The Effects of an Assisted Jump Training Stimulus on Explosive Performance.

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Declaration

I certify that the content of this thesis has not already been submitted for any other qualification or award and is not currently being submitted for any other qualification or award. I also certify that the experimental work, results, analyses, and conclusions reported in this thesis are entirely of my own effort except were otherwise acknowledged.

Paul Croucher

Abstract

Complex training protocols are an effective means to improve explosive performance. However, due to many variations in resistance and plyometric training the effectiveness of different combinations are unknown. Therefore, the purpose of this study was to compare 'traditional' complex training with a 'novel' complex training protocol based on over-speed principles. Seventeen healthy male subjects (20.8 ± 3.6 yrs, 176.2 ± 9.6 cm, and 80.6 ± 13.9 kg) participated in this study. Seven weeks of training was divided into two phases. The first phase of baseline strength training (three weeks) was followed by an intervention (four weeks) consisting of either a strength and vertical jump (SVJ, n=8) phase or a strength and assisted vertical jump (SAJ, n=9) phase. Assessments were conducted prior (PRE1), during (PRE2), and after the training phase (POST1) and included; vertical jump (VJ), 20 m sprint (20m), and squat strength (1RM). All subjects completed the same strength training protocol twice a week. During the four week intervention, jumps were completed 90sec after a lifting set (six sets of six jumps each session). The mean (±CI) vertical jump height improved by 1.6 cm or 3.9%; ±6.6% (SVJ, small effect) and 3.3 cm or 6.8%; 3.5% (SAJ, small effect). The 20 m sprint time improved by 0.03 sec or 0.9%; ±1.8% (SVJ, small effect) and 0.04 sec or 1.3%; ±1.2% (SAJ, small effect). The predicted 1RM squat strength of both groups also improved with increases of 12 kg or 8.9%; ±5.6% (SVJ, small effect) and 15 kg or 10%; ±5.6% (SAJ, moderate effect) found. However there were unclear effects between the two groups in all the performance tests. The strength and assisted jump stimulus was as effective as the traditional strength and vertical jump stimulus to improve strength, power and speed performance.

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Background Literature

Mechanisms for Strength and Power Adaptation

The generation of high forces against heavy resistances and the ability to produce those forces quickly is important for many sports. The use of resistance training to improve one's ability to exert forces quickly has become an integral part of many athletes preparation for their performance during their sporting season (Young, 2006). It is well known that physical training can stimulate adaptation in the neurological and muscular components of the neuromuscular system (Folland & Williams, 2007), which can bring about increases in force and power production. It is generally known that the nervous system can increase force in two main ways 1) by increasing the number of active motor units or 2) by increasing the rate of which the active motor units fire (Christie & Kamen, 2006). It is also well established that, of these components, the neural adaptations are the first to adapt to a new stimulus, after which gradual changes in the muscular components predominate (Moritani & DeVries, 1979). The underlying mechanisms that are responsible for increases in strength and power can be organized into three broad groups, intra-muscular, inter-muscular, and morphological (Young, 2006). The following sections will discuss each broad mechanism for strength and power adaptation.

Neural Mechanisms

The responses of skeletal muscle tissue to resistance training are said to be a major adaptation. However it is not only the size or structure of the muscle that dictates voluntary muscular performance but also the degree to which the muscle can be activated (Sale, 1988). It is commonly known that the nervous system responds favorably to increased physical activity and training by altering the properties of this system, commonly referred to as neural adaptations (Gardiner, Dai, & Heckman, 2006). Neural adaptations are thought to play a major role in the early stages of resistance training (Gabriel, Kamen, & Frost, 2006). This is mainly due to large observed increases in muscular strength without similar increases in muscle hypertrophy (Komi, Viitisalo, Rauramaa, & Vihko, 1978). The term neural adaptation is a rather broad term and could refer to changes in electromyographic (EMG) activity, reflex potentiation, altered co-contractions of antagonists and synergists (Behm, 1995). Possible mechanisms to explain these adaptations will be discussed further under two headings, intra- and inter- muscular mechanisms.

Intra-Muscular Mechanisms

Motor unit recruitment

One neural mechanism that could account for increases in force and power during the early stages of a resistance training programme is the number of motor units recruited. Theoretically, if a person is unable to recruit all of their motor units then increases in forces etc, following training may be attributed to the additional motor units being recruited (Kamen, 2005). Researchers have discovered that the level of motor unit recruitment during voluntary contractions is around 80 - 95%, assessed using the interpolation twitch technique (Belanger & McComas, 1981; Pensini, Martin, & Maffiuletti, 2002). In addition motor units are recruited from smaller to larger units depending on the load or resistance acting on a muscle. This idea has been referred to as the “size principle” by Henneman and colleagues (1965).

It is commonly believed that resistance training can improve motor unit activation. However researchers investigating this idea have found contradictory results. Some reported increases in both maximal voluntary contraction (MVC) and motor unit activation (Del Balso & Cafarelli, 2007; Higbie, Cureton, Warren III, & Prior, 1996; Pensini et al., 2002), while others have found increases in MVC with no differences in motor unit activation after training (Rich & Cafarelli, 2000; Van Cutsem, Duchateau, & Hainaut, 1998). For example the improved motor unit activation reported by Del Balso and Cafarelli (2007) was disproportionate to the increases in MVC, 2.8 ± 0.1% and 20.0 ± 13.9% respectively after four weeks of isometric training. Rich and Cafarelli (2000) also found no change in motor unit activation with a 36% increase in MVC.

