's ability to complete the specific training and testing requirements of the study.

Subjects were allowed to withdraw from the study at any time without negative consequence or reprimand. The study received ethical approval from the Waikato Institute of Technology's Research Ethics Committee prior to its commencement. Subjects were also advised to adhere to the recommendations of their team or personal doctors and physiotherapists concerning their ongoing ability to participate insure the study due to potential rugby related injury. As such, not all subjects completed the entire training study. Information has been included for all subjects who contributed useful data, e.g. pre- and mid-point strength tests, regardless of whether they completed the entire study or not.

Table 1: Subject Information Including (Mean ±SD) Age, Height (of Barbell on Shoulder), Pre-Intervention Mass and Back Squat 1RM.

	Age (years)	Height (m)	Mass (kg)	Back Squat 1RM (kg)
Semi-Elite (n = 11)	19.9 ± 2.0	1.61 ± 0.05	98.5 ± 9.0	187.0 ± 24.4
High School (n = 20)	17.5 ± 0.7	1.59 ± 0.04	87.0 ± 10.3	161.1 ± 15.8
Total	18.3 ± 1.8	1.60 ± 0.05	91.2 ± 11.2	170.3 ± 22.7

Heights was measured from subjects' shoulders i.e. height of the barbell.

Training Protocol

All subjects (n = 31) participated in a five-week back squat training intervention. Although the general training programmes that the subjects were involved in varied, back squat training sets and repetition were identical across all training groups. Rest periods between sets were required to be two minutes. Training repetitions and sets are outlined below.

Table 2: Training Protocol, Weeks 1-5.

	Week 1				
Training session 1	1RM Protocol				
Training session 2	8	6	4		(P)
	Week 2				
Training session 1	6	5	4	4	(S)
Training session 2	6	5	4	4	(P)
	Week 3				
Training session 1	8	6	4	4	(S)
Training session 2	8	6	4	4	(P)
	Week 4				
Training session 1	8	6	6	5	(S)
Training session 2	8	6	6	5	(P)
	Week 5				
Training session 1	8	6	4		(S)
Training session 2	1RM Protocol				

Numbers represent sets and repetitions.
(S) = strength focused session
(P) = power focused session

All squat training took place in training cages, under the supervision of a trained fitness professional and with the assistance of a spotter if required. Throughout testing and training, squat depth was required to reach 90 degrees at the knee. This was visually measured for each subject and a band placed across the cage at gluteal height. Depth was standardised by requiring subjects to touch the band with their glutei at the bottom of their eccentric phase. Variable resistance was obtained through the use of elastic bands (Get Strength, Auckland, New Zealand). When utilising variable resistance, the bands were anchored to the base of the cage and attached to either end of the barbell. This provided increasing tension as the band was stretched through the concentric phase of the squat.

In order to encourage a more specific stimulus toward power adaptations, every second training session was performed with powerful intent under reduced load. During power focused sessions, subjects were instructed to control the eccentric phase of the squat but to move through the concentric phase as quickly and powerfully as possible as it has been suggested that intent to move a load at speed results in power adaptation (Behm & Sale, 1993a; Young & Bilby, 1993). Due to the explosive nature of this movement, this often resulted in subjects moving up onto their toes or having their feet leave the floor completely. During strength focused training sessions, subjects were advised to work through the entire training movement in a controlled manner with no specific instructions concerning the tempo of the movement.

Training Loads

Suggested training loads were prescribed for all subjects, and their repetitions, sets and suggested loads were outlined at the beginning of each session. Subjects were strongly encouraged to lift the suggested training loads, but lenience was allowed for subjects to marginally amend the actual load lifted. Actual load lifted and repetitions were recorded in every training session.

Training loads were initially prescribed based on predicted 1RM using the Brzycki formula (1RM = load/(1.0278-0.0278*reps)) on the subject's pre-training 4RM **(**LeSuer et al., 1997**).** The Brzycki formula was then reversed to indicate the maximum load a subject could lift for the desired number of repetitions (rep max = 1RM*(1.0278-(0.0278*desired reps))). This value was rounded to the nearest 5 kg. The Brzycki formula was chosen primarily because of its close statistical relationship between predicted and 1RM back squat scores and its ease of mathematical reversal.

During strength focussed sessions, the last and heaviest set was left with no suggested load. In this set, subjects were asked to lift a maximal load relative to the repetitions required and to continue the last set until fatigue either caused deterioration in form or prevented the load from being lifted. This was done to allow subjects to choose to lift a greater load as a result of training adaptations, unrestricted by a suggested load. The value of the last set of each strength training session was used to re-predict the subject's 1RM and to determine the training loads for the following training session. The repetition maximum was reduced by 20% when prescribing for power focused trainings sessions, to allow for a more explosive movement to occur.

Prescribing loads based on a percentage of the subjects' 1RM ensured that training loads in both the variable resistance training group and fixed load training group were standardised comparable to those of equal strength. Furthermore, leaving a self-selected training load at the end of a strength training session allowed for adaptation to be expressed through increased training loads outside of the constraints of a predicted load and ensured overload was obtained during each training session.

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During variable resistance lifts, variable resistance made up 25 ± 5% of the total load. This range of variable resistance was chosen to reflect previously determined effective loading procedures (Wallace et al., 2006). A range of ± 5% was allowed due to the difficulty of obtaining specific variable resistance loads. Variable resistance loading was normalised to the fixed load training group by subtracting the mean of peak tension and the lowest tension afforded by the variable resistance load from the fixed load. This allowed the average resistance value to be equitable to a fixed load, and ensured that work done would be equal between the two training groups. As such, any superior strength and power gains seen in the variable resistance training group could not be due to greater loading or greater work done.

Standardising Training Load

In order to account for the differences in the load afforded by variable resistance depending on subjects' height, subjects were categorised into groups based on their height. The height of every subject was measured from bar height at the top of a natural squat movement. Subjects ranged in height from 1.55m to 1.70m and were divided into two height categories: 1.55m-1.625m and 1.625m-1.70m. As it was not logistically possible to measure the resistance afforded by variable resistance bands on each subject, two subjects who closely reflected the median point of each height group (subjects 1.57m and 1.67m in height respectively) were used to determine an average load achieved by the respective height groups

Variable resistance loads were measured using a Kistler 9281B multi-component force measuring plate (Kistler Instruments, Hampshire, UK), measuring at a rate of 500hz. With bands anchored to the bottom of a training cage and attached to each end of an Olympic bar, the mean load afforded by each set of variable resistance band was determined by calculating the average force at the top of the concentric phase and at the bottom of the eccentric phase of a 90 degree squat. Subjects were required to hold the variable resistance load at the top of the concentric phase and the bottom of an eccentric phase as steadily as possible for five seconds. This was repeated with all 6 sets of bands for both subjects. Bands ranged in width from 0.5 to 1.75 inches.