The activation of motor units during activity seems to be task dependant, as discovered by Aagaard and colleagues, (2000). These authors found decreased motor unit activation during maximal eccentric contractions and slow concentric contractions. Babault, Pousson, Ballay, and Van Hoecke (2001) concurred on this issue, finding the relationship between voluntary activation levels and sub-maximal torques was linearly fitted ($P < 0.01$). In particular these authors found that a reduced neural drive is associated with slower (20°/s) maximal concentric and both maximal and sub-maximal eccentric contractions and that voluntary activation is dependent on both tension levels and the type of muscular actions in the human knee-extensor muscle group.

It is well recognised that younger and older adults differ in terms of their physical performance, e.g. strength, speed, power etc. Interestingly, there is little difference in motor unit activation between the two populations (Connelly, Rice, Roos, & Vandervoot, 1999). In fact, older trained men (82 year average) were found to activate 99.1% and younger trained men (20.8 year average) activated 99.3% of their motor units. Furthermore, the maximal voluntary contractions (MVC) in these older subjects were 26% lower than their younger counterparts. Knight and Kamen (2008) investigated the relationships between factors of muscular strength generation, muscle activation and firing rates, and found significant correlations between activation and firing rates. Moreover these researchers found a weak correlation between strength and muscle activation.

These data show that although resistance training can improve force output, the changes in motor unit activation can only account for a small fraction of the increase in maximal force. Concurrent increases in force and EMG amplitude may also be caused by changes in motor unit firing patterns. Thus suggesting other neural mechanisms are, in part, responsible for increases in force following resistance exercise.

Motor unit firing frequency

Many investigations have focused on firing rates during acute sessions with varying types of contractions (e.g. Milner-Brown, Stein, & Yemm, 1973; Grimby & Hannerz, 1977; Connerlly et al., 1999; Adam & De Luca, 2005). Other investigations have focused on the adaptive properties of motor units to change their firing rate patterns over time from resistance training (Van Cutsem, Duchateau, & Hainault, 1998; Rich & Cafarelli, 2000; Kamen & Knight, 2004; Pucci, Griffin, Cafarelli, 2005).

Of the four training studies found, researchers of two studies found positive benefits towards improved motor unit firing rates (Van Cutsem et al., 1998; Kamen & Knight, 2004). These authors found improvements in motor unit firing rates with improved MVC. Although Pucci and colleagues (2005) did not find significant differences before and after training, they did note a trend towards improved firing rates at the end of training. Rich and Cafarelli (2000) found contrasting results and found slight decreases in firing rates on the completion of their training.

Interestingly the two studies that found no significant improvements (Pucci et al., 2005; Rich and Cafarelli, 2000) used isometric muscle contractions. Conversely Van Cutsem and colleagues (1998) and Kamen and Knight (2004), used dynamic contractions and found significant improvements in motor unit firing rates. Moreover, older subjects increased their motor unit firing rates by 49% compared to 15% in younger subjects, with 36% and 29% increases in MVC, respectively (Kamen & Knight, 2004). These data suggests that in order to improve maximal motor unit firing rates dynamic (eccentric and/or concentric) resistance exercise should be prescribed and not isometric.

A phenomenon associated with motor unit firing rates called “doublets”, where a motor unit discharges two action potentials close together (Christie & Kamen, 2006).

Doublets are particularly prevalent at the onset of muscular contraction (Van Cutsem et al., 1998) and during lower contractual efforts, i.e. <50% MVC (Christie & Kamen, 2006); and that trained subjects have a greater proportion of doublets occurring compared to untrained subjects. For example, Van Cutsem and colleagues (1998) found the incidence of doublet firing changed from 5.2 to 32.7% after 12-weeks of dynamic resistance training with a 30.2% improvement of MVC. There were also concurrent significant improvements in time to peak tension (15.9% decrease) and the rate of tension development (82.3% increase). No significant improvements were found in the control subjects. The firing of doublets at the onset of contraction may serve to enhance the initial generation of force by taking advantage of the catch-like property (tension enhancement produced when an initial brief high-frequency burst of pulses (2-4 pulses) is used at the onset of a subsequent subtetanic constant-frequency trains to activate the muscle) of skeletal muscle (Burke, 1970), which could increase the rate of force development.

This data suggests that doublet activity could potentially aid in the development of force and power. However, the increases in doublet discharge were also accompanied by changes in other neural mechanisms e.g. motor unit firing frequency that could explain some of these improvements. Due to a dearth in the literature regarding the benefits of resistance training on doublet activity, further research is warranted.

Synchronization

Another possible mechanism for improving output forces is motor-unit synchronization. This is expressed as a change in the timing of motor-unit activation: that is, an increase in the simultaneous activation of motor units

(Semmler, Steege, Kornatz, & Enoka, 2000). Among the first to establish a link between resistance training and increased motor unit synchronization was Milner-Brown, Stien, and Lee (1975). They reported a greater degree of motor unit synchronization in strength trained subjects when compared to a control group thereby leading to the idea that motor unit synchronization may be enhanced by resistance training and moreover play a role in increasing force output.

Motor unit synchronization has been observed during various types of contractions (Semmler, Kornatz, Dinenno, Shi Zhou, & Enoka, 2002; Datta & Stephens, 1990) and in younger and older persons (Semmler et al., 2000). The data presented by these authors have shown greater motor unit synchronization during lengthening (eccentric) contractions (Semmler et al., 2002) and within motor units with lower recruitment thresholds, < 0.5 N or > 1 N (Datta & Stephens, 1990). Synchronization of motor units has been demonstrated not to be different in the aged and young (Semmler et al., 2000). These authors found similar synchronization between young and older men with a significant difference of MVC, 50.3 and 33.3 N respectively. Strength training has shown to improve motor unit synchronisation (Milner-Brown et al., 1975; Semmler & Nordstrom, 1998). For example Milner–Brown and colleagues (1975) have demonstrated that a 6-week resistance training programme can lead to significantly enhanced motor unit synchronization.

Inter-Muscular Mechanisms

Antagonist and Agonist Interactions

Muscular contraction of an agonist results in movement of a joint in the desired direction whereas muscles opposing the intended contraction are deemed antagonists (Gabriel et al., 2006). Co-contraction occurs when both the agonist and antagonist muscles contract during an intended contraction. This co-contraction increases joint stability and stiffness (Kellis, 1998) and acts as a “brake” during fast ballistic type contractions (Marsden, Obeso, & Rothwell, 1983). The “braking” mechanism allows the antagonist to oppose the agonist therefore reducing the force potential of the agonist (Gabriel et al., 2006). In addition, any inhibition of the antagonist activation during fast explosive muscular contractions would theoretically increase the agonists force potential.

Co-contractions of agonists and antagonists have been investigated at different joints (Yildiz, Aydin, Sekir et al., 2006), different muscle contractions (Bassa, Kotzamanidis, Siatras, Mameletzi, & Skoufas, 2002), different speeds (Bassa, Patikas, & Kotzamanidis, 2005), different joint angles (Kubo, Tsunoda, Kanehisa, & Fukunaga, 2004), different ages (Hakkinen, Alen, Kallinen et al., 1998), and during differing levels of fatigue (Croce, Miller, & Horvat, 2008). These researchers have found that antagonist co-contraction appears to be dependent on many factors including: the speed and type of contraction, length of muscle, the age of the muscle, and the level of fatigue present. For example, Bassa and colleagues (2005) found the activity of the antagonist co-contractors were significantly lower during concentric knee flexion than concentric knee extension. In addition there were significant increases in co-contraction activity during faster concentric muscular contractions during knee flexion and extension at different velocities, 45, 90, and 180 deg/s. Interestingly no differences were found between young (10.94 ± 0.6 years) and adult (18.1 ± 0.1 years).

Morphological Mechanisms

Hypertrophy

For the cellular re-organisation of skeletal muscle, exercise is one of the most powerful stimuli for inducing changes; in particular skeletal muscle responds to resistance exercise by means of muscular hypertrophy (Cameron-Smith, 2002). It is acknowledged that morphological adaptation can account for increases in strength and power with resistance training lasting 12 weeks or more (Staron, Karapondo, Kraemer, et al, 1994). However more recent findings of Seynnes, Boer, and Narici (2007) and Blazevich, Gill, Bronks, and Newton (2003) have found significant growth of muscle fibres in as little as three and five weeks respectively. For example Seynnes and colleagues (2007) found significant increases in the quadriceps femoris muscle of 3.5 and 5.2% (at central and distal locations respectively) in as little as 20 days of high intensity leg extension and also after 35 days (6.5 and 7.4% respectively). These new findings suggest that muscle hypertrophy may contribute to strength and power output much sooner than previously thought. The intriguing findings of these studies may have been due to enhanced techniques/equipment available nowadays e.g., high definition sonagraphs and magnetic resonance imagery, compared with much earlier techniques, making it easier to map smaller changes more precisely. Hypertrophic changes within muscle is now thought to be a gradual/progressive process beginning in the early phases of the training period rather than a increase in CSA after a given time during the training period (Seynnes et al., 2007).

Hypertrophy of the muscle fibres following maximal strength or power training are reported to be greater in fast twitch fibres, 19.5% (type IIA) and 26% (type IIB), more so than the slow twitch, 12.5% (type I) fibres (Campos, Luecke, Wendeln, et al., 2002). The greater increases of fibre size of the fast twitch fibres are thought to be from greater relative involvement during high explosive or maximal effort exercise compared to the type I fibres (Adams et al, 1993). Moreover fast twitch fibres are recruited predominately (type IIb, IIab, IIa to type I) during explosive resistance exercise (Harris & Dudley, 2000) and therefore undergo more stress and damage requiring more remodeling and subsequently a greater capacity to adapt compared to slow twitch (type I) fibres.

Hyperplasia

Hyperplasia is a term used to describe the increases in muscle CSA by way of increasing the number of individual muscle fibres as opposed to hypertrophy that increases the size of the individual fibres (Folland & Williams, 2007). Hyperplasia has been documented in animals, and significant increases of ~19% in the number of muscle fibres have been reported (Gonyea, Ericson, and Bonde-Petersen, 1977). However, due to the many ethical and methodological issues trying to assess the amount of fibres *in vivo,* evidence of human muscle fibre hyperplasia are limited to cadaver studies (Folland & Williams, 2007). Researchers do acknowledge the process of hyperplasia occurring within human muscle fibres albeit at a much slower rate than hypertrophy and thus accounts for minor improvements in either strength or power (Appell, 1990; Sjostrom, Lexell, Eriksson, & Taylor, 1991).