The mean load was then converted from load in newtons to mass in kilograms (N/9.81). The system load i.e., the weight of subject plus the weight of the bar, was then subtracted from both the peak tension and the lowest tension measured at the highest and lowest points of the squat in order to isolate the load afforded by the elastic tension. From this, an average of the isolated load at peak tension and at the lowest tension was calculated. This value represented the average load produced through variable resistance and is comparable in terms of work done to an equal fixed load. With this information, variable resistance loads could be prescribed with an equal mean weight as fixed loads. This was important in helping to insure the reliability of this research.

Furthermore, in order to insure the reliability of training loads used throughout the study, each set of bands was also measured at the mid-point and completion of the training study. This determined the rate of stretch and relaxation that occurred to variable resistance elastic bands with use. Due to minor changes in the amount of variable resistance afforded by the bands after use, loading protocols were changed slightly at the midpoint of training to ensure that loads prescribed reflected the actual load lifted.

Testing

The physiological tested used in this study consisted of a 4RM back squat from which a predicted back squat 1RM was calculated, vertical jump height and 30m sprint speed. All tests were completed pre- and post-training, while 1RM was also obtained from training values in the third week of training.

Back Squat 1RM Protocol

During testing, subjects were required to achieve a depth of 90 degrees at the knee. This was visually measured for each subject and a band placed across the cage at gluteal height at the required depth. Tape was placed on the floor across the line of the subject's toes to mark the foot position at which the subject achieved their required depth. Depth was standardised by requiring subjects to start each squat with their feet at the same position during each set and by requiring subjects to touch the band with their glutei at the bottom of the eccentric phase.

Subjects were required to complete a warm up set of eight repetitions at a self-selected load. This was followed by a set of six repetitions at approximately 7RM load. Subjects' first 4RM lift was performed at a load recommended by a trainer in consultation with the subject. If this load was achieved, subjects were then allowed to attempt a heavier load, as agreed upon by the subject and trainer, after 3 - 5 minutes' rest. If this greater load was not lifted successfully, the previous successful load was recorded. If a subject was not able to achieve the required depth, or required the assistance of a spotter, the repetition was not counted. If a subject failed to lift the load or suffered lack of form, he was not allowed to continue the set. Once a 4RM had been achieved, a 1RM was calculated using the Brzycki formula (LeSuer et al., 1997).

Vertical Jump Protocol

Vertical jump height was measured with the assistance of a Swift Yardstick (Swift Performance Equipment, NSW, Australia). Subjects were required to complete three maximal effort vertical jumps. The best result of the three efforts was recorded. Vertical jump testing was completed prior to back squat testing.

Subjects were required to stand with their right foot at the base of the Yardstick and to reach as high as possible with their right arm to determine reach height. Once the Yardstick had been adjusted to the subject's reach height, he was instructed to jump naturally with maximal force. Natural arm swing and counter movement depth was allowed. This was repeated three times with self-selected rest intervals between attempts. Many subjects were already familiar with this testing protocol due to prior, non- related, testing.

30m Sprint Speed Protocol

Subjects were required to warm up as a team before beginning speed testing. Warm up protocols were standardised pre- and post-test within groups, but varied between the high school and semi elite training groups. Warms ups generally consisted of light aerobic activity and dynamic stretches. Subjects were then allowed up to two practise sprints through speed lights before completing their recorded maximal effort sprints. Two maximal 30m sprint efforts were recorded. A rest period of three minutes was required between sprint efforts. Sprint speeds were measured at 10m, 20m and 30m using speed lights (Swift Performance Equipment, NSW, Australia). Times from both sprint efforts were recorded and the average calculated for both 10m, 20m and 30m sprint speed. This was done in order to minimise subject error due to potentially uncharacteristic fast or slow test speeds in any one given sprint performance.

Sprint surfaces were standardised pre- and post-test within groups. However sprint surfaces varied between firm grass, artificial turf and gym floor. All sprint tests were conducted across wind when performed outdoors. Subjects were required to start sprinting with their feet placed in line with the back of the first timing light tripod and were instructed not to slow until the last timing light had been passed. Footwear was determined by the testing surface. Sprint tests were not performed on the same day as strength or vertical jump tests.

Statistical Analysis

Changes in the pre-, post- and mid-point data (where relevant), for back squat 1RM, vertical jump and sprint speed were analysed using a pre-post controlled trial spreadsheet (Hopkins, 2006b). Changes in elastic band tension were analysed using a post- only crossover trials spreadsheet (Hopkins, 2006a). All data were log-transformed and adjusted to the mean of pre-test values before analysis as a covariate. All statistical analyses were determined to a 90% confidence interval (CI). Data were back transformed for use in analysis and is presented as the percentage difference in change ±confidence limit unless otherwise stated. Magnitudes in the differences between within-group changes were based on recommendations outlined by Hopkins et al, utilising a modified Cohen scale, with <0.2 representing a trivial difference, 0.2 - 0.6 representing a small difference, and 0.6 - 1.2 representing a moderate difference (Hopkins, Marshall, Batterham & Hanin, 2009). Data that crossed the threshold for a small positive and small negative difference (-0.2 – 0.2) was determined as unclear. This threshold approach to statistical analysis was chosen above the traditional approach utilising p values because of its ability to clearly state the magnitude and importance of findings. Further the traditional p value approach was forfeited due to it's fails to deal adequately with the real-world importance of an effect as outlined by Hopkins et al (2009).

Mean changes and between-group difference in the pre-, post- and (where relevant) mid-point back squat 1RM, vertical jump and sprint speed in the semi-elite case study group were calculated using a pre-post controlled trial spreadsheet (Hopkins, 2006b). These results were compared to findings in the fixed load training group. However, more in-depth statistical analysis of the semi-elite case study group was not completed due to a lack of statistical power.

Treatment of Subject Groups

The methodological procedures outlined above were implemented identically for both the high school athletes and the semi-elite athletes. Results obtained from the high school athletes experimental investigation has been presented as a research paper appropriate for submission to a peer review journal (Chapter 4). The methods outlined above are repeated in an abbreviated form in the experimental investigation to satisfy the submission requirements of a peer review article.

Due to lack of completion of many of the performance tests in the semi-elite training group, a lack of statistical power resulted. Consequently these data have been treated as a case study (Chapter 5). Variation exists in physiological responses to resistance training in pubescent and mature athletes, with greater muscular improvements in pubescent boys compared with mature males (Crewther et al., 2006). Furthermore, highly trained athletes tend to develop muscular strength and power at slower rates than non-trained or less highly trained athletes (Baker & Newton, 2006). Although strength and power can still be developed in highly trained athletes, the degree of improvement decreases as strength and power increases (Baker & Newton, 2006). As well as this, during training under a particular stimulus, a plateau or even a decline in muscular performance may occur (Wernbom, Augustsson & Thomee, 2007). In light of these differences between pubescent boys and mature, highly trained athletes, the findings obtained from the semi-elite case study was included to provide a comparison between these results and the findings of the high school athletes. From this comparison, inferences were made regarding the effect of VRT in semi-elite athletes, although the findings in this population group were not clear due to a large amount of drop out as a result of sport related injury.

Regression in Loads Afforded by Variable Resistance Bands

Each resistance band was utilised in an average of 235 lifts by the mid-point of the study and an average of 557 times by the end of the study. There were minimal changes in the mean loads afforded by variable resistance bands both between pre- and mid-study values and mid- to post-study values (see table 3 below). Changes in load afforded by variable resistance bands were statistically unclear.

Table 3: Mean ± SD Pre-, Mid- and Post-Training Load Afforded by Variable Resistance Short and Tall Subject.

Height	Pre-Training Load (kg)	Mid-Training Load (kg)	Post-Training Load (kg)
Tall (1.67m)	28.44 ± 77.90	27.46 ± 78.42	27.60 ± 80.70
Short (1.57m)	25.73 ± 73.89	25.23 ± 74.85	25.65 ± 88.84

Heights was measured from subjects' shoulders i.e. height of the barbell. The large SD is caused by the range of loads afforded across band widths.

The maximum number of lifts for a set of variable resistance bands was 838. This set saw a pre- to post-training regression in force of 2.48kg when lifted to a height of 1.67m and 2.03kg when lifted to a height of 1.57m. This is greater than the average regression of 0.84kg and 0.08kg respectively. This suggests regression in force afforded by variable resistance bands will continue to occur as use increases.

It should be noted that mean regression in tension was minimal, although the average resting length of variable resistance bands increased by 19.4mm over the duration of the training period. This suggests that changes in elasticity may not be uniform throughout the range of a variable resistance band’s stretch. It was also observed that regression in variable resistance bands tended to be greater in the heavier (wider) bands, i.e. the bands that provided greater elastic tension, despite often being lifted fewer times. However, these trends are not conclusive and require further research.

Monitoring the regression in variable resistance bands and adjusting loading protocols as appropriate insured that VRT loads could accurately be prescribed throughout this study. This helped to ensure that variations in training adaptations between the training groups resulted from a variation in the training technique, rather than from variation in loads lifted between the VRT and fixed load training groups, and adds to the reliability of the study. As well as this, the lack of meaningful regression in the average force provided by variable resistance bands over an average of 557 lifts suggests that they may be used confidently over an extended period. However, further research is required in this area of study to accurately determine the effective life span of variable resistance training bands.

Limitations

1. The use of 4RM lifts was necessitated by safety concerns due to the relatively young age of subjects. Although the formula used to predict 1RM scores has been shown to be very precise (LeSuer, McCormick, Mayhew, Wasserstein & Arnold, 1997**),** a direct 1RM score would have been more accurate.

2. Although subjects were instructed not to participate in trainings outside of the research gym session and organised team trainings, this was not monitored. Furthermore, factors such as sleep patterns and nutritional habits may have affected subjects' physiological responses to this research.

3. Ideally additional factors such as nutritional intake, sleep and incidental activity levels should have been standardised. However, this was outside the scope of this study.

4. Although efforts were made to standardise sprint testing protocol, as sprint testing occurred in an open environment factors such as wind level and slight variations in surface moisture may have affected results. Speed testing lights were set across wind although changes in wind direction during testing were not accounted for.

5. Rest period between efforts in vertical jump testing should have been standardised in order to help to insure the reliability of this test.

CHAPTER FOUR:

THE EFFECT OF VARIABLE RESISTANCE TRAINING ON LOWER LIMB STRENGTH AND POWER DEVELOPMENT: TRAINING STUDY

Abstract

New training methods are constantly being sought in an attempt to improve strength and power development. One such method is variable resistance training (VRT). This research aims to determine the effect of VRT on one repetition max (1RM) back squat strength, vertical jump height and 30m sprint time. Twenty male athletes (mean age 17.5 ± 0.7 years) were pair matched based on 1RM scores. Subjects completed a five-week within-group standardised training programme with the control group completing fixed load back squats and the experimental group completing variable resistance back squats (with the use of elastic bands). Pre- and post-training vertical jump height, predicted 1RM squat strength and 10m, 20m and 30m sprint speeds were measured. The VRT group had a greater increases in strength and vertical jump, with a moderate difference in predicted 1RM (mean; ± 90% confidence limit; 7.0; ±6.1%) and a small difference in the within-group changes in vertical jump height (4.6; ± 5.4%) from pre- to post-training. All other changes were trivial or unclear. These results suggest that VRT is a useful training technique in lower body strength and power development.

Introduction

Muscular strength is a foundational prerequisite of muscular power (Tan, 1999). Furthermore, a strong relationship between power and dynamic athletic performance has been well established in prior research (Baker & Nance, 1999; Kawamori & Haff, 2004). As such, the ability to develop high levels of muscular strength and power are considered to be critical components in many sporting activities (Kilduff et al., 2007). Due to the importance of strength and power to a wide range of sports, new methods for improving strength and power are continually being sought (Wallace et al., 2006). This is exemplified by the development of training techniques such as ballistic weight training (Crewther et al., 2005; Cronin et al., 2003; Kraemer & Newton, 2000), plyometric training (Fatouros et al., 2000; Luebbers et al., 2003), and Olympic style weight training (Garhammer, 1993; Newton & Kraemer, 1994). One such method that has recently become popular is variable resistance training (Wallace et al., 2006).

Variable resistance training (VRT) is designed to vary a training load throughout a movement, as resistance increases during the concentric phase and decreases through the eccentric phase (Ebben & Jensen, 2002; Wallace et al., 2006). Early examples of VRT consisted of counter balances and pulley systems producing "progressive resistance exercise" (Keohane, 1986). In recent years VRT, provided by the use of elastic bands, has been utilised in rehabilitation to provide controlled stretch and strengthening, and to increase range of motion after trauma (Patterson et al., 2001; Wallace et al., 2006). More recently, however, by attaching elastic bands or chains to a fixed load, variable resistance has been applied to strength and power training in an attempt to improve training adaptations (McCurdy et al., 2008; Wallace et al., 2006).

There are a number of theoretical advantages of VRT as a tool for strength and power development. It has been suggested that variable resistance may allow an optimal load to be maintained consistently throughout the range of motion. This is achieved by increasing the load as mechanical advantage increases through the accumulation of muscular force during the concentric phase of a movement (Ebben & Jensen, 2002;

Faron, 1985; Ghigiarelli et al., 2009). This is thought to combine the benefits afforded from the range of motion and acceleration of ballistic type training, while at the same time including the higher loads normally utilised in traditional resistance training (Wallace et al., 2006). Furthermore, it has been suggested that the use of elastic tension provides a more rapid descent phase than in fixed load training, causing greater eccentric muscular contraction and improved adaptations (Conlin, 2002).

Despite the theoretical advantages of VRT and the recent popularity of utilising chains and bands in training movements (McCurdy et al., 2008), there is still a lack of research into the effects of variable resistance as a training tool. The majority of research that does exist in this field has been acute in duration and only a small amount of research exists investigating the training effects of variable resistance on upper body power (McCurdy et al., 2009; Ghigiarelli et al., 2009). Some research into the effects of prone machine squat jump VRT has been undertaken, although this has some limitations due to the body position and the specific ballistic type training utilised (Cronin, 2003). Therefore, further research is required investigating the longitudinal effects of VRT, specifically on lower limb strength and power development.