There are two possible mechanisms for the process of hyperplasia to eventuate. Firstly, during the remodeling phase, myoblasts fuse to each other (outside of the damaged fibre) instead of fusing with the damaged fibres (Grobler, Collins, & Lambert, 2004). The joining of these myoblasts together outside of the muscle fibre, signal protein synthesis around the fused myonuclei, thus forming new muscle fibres. Secondly, Patterson & Goldspink (1976) and Goldspink (1970) have found hyperplasia to be caused by the branching and splitting/tearing within the sarcomere due to excess tension developed during muscular contraction. Once one Z disc has ruptured the next Z disc in line has greater stress placed upon it which could cause a sort of domino effect of additional splitting of neighboring z disks. Indeed, the rupturing of many Z discs in a sequential manner has shown to cause longitudinal tearing of the muscle fibre. For example, Patterson & Goldspink (1976) found the splitting of muscle fibres occurred at a critical size, approximately 1.1 – 1.2 μm for white fibres and 1.2 – 1.4 μm for red fibres of fish muscle. Patterson & Goldspink (1976) also observed that when a fibre splits the two daughter parts, when combined, ware larger in size than the initial parent leading to their conclusion that additional muscle filaments were added to the daughter regions while the splitting of the fibre is occurring. The addition of filaments could then increase the ability of the muscle to improve strength and power output.

Muscle Geometry

Muscle pennation angle is a term used to describe the angle of which the individual muscle fibres are arranged within the muscle, specifically the angle of the fibre to the tendon or aponeurosis (Kawakami, Ichinose, Kubo, et al., 2000). The angle of pennation and the length of the muscle fascicle (architectural arrangement) within a muscle has shown to affect the amount of force the muscle can produce (Blazevich, Cannavan, Coleman, & Horne, 2007).

The optimum pennation angle of a muscle fibre for maximal force generation has been thought to be 45^{o}. Although few muscle have fibres arranged at this angle, increasing the angle of pennation has been thought to increase force output even in the absence of muscle fibre hypertrophy (Folland & Williams, 2007). Indeed, increases in pennation angle are associated with an increase force output demonstrated by Blazevich and colleagues (2007). These authors found after 10 weeks of either eccentric or concentric knee extension, the angle of pennation increase significantly by an average of ~ 17.9 % accompanied by an average increase of peak torque of ~20.5%.

The length of a muscle fibre has also been reported to have a dramatic effect on force and power generation. This is due to longer muscle fibres are capable of generating forces over longer ranges and are capable of faster contraction speeds (Blazevich et al., 2007). According to Maxwell's model (Maxwell, Faulkner, & Hyatt, 1974), changes in one or more architectural factors of a fibre (length, CSA, or angle of pennation) would cause a change in other factor/s. For example, an increase in muscle fibre length would decrease the angle of pennation and vice versa. However this is not always the case, e.g. Balzevich et al., (2007) and Seynnes et al., (2007) found increases in fibre length, angle and size after resistance training.

The extent to which architectural adaptation occurs depends heavily on the type of exercise and how the exercise is performed (Balzevich et al., 2007). For example, Abe, Kumagai & Brechue (2000) investigated muscle architecture within elite sprinters and distance runners. The authors found sprinters had longer and larger muscle fibres and smaller pennation angle than distance runners. In addition Blazevich and colleagues (2003) investigated different types of resistance exercise along with sprint training on muscle architecture. It was found that subjects that participated in explosive type exercise (squat jumps) decrease their fascicle angle and increased fascicle length whereas those subjects performing strength based exercise (squats and forward hack squats) had increases in pennation angle and decreased fascicle length.

Fibre Type Conversion

Muscle fibres are classified according to their functional capabilities and enzymatic profiles. Fibres are referred to as either ‘slow twitch’ or ‘fast twitch’ based on their contractile properties. Muscle fibres can also be classified according to their myosin ATPase isoform (Pette & Staron, 2000) and/or by myosin heavy chain (MHC) isoform (Schiaffino, Gorza, Sartore et al., 1989). Moreover, MHC types correlate strongly with myosin ATPase isoforms. Slow forms of myosin ATPase (type I) are associated with slow contraction and relaxation times and are more resistant to fatigue. Alternately, fast forms of myosin ATPase (type IIA, IIB and type IIX) are associated with fast contraction and relaxation times and high fatigability (Schiaffino et al., 1989).

Another possible mechanism for increased strength and power output following chronic resistance training is the conversion of one fibre type to another. Researchers have found resistance training can alter the proportion of fibres within the type II subtypes (Campos, Luecke, Wendeln et al., 2002; Staron, Malicky, Leonardi et al., 1990) Resistance training has shown to increase the percentage of type IIa fibres (32.5% pre training vs 39.3% post training) and to decrease the percentage of type IIb fibres (16.2% pre-training vs 2.7% post-training) (Staron et al., 1990). Similar findings have also been demonstrated during different lengths of training ranging between two and 20 weeks (Staron, Karapondo, Kraemer et al., 1994; Staron et al, 1990). In agreement with the findings on fibre type, measurements of MHC show the proportion of MHC IIX (equivalent to type IIX fibres) to fall 5–11% with a similar rise in MHC IIA (equivalent to type IIa fibres) after 12–14 weeks of training (Williamson, Gallagher, Carroll et al., 2001; Andersen, Andersen, Magnusson et al., 2005). However, no convincing evidence has been found for conversion between type I and type II fibres (Andersen & Aagaard, 2000).