This study aims to evaluate the effect of VRT, with loads afforded by variable resistance elastic bands, on lower limb strength and power development. Tests consisted of one repetition maximum (1RM) back squat, predicted from a four repetition maximum (4RM), vertical jump and 30m sprint speed.

Methods

Experimental Design

A pair matched training study was implemented over a five week training period to compare the mean changes in predicted 1RM back squat strength (from a 4RM test), vertical jump height and 30m sprint speed between a VRT group and a fixed load training group. Subjects were pair matched based on pre-training predicted 1RM strength. Vertical jump height and 30m sprint speed were tested both at the beginning and the end of the training period, while the 4RM test was implemented at the beginning, mid-point and end of the five-week training period.

Subjects

Twenty male high school rugby union players participated in the study (Table 4). Subjects were all involved in pre-existing training environments. A small number of subjects within the training group did not complete all testing measures due to sports related injuries. However, subject information was included for all subjects who contributed meaningful data.

Table 4: Physical Characteristics of High School (Subjects Mean ± SD).

	Training Group		
	Fixed Load	Variable Resistance	Combined
Number of Subjects	10	10	20
Age (y)	17.5 ± 0.5	17.4 ± 0.8	17.5 ± 0.7
Height (m)	1.60 ± 0.05	1.58 ± 0.03	1.59 ± 0.04
Mass (kg)	85.2 ± 11.8	88.6 ± 9.1	87.0 ± 10.3

Heights was measured from subjects' shoulders i.e. height of the barbell.

Protocol

All subjects participated in a five-week back squat training intervention. Back squat training sets and repetition were identical between the fixed load and VRT groups. All squat training took place in training cages, under the supervision of a trained fitness professional and with the assistance of a spotter if required. Throughout testing and training, squat depth were standardised to a depth of 90 degrees at the knee. Training repetitions and sets are outlined in the methods section (Table 2).

Suggested repetitions, sets and loads were provided to the subject at the beginning of each session, for both training groups. Training loads were prescribed based on a reverse Brzycki formula from the subjects' predicted 1RM and rounded to the nearest 5kg. One repetition max strength scores were predicted using the Brzycki formula on subjects' pre-training 4RM scores **(**LeSuer et al, 1997**).** The Brzycki formula was chosen primarily because of its close statistical relationship between predicted and actual 1RM back squat scores and its ease of mathematical reversal.

During variable resistance lifts, elastic band variable resistance made up 25 ± 5% of the total load. This range of variable resistance was chosen to reflect previously determined effective loading procedures (Wallace et al., 2006). A range of ± 5% was allowed due to the difficulty of obtaining specific variable resistance loads with the commercial bands available. In order to encourage a more specific stimulus toward power adaptations, every second training session was performed under 20% reduced load with powerful intent as it has been suggested that intent to move a load at speed results in greater power adaptation (Behm & Sale, 1993a; Young & Bilby, 1993).

Variable resistance training loads were standardised to fixed loads in order to ensure that differences in training adaptations were due to variations in the training stimulus rather than variations in training loads. This was achieved by measuring the load afforded by variable resistance bands on a force measuring plate (Kistler 9281B, Kistler Instruments, Hampshire, UK) and subtracting half of the load afforded by variable resistance bands from the fixed load, insuring that the mean load lifted in the VRT group was equivalent to those in the fixed load training group.

In order to account for the differences in the load afforded by variable resistance depending on subjects' height, VRT subjects were categorised into groups based on their height. The height of every subject was measured from bar height at the top of a natural squat movement with subjects subsequently divided into two height categories. As it was not logistically possible to measure the resistance afforded by variable resistance bands on each subject, two subjects who closely reflected the median point of each height group were used to determine an average load achieved by the respective height groups. The heights of these subjects were 1.67m and 1.57m when measuring the height of a barbell on the shoulders at the top of a natural squat movement.

To determine the reliability of training loads used throughout the study, the resistance of each band at 1.67m and 1.57m stretch was also measured at the mid-point and completion of the training study. This was done in order to determine the rate of relaxation that occurred to the variable resistance elastic bands with use. Due to minor changes in the amount of variable resistance afforded by elastic bands after use, loading protocols were adjusted accordingly at the mid-point of training to ensure that loads prescribed reflected the actual load lifted.

Statistical Analysis

Changes in the pre-, post- and mid-data (where relevant), for back squat 1RM, vertical jump and sprint speed were analysed using a pre-post controlled trial spreadsheet (Hopkins, 2006b). All data were log-transformed and adjusted to the mean of pre-test values before analysis as a covariate. All statistical analyses were determined to a 90% confidence interval (CI). Data were back transformed for use in analysis and is presented as percentage difference in change; ±confidence limit unless otherwise stated. A modified Cohen scale was used to determine the magnitude of the differences between the within-group changes, with <0.2 representing a trivial difference, 0.2 - 0.6 representing a small difference, and 0.6 - 1.2 representing a moderate difference (Hopkins et al, 2009). Data that crossed the threshold for a small positive and small negative difference (-0.2 – 0.2) was determined as unclear.

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Results

The mean predicted 1RM of the VRT group increased more in both pre- to mid-training and pre- to post-training than the fixed load group (Table 6). Specifically, percent changes in strength measures for high school athletes shows a small (4.8; ±5.3%) and a moderate (7.0; ±6.1%) differences in changes between the fixed load training and the VRT in predicted 1RM in pre-mid and pre-post values respectively (Table 6). Pre-training performance measures are included in Table 5.

Table 5: High School Subjects' Pre-Training Performance Measures (Mean ± SD) of Variable Resistance Training (n=10) and Fixed Load Training (n=10) Groups.

	Training Group		
	Fixed Load	Variable Resistance	Combined
Back Squat 1RM (kg)	158 ± 16	165 ± 15	161 ± 16
Vertical Jump Height (cm)	58.6 ± 4.1	54.2 ± 7.4	56.13 ± 6.4
10-m Sprint Time (s)	1.8 ± 0.08	1.8 ± 0.08	1.8 ± 0.08
20-m Sprint Time (s)	3.2 ± 0.16	3.2 ± 0.09	3.2 ± 0.11
30-m Sprint Time (s)	4.5 ± 0.22	4.4 ± 0.12	4.4 ± 0.16

Table 6: A Comparison of High School Subjects' Variable Resistance Training (n=10) and Fixed Load Training (n=10) Groups Performance Measures. Including Percent Change in Back Transformed Mean ± SD and Difference in Mean Change; ± 90% Confidence Limit.