Summary

It is clear that numerous adaptive mechanisms can aid in increased force and / or power production including many neural (inter-muscular and intra-muscular) and morphological (hypertrophy, hyperplasia, muscle fibre pennation and length). However the exact mechanism or mechanisms for the observed increases in force or power is as of yet still undetermined and the aforementioned factors are at the forefront of possible likelihoods. What is clear though is changes appear to be dependent on the specific nature of the training stimulus. No single mechanism can account for the total improvements measured within the literature and thus combinations of both morphological and neural mechanisms may be aiding improvement at the same time. Further research into the precise mechanisms of increased strength and power output is warranted.

Training Protocols that Contribute to Lower Body Explosiveness

Lower body explosiveness is an important component for the successful completion of many sporting events and the vertical jump is possibly the best exercise to represent this (Potteiger, Lockwood, Haub, et al., 1999). Several training schemes have been developed over the years with a focus on improving the ability of the neuromuscular systems responsible for power production (Smilios et al., 2006). Different training protocols have been found to elicit different adaptations within the human body which account for the observed changes in performance (Hass, Feigenbaum, & Franklin, 2001). Some of the more recognised training protocols for improving explosive performance include; maximum strength training (80-100% of 1RM), higher velocity training (0-70% of 1RM [Cormie, McCaulley, Triplett, & McBride, 2007; Siegel, Gilders, Staron, & Hagerman, 2000]), plyometrics, over-speed, and combinations of these (Wilson et al., 1993). These training protocols will now be discussed for their significance in the development of explosive performance. The training schemes will be separated into two sections, single and mixed methods.

Single Focus Training Protocols

Slow Movement Velocity Training Protocols

Slow movement velocity training protocols (maximal strength training) are associated with relatively high loads (80-90% 1RM) that are lifted for few repetitions (4-8) (Wilson et al., 1993). This method of training is seen to improve both muscular strength and power output (Brown et al., 2007). The observed increases in power production following heavy strength training may be due to the result of two main factors. Firstly: type II muscle fibre adaptations. During explosive muscular contractions (jumping, sprinting, maximal lifting etc), type II fibres are recruited more so than type I fibres, therefore adaptations (morphological) occur predominately within the type II fibres (Campos et al., 2002). These resulting adaptations within the type II muscle fibres (increased emzyme activity, conversion to type II fibres from type I, etc) have shown to increase strength and power output (Costill, Coyle, Fink, Lesmes, & Witzmann, 1979). Secondly, increases in the speed of muscular contraction due to neural adaptations include: increased motor unit activation, co-ordination, and motor unit synchronisation (Baker, Wilson, & Carlyon, 1994). Although maximal strength training involves slower movement velocities, power output can still be enhanced provided the intention to move the resistance is quick (Behm & Sale, 1993).

The use of maximal strength training to improve an individual's strength is very consistent throughout the literature (Table 1). Of the reviewed studies only Kotzamanidis, Chatzopoulos, Michailidis, Papaiakoyou, & Patikas (2005) failed to measure strength. Strength was measured by one repetition maximum (1RM) leg press (Sayers, 2007), 1RM squat (Brown et al., 2007), or maximal isometric force (Wilson et al., 1993) tests in the other reviewed studies. The reported increases in strength ranged from 6% (0.2 effect size [ES]) to 32% (1.6 ES) (Neils, Udermann, Brice, Winchester, & McGuigan, 2005; Brown et al., 2007). Interestingly, the many variations in this training protocol (sets, reps, frequency etc) made no difference to the effectiveness of the protocol on strength development. For example the researchers who reported the greatest gains in strength utilized the shortest and the longest training periods of six and 12 weeks (Brown et al., 2007; Vissing, Brink, Lonbro, et al., 2008).

Table 1: Maximal strength training protocols and their influence on lower body explosiveness.

Author	Subjects	Training Status	Study length	Tests	Results (Effect Size)
Brown et al, 2007	18 FM	Untrained	6 wk	1RM LP, VJ HT	*↑ 32% (1.6), #↑ 4.0%(0.16) 1RM Leg Press and Vertical Jump Height
				30 sec WG PP, MP	#↑ 4.0%(0.5), *↑ 6.0%(0.3) Wingate Peak Power and Mean Power
Harris et al, 2000	51 M	Recreational	9 wk	1RM Squat	*↑ 10%(1.7) 1RM Squat Strength
				VJ HT, MP, PP	#↑ 2.0%(CC), #↑ 3.0(0.6), #↑ 3.0%(0.6) Vertical Jump Height, Mean, Peak Power
				30m sprint	↔(0.0) 30m sprint
Jones et al, 2001	26 M	Trained	10 wk	1RM Squat	*↑ 16%(1.7) 1RM Squat Strength
				30 and 50% 1RM JS PP	#↑ 5.0(0.2) and 2.9%(0.19) in 30 and 50% Jump Squat Peak Power
Kotzamanidis, et al, 2005	35 M	Untrained	13 wk	CMJ	#↑ 1.0%(0.07) Counter Movement Jump
				30 m Sprint	↔(0.12) 30m sprint
Neils et al, 2005	16 MX	Recreational	8 wk	1RM Squat	*↑ 6.0%(0.2) 1RM Squat Strength
				CMJ, HT and P	#↓ of 2.0%(0.06) , *↑ 8.4%(0.16) in Counter Movement Jump Height and Power
Sayers, 2007	12 OMX	Untrained	12 wk	1RM LP	↑ 21% (CC) 1RM Leg Press
				KE PP at 40, 50, 60, 70, 80, and 90% 1RM	↑ 9.0 - 22% (CC) Knee extensor Peak Power
Vissing et al, 2008	16 M	Untrained	12 wk	1RM LP	*↑ 29.0%(CC) 1RM Leg Press
				CMJ HT and PP	↔(CC) Counter Movement Jump Height and Peak Power
Wilson et al, 1993	64 NM	Recreational	10 wk	Max Iso Force, CMJ HT	*↑ 14%(0.6) Max Isometric Force, *↑ 5.0%(0.2) Counter Movement Jump Height
				6 sec PP Cycle	*↑ 5.0%(0.2) Peak Power Cycle

M = Male; FM = Female; MX = Mixed Gender; O = Older; OMX = Older Mixed Gender; NM = Not Mentioned; wk = weeks; P = Power; PP = Peak Power; MP = Mean Power; VJ = Vertical Jump; DJ = Depth Jump; SJ = Squat Jump; CMJ = Counter Movement Jump; HT = Height; KE = Knee Extension; SJ = Squat Jump; JS = Jump Squat; MK = Margaria-Kalamen; WG = Wingate; ↑ = Increase; *↑ = Significant Increase; #↑ = Non Significant Increase; ↔ = No difference / No Change; *↓ = Significant Decrease; #↓ = Non Significant Decrease; CC = Couldn't Calculate.

For the purpose of this review to distinguish between the level of training the following categories were used: untrained = subjects with no resistance training experience and/or sedentary individuals; recreationally trained = subjects who play recreational sports and/or up to one year resistance training experience; trained = subjects who play competitive sports and have greater than one year resistance training experience; elite = subjects who compete in either national or international sport.

Of the reviewed literature the researcher that recruited the less trained subjects i.e. untrained, found the greater magnitudes of improvement compared to the literature involving more trained subjects. For example, Vissing et al., (2008), Sayers (2007), and Brown et al., (2007) all recruited untrained subjects and found after 12 and six weeks of strength training between 21 – 32% (1.6 ES Brown et al., 2007) increases in strength. Those studies with more trained subjects (recreationally trained) found 6 – 14% (0.2 - 1.7 ES) improvements in strength (Harris, Stone, O'Bryant, Prolux, & Johnson, 2000; Neils et al., 2005; Wilson et al., 1993) and trained subjects found a 16% (1.7 ES) increase in strength (Jones, Bishop, Hunter, Fleisig, 2001).

Strength training schemes have been investigated with the intent of increasing power output by increasing maximal strength (Jones et al., 2001; Vissing et al., 2008; Sayers, 2007). This type of training has been somewhat successful in improving power output (Table 1). For example, Jones et al., (2001) found high load intervention groups improved 1RM squat strength by 16% (1.7 ES) with a concurrent increase in power output of 5.0% (0.2 ES) compared to controls. Not surprisingly the increases in power output were seen at the intensities similar to that of the training loads, i.e. greater power outputs at load ranges of 35% to 90% 1RM. Some researchers have not recorded similar improvements in power output following high load / maximal strength training protocols (Vissing et al., 2008).

Of the eight research articles that were found, three utilised bi-weekly training (Brown et al., 2007; Wilson et al., 1993; Harris et al., 2000) and four trained tri-weekly (Vissing et al., 2008; Kotzamanidis et al., 2005; Sayers, 2007; Neils et al., 2005) and one trained four times per week (Jones et al., 2001). Research results seem mixed after twice a-week training with results showing significant improvements in cycling power (Wilson et al., 1993; Brown et al., 2007). Vertical jumping however was not so favorable after bi weekly strength training, with only Wilson and colleagues (1998) showing significant improvement in both squat jump (SJ) and counter movement jump (CMJ) jump height of 6 and 5% (0.2 ES) respectively. Training tri weekly, researchers found a 4% improvement in ballistic leg press peek power (PP) (Vissing et al., 2008), 8.4% (0.16 ES) CMJ PP (Neils et al., 2005) and between 9-22% knee extensor (KE) PP through a 40-90% 1RM (Sayers, 2007). Training four times a week saw no significant improvements in power output during drop jumps (DJ) or 30 and 50% 1RM jump squats (JS) (Jones et al., 2001).

Two investigations utilized untrained subjects (Sayers, 2007; Vissing et al., 2008), three used recreational trained subjects (Brown et al., 2007; Kotzamanidis et al., 2005; Neils et al., 2005), two had trained subjects (Wilson et al., 1993; Harris et al., 2000), and one used elite subjects (Jones et al., 2001). Of these studies only Wilson and colleagues (1993), using trained subjects, showed significant increases in all power measures (CMJ, SJ height (HT), 6 sec PP Cycle). It is interesting that no consensus regarding training age and improvements in power exist when training at high loads. Researchers have found untrained subjects, who would expect to gain the most, not to improve CMJ HT and PP but increase ballistic leg press PP by 6.0% (Vissing et al., 2008). However, untrained subjects did improve PP output during KE through a range of intensities (Sayers, 2007). The inconsistent effects of maximal strength training exist with more trained subjects as well. No improvements were found within the reviewed literature on sprint speed after strength training. Both studies (Harris et al., 2000; Kotzamanidis et al., 2006) reported no improvement in sprint tests.