	Training Group		% Difference in
Performance Measure	Fixed Load (mean ± SD)	Variable Resistance (mean ± SD)	Change[a] (mean; ±CL)
Pre-Mid 1RM (kg)	9.1 ± 7.4	14.4 ± 5.0	4.8; ±5.3*
Pre-Post 1RM (kg)	17.8 ± 7.7	26.0 ± 5.7	7.0; ±6.1‡
Vertical Jump (cm)	4.5 ± 5.5	9.3 ± 4.3	4.6; ±5.4*
10m Sprint (s)	2.3 ± 1.1	0.5 ± 4.2	1.8; ±3.4
20m Sprint (s)	-0.8 ± 1.8	-0.9 ± 3.9	-0.1; ±3.2
30m Sprint (s)	-2.2 ± 1.5	-1.5 ± 4.1	0.7; ±3.4

[a]Note that the difference in change of mean does not reflect the exact difference in the change between the control and experimental groups due to back transforming the difference in the change and working with factors. * = small difference: ‡ = moderate difference.

Subjects in both the VRT and fixed load training groups with lower pre-testing predicted 1RM scores showed greater strength improvements. However, the improvement in subjects with higher pre-training 1RM scores was lower in the fixed load training group than the VRT training group (see Figure 1).

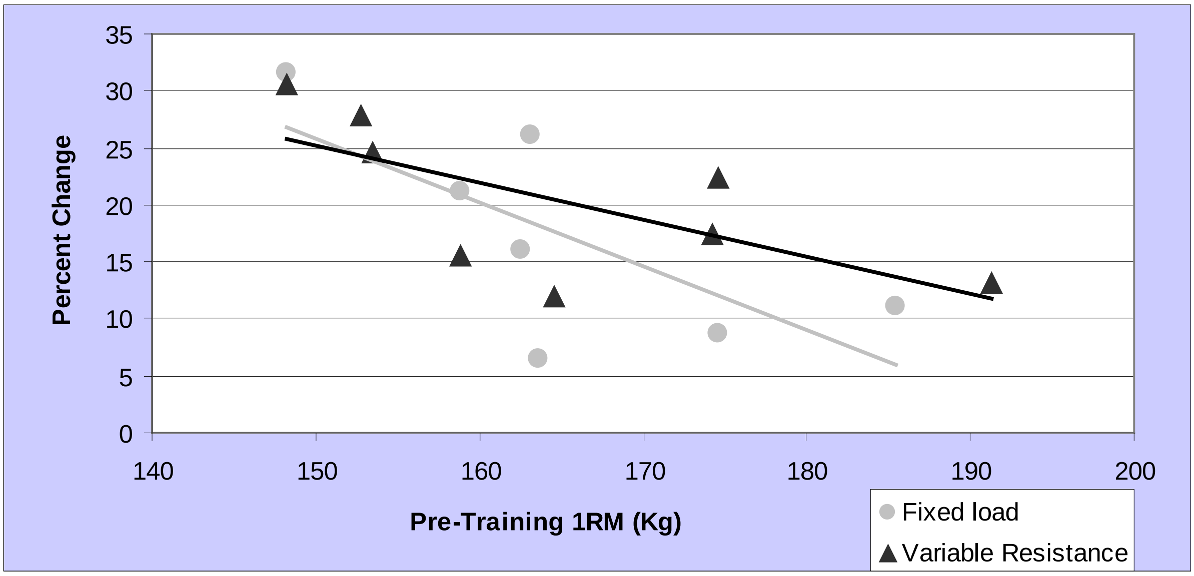

Figure 1: A Comparison of Pre-Training Back Squat 1RM strength and Percent Improvement in Pre-to Post-training Squat Strength Between the Fixed Load Training Group (n=10) and the Variable Resistance Training Group (n=10).

The VRT group also showed a greater improvement than the fixed load training group in pre- to post- study vertical jump height (Table 6). A small difference in pre-training vertical jump height was observed between the training groups (4.35cm greater vertical jump height in fixed load group). Furthermore, for the VRT group, improvements in vertical jump height were greater in subjects with better pre-test vertical heights (Figure 2). This trend was not reflected in the fixed load training group.

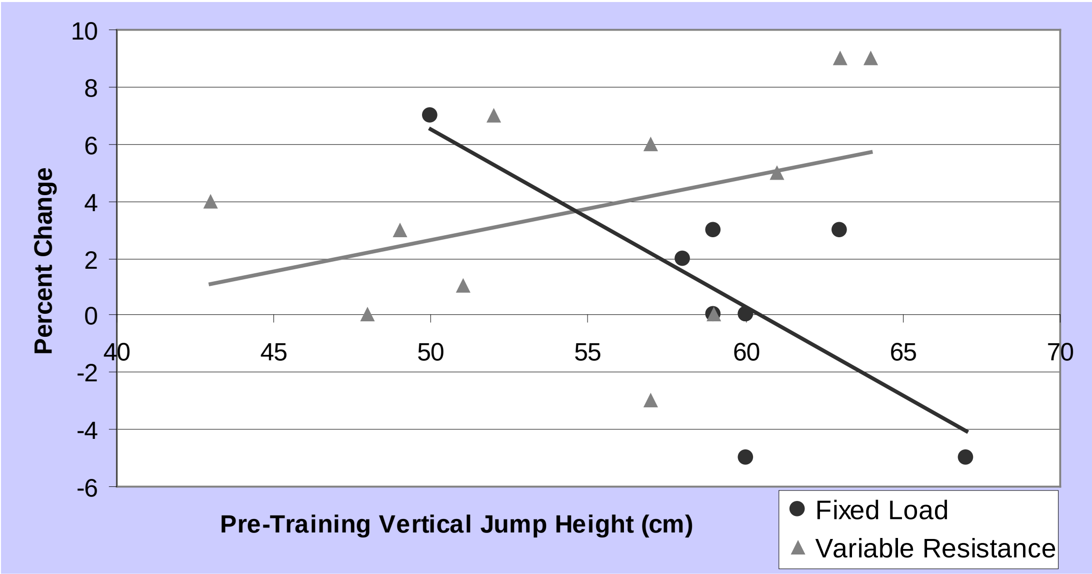

Figure 2: A Comparison of Pre-Training Vertical Jump Height and Percent Improvement in Pre- to Post-Training Vertical Jump Height Between the Fixed Load Training Group (n=10) and the Variable Resistance Training Group (n=10).

Changes in sprint times over all distances were unclear. A decrease in performance was measured over 10m meters in pre-post study sprint speeds in both the variable resistance and fixed load training group. However, both groups showed improvements over 20m and 30m (see Table 6). Greater improvements in sprint times were only seen in the VRT group as compared to the fixed load training group over 20 m.

Discussion

The primary aim of this research was to determine the effect of VRT using band tension on strength and power measures of predicted 1RM, vertical jump and sprint speed. This study has found a small difference in mean change in pre-mid training predicted 1RM of 4.8; ±5.3% and a moderate difference in mean change in pre-post-training predicted 1RM of 7.0; ±6.1% in high school athletes. It is clear, based on these findings, that variable resistance produces a greater improvement in back squat strength than traditional fixed load training in this population group.