The training variables (sets, reps, frequency etc) within this training protocol were varied within the reviewed literature. Four of the studies used a straight set design (sets and repetitions do not vary and stay the same throughout the programme) (Sayers, 2007; Harris et al., 2000; Neils et al., 2005; Brown et al., 2007), four utilised a linear periodization model (increasing load and volume decreases, changes roughly every four weeks [Fleck, 1999]) (Kotzamanidis et al., 2005; Vissing et al., 2008; Wilson et al., 1993; Jones et al., 2001). As before no one training protocol was better than the other within maximal strength training schemes to improve power output. Results varied from no change, decreases (Neils et al., 2005), to significant and non significant increases (Wilson et al., 1993; Harris et al., 2000) with no consistency within the training protocols.

Plyometric Training Protocols

Plyometric training is another training scheme utilised to develop muscular power and to enhance jumping ability. In addition it is a method of choice for practitioners when developing lower body explosiveness in performance utilising the stretch shortening cycle (SSC) (Fatourus et al., 2000). Training in this manner involves individuals to exert maximal effort to move a sub-maximal load as fast as possible; resulting in the load becoming airborne (Kreamer & Newton, 2000) moreover it negates the negative deceleration aspect of traditional resistance training (Newton, Kraemer, & Hakkinen, 1999). Lower body plyometric exercises are similar to the movement patterns of athletic performance. The exercises include: bounding, hopping, and various jumping activities on one and two legs (Potteiger et al., 1999). Plyometric training is defined more so by the amount of foot contacts within a training session, which is dependent on the level of the athlete. For example, a novice athlete would perform approximately 80 – 100 foot contacts, an intermediate athlete would perform 100 - 120 foot contacts, and an advanced athlete would perform 120 – 140 foot contacts per session (Potach & Chu, 2000). Plyometric training is believed to improve explosive performance by enhancing the coordination of the neural control of the SSC (Newton et al., 1999). Although sometimes called ballistic training (Newton et al., 2006) because of similarities between the two training protocols, ballistic training can involve elements of both plyometric and traditional weight lifting (McEvoy & Newton, 1998). For example, ballistic training exercises could include; jumping movements or only involve concentric only elements like a squat jump.

Plyometric training appears to be an effective means to either maintain or improve lower body strength (Table 2). Of the reviewed studies, six measured strength by 1RM leg press (Brown et al., 2007; Vissing et al., 2008), 1RM squat (Fatouros et al., 2000), knee extensor MVC (Kyrolainen, Avela, & McBride, et al., 2005), maximum isometric force (Markovic et al., 2007). All but one study (Markovic et al., 2007) found improvements in strength after training with magnitudes between 12 (2.5 ES) and 37% (1.9 ES). None of the subjects within the reviewed literature were experienced weight lifters and therefore it is not surprising to see the large gains. The largest magnitude of change (37%) occurred in only six weeks of training (Brown et al., 2007) whereas the smallest magnitude of change (12%) occurred after a longer training intervention period of 12 weeks (Fatourus et al., 2000).

Plyometric training has been effective to improve a variety of explosive performance measures, e.g. vertical jump ability and power output (Vissing et al., 2008; Fatouros et al., 2000; Markovic et al., 2007) (Table 2). Within the reviewed literature, untrained subjects undertaking plyometric training improved jumping performance between 8.0 (0.9 ES) – 35% (1.8 ES) (Brown et al., 2007; Fatouros et al., 2000; Kotzamandis, 2006; Vissing et al., 2008). Recreational trained subjects improved from 4.6 – 35% (0.9 ES) in jump height (Kyrolainen et al., 2005; Potteiger et al., 1999; Salonkidis & Zafeiridis, 2008) and trained subjects improved between 6.3 (0.5 ES) – 8.0% (0.4 ES) (Saunders et al., 2006; Markovic et al., 2007; Thomas, French, & Hayes, 2009). Within these studies, only two involved subjects with a resistance training background and currently training (Markovic et al., 2007; Potteiger et al., 1999). Interestingly these subjects saw the least magnitude of improvement in jump height, 4.6 – 6.3% (0.5 ES). Also Subjects with no or recent resistance training experience prior to training with a plyometric protocol significantly improved between 8 (0.4 ES) – 35% (1.8 ES) (Salonkidis & Zafeiridis, 2008; Thomas et al., 2009; Saunders et al., 2006; Kyrolainen et al., 2005; Kotzamandis, 2006; Vissing et al., 2008; Fatouros et al., 2000).

Table 2: Plyometric training protocols and their influence on lower body explosiveness.