As variable resistance loads were normalised to the fixed load training group, average resistance values were equitable to a fixed load. This ensured that work done was equal between the two training groups, comparative to pre-test strength results. As such, superior strength and power gains in the VRT group cannot be due to greater loading or greater work done and reflect a real advantage in this training technique. As well as this, changes in the load afforded by the bands used in the present study over the five-week training period were shown to be minimal. By monitoring the changes in resistance afforded by variable resistance bands due to repeated use, and adjusting for these changes when prescribing variable resistance loads, variable resistance loads were consistently accurate throughout the training study.

The exact physiological mechanism which contributes to the effectiveness of VRT in strength development is unclear. It has been suggested that variable resistance may allow an optimal load to be maintained throughout a range of motion (Ebben & Jensen, 2002; Faron, 1985; Wallace et al., 2006). This is thought to be achieved because variable resistance affords increasing load as accumulated muscular force throughout a concentric movement, or mechanical advantage, increases (Ebben & Jensen, 2002; Faron, 1985; Ghigiarelli et al., 2009; Wallace et al., 2006). However, during fixed load training, optimal load may only be obtained over the weakest point of a movement, the biological “sticking point” (Fleisig, 2001; Faron, 1985; Keohane, 1986). By optimising loading throughout the movement, greater muscular stimulus may occur, resulting in greater strength adaptations (Faron, 1985; Wallace et al, 2006).

Another theory concerning the superiority of VRT over fixed load training in the development of strength is that it produces eccentric loads which exceed normal training stimulus by increasing the return velocity. This necessitates greater muscular force to decelerate a load, causing greater muscular adaptation (Conlin, 2002; Cronin et al., 2003). This concept, however, is still very much speculative with very little scientific evidence to support the concept that the use of elastic tension results in greater eccentric loading than concentric loading. Furthermore this current study does not shed light on the physiological mechanism by which VRT produces physiological adaptations. However results do demonstrate that there are mechanisms at work that result in greater improvements in lower limb strength and vertical jump height using VRT over fixed load training.

The present study also found that a 4.6; ±5.4% greater improvement occurred in vertical jump height in the VRT group as compared to the fixed load training group. This suggests that VRT may also be beneficial in improving lower limb power. It has been suggested that VRT may provide greater improvements in muscular power development by affording an increased range of acceleration compared to fixed load training (Wallace et al., 2006). One of the limitations of traditional weight training is that it produces a significant deceleration phase at the end of the concentric motion (Cronin et al., 2003). During variable resistance movements, resistance increases progressively throughout the concentric contraction allowing for greater muscle activation (Ebben & Jensen, 2002; Wallace et al., 2006), which in turn allows for velocity to be maintained at greater loads at the top of the concentric movement (Conlin, 2002). This is supported by research demonstrating that both peak and mean force increases under variable resistance loading, as greater loads can be moved at greater velocity (Wallace et al., 2006). However, no specific research exists supporting this suggested kinematic cause of increased peak power due to VRT.

An interesting finding of this research is that the VRT group showed greater improvements in vertical jump height in subjects with superior pre-training jump heights. This suggests that VRT may be more effective in improving power in athletes who already have muscular ability. If this trend is representative of the wider training population, it is a noteworthy finding in the development of lower limb power, particularly for highly trained athletes who already possess great lower limb power. As well as this, lower 1RM back squat improvements were found in fixed load subjects with higher pre-training 1RM scores as compared to VRT subjects. Although this trend is not as prominent as that found in vertical jump height, this too suggests that VRT may also be more advantageous to highly trained athletes in developing lower limb strength. However, further research is required to determine the validity of these findings.

No clear difference in pre-post changes in sprint speed was observed between the fixed load and VRT groups. It is interesting that clear improvements were found in vertical jump height, but not in sprint speed, even though vertical jump height is commonly used as an indicator of lower limb power and subsequently a predictor of sprint speed (Rafael, Del Olmo, Gonzalez, Jodar & Perez, 2008; Meylan et al., 2009). However, most human movements, including sprinting, utilise both horizontal and lateral force production (Meylan et al., 2009). Although vertical jump height and explosive squat movements have been shown to have a high correlation to vertical sprint force (Harris, Cronin, Hopkins & Hansen, 2008; Rafael et al., 2008; Meylan et al., 2009), it is also generally accepted that physiological adaptations closely reflect training stimulus (Hill, Leiferman, Lynch, Dangelmaier & Burt, 1997). As both vertical jump and squat movements rely on vertical force production with little consideration for horizontal or lateral force production (Meylan et al., 2009), it may be that back squat VRT produces greater improvements in vertical power than fixed load training, but that this improvement in vertical power is not readily transferred into improvements in sprint speed which also requires force production in the horizontal plane.

A pre-post improvement of 26.0 ± 5.7% and 17.8 ± 7.7% (% difference in mean change ± SD) were observed in the variable resistance and fixed load training group respectively in predicted 1RM strength. Although these gains may seem large, these results are not unusual for adolescent training groups. It is common for gains of approximately 30% to be obtained in adolescents over short (8-20 week) training periods (Faigenbaum et al., 2009), with the majority of improvement occurring early in the training periods (Falk & Tenenbaum, 1996). There are some limitations to the applicability of findings from research on adolescent populations to wider population groups. However, the accelerated rate of improvement in adolescent athletes has been shown to slow by the age of 16-17, particularly in population groups that have trained throughout their early pubescent years (Jagiello et al., 2004). This suggests that athletes at this age or older more closely reflect adult physiologies than younger athletes do. In light of this, as the high school athletes utilised in this research were pre-trained and had a mean age of 17.5 ± 0.7 years, the results of this research may also be applicable to more mature athletes.

The findings of this research have shown that VRT improves predicted 1RM back squat strength and vertical jump height to a greater extent than traditional fixed load training in high school athletes. No differences were found in sprint speed between the VRT and fixed load training groups, suggesting that the advantages of VRT seem only to be obtained in the plane of motion in which training occurs.

Practical Application

The loading procedure utilised in this study, utilising of 25% variable resistance, was shown to be effective in producing greater 1RM strength and vertical jump height during back squat training. As such, this loading procedure may be implemented into back squat training protocols in order to improve adaptations. Although other VRT loading procedures may also be useful in improving lower limb strength and power, to date, this training procedure is the only one proven to be beneficial in improving lower limb 1RM and vertical jump height. Prior research has been inconclusive in showing benefits of VRT in upper body strength and power.

As a result of these findings, it is suggested that back squat VRT be included in resistance training programmes that aim to improve lower limb strength and vertical jump height in high school age athletes. Back squat VRT is a viable training tool that may effectively be implemented by conditioning and strength specialists in this age group. Although these findings are specific to younger athletes, trends indicate that VRT may also be implemented into training protocols for mature and highly trained athletes.

CHAPTER FIVE:

THE EFFECT OF VARIABLE RESISTANCE TRAINING ON LOWER LIMB STRENGTH AND POWER DEVELOPMENT:

SEMI-ELITE CASE STUDY

Subjects

Eleven semi-elite rugby union players participated in the study (table 7). Subjects were all involved in a pre-existing regional high performance training environments. Due to a number of sports related injuries and complications in training schedules, some subjects did not complete all performance measures thus lowering the subject sample and decreasing the statistical power. As a result of this, data from the semi-elite training groups was treated as a case study, with results compared to those found in the statistically powerful high school training group.

Table 7: Physical Characteristics of Semi-Elite Subjects (Mean ± SD).

	Training Group		
	Fixed Load	Variable Resistance	Combined
Number of Subjects	4	7	11
Age (y)	21 ± 1.8	19.3 ± 1.4	19.9 ± 2.0
Height (m)	1.58 ± 0.03	1.63 ± 0.06	1.61 ± 0.05
Mass (kg)	95.7 ± 7.6	100.1 ± 9.8	98.5 ± 9.0

Heights was measured from subjects' shoulders i.e. height of the barbell.

Results

Pre-training performance measures for the semi-elite subjects are included below (Table 8). All differences in between-group changes in performance measures were unclear and statistically insignificant (table 9). Changes in predicted 1RM strength in the semi-elite case study are similar to those found in the high school subjects, with greater improvements in pre-mid and pre-post scores in the VRT group than the fixed load training group. Within the fixed load training group the decrease in mean pre-mid test 1RM strength did not represent a decrease in strength in all fixed load subjects. These data were skewed by an outlier who obtained a pre-mid test change in 1RM strength of -16.0%.

The VRT group did show greater improvements than the fixed load training group over 20m and 30m sprint time. Both the fixed load and variable resistance semi-elite subject groups showed a decrease in mean vertical jump height although the VRT group showed the greater regression (Table 9). Although the VRT group showed a greater regression, dis-improvements in the VRT group were not as great in those subjects with better pre-training vertical jump heights. This trend was not reflected in the fixed load training group.

Table 8: Semi-Elite Subjects' Pre-Training Performance Measures (Mean ± SD) of Variable Resistance Training (n=7) and Fixed Load Training (n=4) Groups.

	Training Group		
	Fixed Load	Variable Resistance	Combined
Back Squat 1RM (kg)	202 ± 32	179 ± 17	187 ± 24
Vertical Jump Height (cm)	63.0 ± 5.7	58.0 ± 1.4	60.5 ± 4.4
10-m Sprint Speed (s)	1.7 ± 0.05	1.8 ± 0.12	1.7 ± 0.09
20-m Sprint Speed (s)	2.9 ± 0.1	3.1 ± 0.16	3.0 ± 0.15
30-m Sprint Speed (s)	4.1 ± 0.12	4.3 ± 0.23	4.2 ± 0.19

Table 9: A Comparison of Semi-Elite Subjects' Variable Resistance Training (n=7) and Fixed Load Training (n=4) Groups Performance Measures, Including Change in Mean ± SD and Difference in Mean Change.

	Training Group		Difference in Mean
Performance Measure	Fixed Load (X ± SD)	Variable Resistance (X ± SD)	Between Groups
Pre-Mid 1RM (kg)	-3.7 ± 19.0	33.3 ± 8.9	37
Pre-Post 1RM (kg)	28.4 ± 5.6	34.1 ± 5.2	5.7
Vertical Jump (cm)	-1.0 ± 5.7	-1.5 ± 2.1	-0.5
10m Sprint (s)	0.00 ± 0.0	0.02 ± 0.01	0.02
20m Sprint (s)	-0.01 ± 0.1	-0.04 ± 0.0	-0.03
30m Sprint (s)	0.00 ± 0.02	-0.03 ± 0.0	-0.03

Note that all differences in mean change between groups were unclear.

Discussion

The case study undertaken into the effect of VRT in semi-elite athletes has shown mean predicted 1RM scores to improve to a greater extent in response to VRT than fixed load training, particularly in pre-mid training results. This suggests that VRT may also produce greater improvements in lower limb strength than traditional fixed load training in this population group. However, results concerning differences between the groups in this population were unclear due to a lower sample size and require further research.

A regression within the fixed load training group in pre-mid test 1RM was observed. As fixed load back squat training is a common training technique in semi-elite rugby players, this may be explained by a plateau or even a decline in muscular performance that often occur as a result of training with a particular stimulus over a period of time (Werbom et al., 2007). This result may additionally be explained by an outlier in the fixed load training group who obtained a pre-mid test change in 1RM strength of -16.0%.

Unlike the high school training group, improvements in vertical jump height were not found in either the fixed load or variable resistance groups in the semi-elite case study. This may reflect between group training variations in the high school training group and the semi-elite subject case study. However, it may be a more important finding that the regressions in vertical jump height performance were greater in the VRT group than the fixed load training group in the semi-elite training case study. This is in direct contrast to findings in the high school athletes who achieved greater improvements in vertical jump height in the VRT than to the fixed load training group. However, findings in the semi-elite case study are not clear. Differences between the results of high school and semi-elite training groups may be explained by the small sample size and subsequent lack of reliability in the semi-elite training case study.

No clear change was found in sprint speed between the fixed load and VRT groups in the semi-elite case study. These findings are consistent with the high school subject study which also failed to show a clear difference between the VRT and fixed load training groups. Both the high school athletes and the semi-elite athletes showed a greater improvement in sprint time over 20m in the VRT group over the fixed load training group although no clear conclusions can be drawn from this. Additionally semi-elite athletes showed greater improvements in speed in the VRT training group as compared to the fixed load training group over 30m.

Practical Application

Although this case study suggests lacks the statistical power to draw any clear conclusion, it does however *suggest* that VRT is a useful training tool in improving back squat 1RM strength in semi-elite athletes. As such, VRT may be implemented into training protocols for mature and highly trained athletes with a little confidence. Variable resistance training has not been shown to improve either vertical or horizontal power in semi-elite athletes and, as such, cannot be utilised with confidence as a training tool to improve lower limb power in highly trained athletes. However, it should be noted that the results in the semi-elite case study are unclear and are subject to further research.

CHAPTER SIX CONCLUSION

Restatement of Aims and Hypotheses

The primary aim of this research was to determine the effects of VRT on back squat strength, vertical jump height and 30m sprint time compared to traditional fixed load training. It was hypothesised that VRT would cause greater improvements than fixed load training in all of these measures.

Summary of Results and Conclusion

This study found that VRT improves predicted 1RM back squat strength to a greater extent than traditional fixed load training in high school athletes as VRT produced a small (4.8; ±5.3%) and moderately (7.0; ±6.1%) greater improvement in pre- to mid- and pre- to post-training predicted 1RM strength respectively. This study also found that VRT produced a 4.6; ±5.4% greater improvement in vertical jump height in comparison to fixed load training in high school subjects. No clear changes were found in between group sprint times. These results show that VRT is useful in developing lower limb strength vertical power development. However, the failure of VRT back squat training to improve sprint speed suggests that VRT is only beneficial in improving power within the plane of movement in which training occurs. Furthermore, it was found that athletes with greater pre-test vertical jump height achieved greater improvements in vertical jump height. This suggests that VRT may be particularly beneficial in developing lower limb vertical power in highly trained athletes or naturally talented athletes with already great lower limb power.

The effect of VRT on strength and power development in semi-elite subjects was also explored. Although none of these findings were statistically clear, it was found that semi-elite athletes had greater improvements in predicted 1RM strength as a result of VRT similar to those found in the high school athletes. This supports findings in the high school training group that VRT is an effective training tool for improving lower limb strength. In contrast to the findings of the high school subjects, semi-elite subjects did not show improvement in vertical jump height in either the VRT or fixed load training groups. This variation in findings may be explained by limited numbers of subjects in the semi-elite training study.

Regression in the tension afforded by variable resistance bands was very small at both the mid-point and after the completion of training. This indicates that the useful life span of the variable resistance elastic bands was greater than the average use of bands in this study (an average of 557 repetitions). This suggests that variable resistance bands may have a relatively long effective life span. Monitoring changes in variable resistance also helped to ensure that the training loads afforded during variable resistance training were accurate and helped to ensure that variations in improvements between the VRT and fixed load training groups were due to differences in the training stimulus, not from differences in loads lifted.

Future Direction in Research

There is a small body of both acute and longitudinal studies addressing the effect of VRT as a training technique, resulting in the need for further research in this field. Furthermore, the acute research that exists concerning VRT is not in agreement as to the effect of VRT in mean and peak force production during training movements (Ebben & Jensen, 2002; Wallace et al., 2006). This is predominantly due to variation in methodological procedures, particularly in standardising variable resistance loads with fixed loads. Because of this, further research is required to clarify the effect that variable resistance has on force production during training movements.

Previously completed longitudinal research in this field of study has focused on the effect of VRT in upper body training, predominantly the bench press. This research has been largely unsuccessful in demonstrating an advantage of VRT over fixed load training, although this may be due to ineffective training and loading procedures. Although research into the effect of VRT in squat jumps has been investigated, very little other research has been undertaken into the effect of VRT on lower limb strength and power development up until this point. The findings of this study have shown variable resistance back squat training to improve lower body strength and power in the vertical plane to a greater extent than fixed load training in high school athletes. This warrants further investigation in to the effect of lower limb VRT in mature athletes. Further research is also required to determine whether VRT may be advantageous in the upper body strength and power development under different training and loading protocols.

Further research is required into the regression in force provided by variable resistance bands with repeated use. This study showed that very little regression in force occurred during the implemented training period. However, further research to determine the deterioration in elasticity of variable resistance bands after a greater number of repetitions, and hence to determine the expected useful life span of variable resistance elastic bands, is warranted.

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APPENDIX A: INFORMATION SHEET

Research Study Information Sheet

The Effect of Variable Resistant Training on Lower Limb Strength and Power Development.

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Introduction

I am currently in the process of assembling an appropriate number of subjects to participate in research designed to investigate the effect that variable resistance has on strength and power development. This training study has been designed to fit into and complement pre-existing training structures and is being implemented into the Waikato High performance, Waikato Academy, St Peters rugby development training programmes and the St Pauls development training programme.

If you do agree to participation in this research you will be required to complete a 5 week training programme and testing session both before and after the completion of the training programme. Two training sessions will be required per week. You will be free to withdraw at any time without consequence or repercussion from any party.

What is variable resistance training?

Variable resistance training is a relatively new training technique in which elastic bands or chains are attached to a traditional barbell during weight training. Variable resistance changes the load throughout the training movement, as elastic tension or the number of links off the ground increase or decrease. This has been suggested to allow an optimal load to be maintained consistently throughout the movement by varying the load as load is increased with muscular mechanical advantage.

Subject requirements

Subjects should be able to complete a four repetition maximal effort back squat, vertical jump and 30m sprint test. Subjects must be willing to complete a 5 week training programme. Subjects must be aged 16 or over.

Benefit to participants

By participating in this training involved in this study subjects will be expected to increase in lower limb strength and power and to improve practical performance measures such as back squat 1RM and 30m sprint speed.

Benefit to the rugby community

The ability to develop muscular power is regarded as one of the most important factors involved in sporting performance. This is certainly true in rugby. Prior research has determined that variable resistance training has the ability increase maximal power outputs in the back squat movement. This would seem to suggest that variable resistance training will be effective in developing muscular power. However no specific training study has been completed to test this hypothesis.

When the research has concluded, a greater understanding of the effectiveness variable resistance training as a training technique will help to inform and improve training strategies within the rugby community.

Possible risks of participation

There is always an element of risk during physical activity. However the back squat is a commonly used exercise and is not related to high levels of injury or physical harm. In order to minimise the risk of physical harm a spotter will be present to provide assistance to subjects during maximal and near maximal efforts. Safety rails will be present to take the load in case of failure during the back squat movement. Subjects will be advised to cease exercise in the presence of any non fatigue related pain.

Measurements that will be taken

- Weight and height.
- One repetition max back squat.
- Maximum vertical jump height.
- 30m sprint time.

Subject confidentiality

All personal information collected during this research will be kept under lock and key in a secure filling cabinet or in a secure computer file which will be accessible only by the principle researcher and their direct supervisor. To protect you identification during presentation of data to the wider public you will be represented as a number rather than with your name and therefore no individual participating in the research will be directly identifiable. Additionally, no direct comparisons between subjects will be made and therefore no individual will be made to feel that their results are wrong or inferior to others.

Ethics

All subjects who chose to participate in this research will be treated fairly and equally. You are not required to participate in this research and should not feel pressured to participate by your club or by Wintec. If you do chose to participate in this research you will be allowed to withdraw at any time for any reason without prejudice.

This study has received ethical approval and will conform to the guideline set by the Wintec ethics committee. No conflicts of interest exist in this research.

Venue of testing and training

Trainings will take place at the Ring Side gymnasium, St Peter's gymnasium and St Paul's gymnasium as appropriate.

APPENDIX B: PARTICIPANT CONSENT FORM

Participant Consent Form

I ____________________________ (please print name) have read and understood the information sheet and consent to participate in the study entitled "The Effect of Variable Resistant on Kinetic Strength and Power Development". I understand all inherent risks, requirements and rights that I have in regards to being a participant in this study and understand that participation in this study is my own choice and that I have the right to withdraw at any time.

Signed________________________ Date___/___/___

Contact details

Phone (home):__________________ (Mobile):_________________

Email:__________________________

Subject Number: _______________ **(researcher use only)**

APPENDIX C: MEDICAL QUESTIONNAIRE

Pre-Exercise Screening Questionnaire

Date of Birth:____/____/_____ Height:______(cm) Weight:______(kg)

Are you currently able to perform a back squat movement under load, 30m sprint or Vertical jump test (please circle): Yes / No

If you answered no please specify why:_____________________________________

____

____

____

Have you ever experienced chest pains while exercising (please circle): Yes / No

Have you been hospitalised in the last 6 months (please circle): Yes / No

Are you currently taking any medication (please circle): Yes / No

Do you experience lower back pain while weight training (please circle): Yes / No

If you answered yes to any of the following please specify why:__________________

____

____

____

I have understood the questionnaire and answered all questions truthfully.

Name:_______________________ Signed:___________________________