Author	Subjects	Training Status	Study length	Tests	Results (Effect Size)
Brown et al, 2007	18 FM	Untrained	6 wk	1RM LP, VJ HT	*↑ 37%(1.9) 1RM Leg Press, *↑ 8.0%(0.9) Vertical Jump Height
				30 sec WG PP MP	#↑ 4.0% (0.12), *↑ 6.0%(0.2) in Wingate Peak and Mean Power
Fatouros et al, 2000	41 M	Untrained	12 wk	1RM Squat	*↑12%(2.5) 1RM Squat Strength
				VJ HT P	*↑ 17%(1.7), *↑ 11%(2.6) in Vertical Jump Power and Height
Kotzamanidis, 2006	30 M	Untrained	10 wk	VJ, 30m Sprint	*↑ 35%(1.8) Vertical Jump Height, *↓ 2.5% (0.3) 30m Sprint
Kyrolainen et al, 2005	23 M	Recreational	15 wk	MVC KE	#↑ 25%(0.6) Maximal Voluntary Contraction of Knee Extensors
				DJ	*↑ 23%(1.2) Depth Jump Height
Markovic et al, 2007	93 M	Trained	10 wk	Max Iso Force,	↔(0.04) Max Isometric Force,
				SJ and CMJ HT, 20m Sprint	*↑ 6.5%(0.5), *↑ 6.3%(0.5) for Squat Jump and Counter Movement Jump Height, #↓ ~1.5%(CC) 20m Sprint
Potteiger et al, 1999	19 M	Recreational	8 wk	VJ HT, PP, MP	*↑ 4.6% (CC), *↑ 2.8%(1.4), and *↑ 5.5%(1.5) in Vertical Jump Height, Peak and Mean Power
Salonkidis & Zafeiridis, 2008	64 MX	Recreational	9 wk	Unilateral 20 cm Drop Jumps	*↑ 35%(0.9) Depth Jump Height
Saunders et al, 2006	15 M (T)	Trained	9 wk	5 VJ MHT	↑ of 8.0%(0.4) Vertical Jump Mean Height
				SJ RFD	↑ 16%(0.7) in Squat Jump Rate of Force Development
Thomas et al., 2009.	12 YM	Trained	6 wk	CMJ HT, 20 Sprint	*↑ of ~8.0%(CC) Counter Movement Jump Height , ↔0.6%(0.09) 20m Sprint
Vissing et al, 2008	16 M	Untrained	12 wk	1RM LP	*↑ 22%(CC) 1RM Leg Press
				CMJ HT	*↑ 10%(CC) Counter Movement Jump Height

M = Male; FM = Female; MX = Mixed Gender; Y = Younger; wk = weeks; P = Power; PP = Peak Power; MP = Mean Power; VJ = Vertical Jump; DJ = Depth Jump; SJ = Squat Jump; CMJ = Counter Movement Jump; HT = Height; MHT = Mean Height; SJ = Squat Jumps; 1RM = One Repetition Maximum; LP = Leg Press; MVC = Maximum Voluntary Contraction; Max Iso = Maximum Isometric; WG = Wingate; ↑ = Increase; *↑ = Significant Increase; #↑ = Non Significant Increase; ↔ = No difference / No Change; *↓ = Significant Decrease; #↓ = Non Significant Decrease; CC = Couldn't Calculate

Training frequency had no impact on improvements as subject who trained twice a week improved jump height between 8.0 (0.9 ES) – 35% (1.8 ES) (Brown et al., 2007; Kotzamandis, 2006) and those subjects who trained three time per week improved to a similar magnitude of between 4.6 – 35% (0.9 ES) (Potteiger et al., 1999; Salonkidis & Zafeiridis, 2008). Researchers utilising jumping tests that allowed a CMJ and arm swing produced increases ranging from 8.0 (0.9 ES) – 11% (1.7 ES) (Brown et al., 2007; Fatouros et al., 2000), CMJ jumps without an arm swing between 8.0 – 35% (0.9 ES) (Salonkidis & Zafeiridis, 2008; Thomas, French, & Heyes., 2009), and SJ of 6.5% (0.5 ES) (Markovic et al., 2007).

Horizontal explosiveness has been investigated in three of the reviewed literature with mixed results. Kotzamanidis and colleagues (2006) found a 2.5% (0.3 ES) increase in 30m sprint time and Markovic et al., (2007) found a 1.5% improvement in 20m sprint performance. However Thomas and colleagues (2009) found a small 0.6% (0.09 ES) improvement in performance. Given that only a small number of the reviewed literature measured explosive performance in this manner (sprinting) it would be speculative of the authors to say that plyometric training protocols are effective to improve this type of performance.

Improvements in power after completing plyometric training protocols have been attributed to increases in power output and maximum rate of force development (RFD) (Newton et al., 1999). Within the reviewed literature four researchers measured PP and mean power (MP) by way of the Wingate cycle test (WG) and estimation equations from vertical jump (VJ) performance (Potteiger et al., 1999; Fatouros et al., 2000; Brown et al., 2007; Vissing et al., 2008). Plyometric training protocols lead to improvements in all four studies. A 4.0% (0.12 ES) and 6.0% (0.2 ES) improvement were found in WG PP and MP respectively (Brown et al., 2007), VJ PP increases of 26% (2.6 ES) (Fatouros et al., 2000) and 2.8% (1.4 ES) and 5.5% (1.5 ES) improvement in VJ PP and MP respectively (Potteiger et al., 1999). Plyometric training protocols have also shown to improve RFD by 17% (0.7 ES) with a concurrent 10% (0.4 ES) increase in VJ height (Saunders et al., 2006). Increases in CSA have also been found following plyometric training suggesting muscle morphology may play a role in dynamic explosive activity (Potteiger et al., 1999).

Dynamic Training Protocols

Another resistance training method that has been developed is dynamic training. This can be further split into two protocols, maximum power (Pmax) and high velocity. Pmax is defined as the % load of 1RM (or isometric force) that induces the maximum amount of power output (Baker et al., 2001). There is still much debate over what load maximal power is achieved. The range of load in which generates maximal power output has been inconsistent, with loads ranging between 0-70% 1RM, (Cormie, McCaulley, Triplett, & McBride, 2007; Siegel, Gilders, Staron, & Hagerman, 2000) and appears to be movement specific. Training at Pmax is believed to improve RFD, and the intra- and inter-muscular co-ordination (Harris et al., 2000). Both Pmax and high velocity training protocols require lifting a sub-maximal load as quickly as possible. However, during high velocity training protocols the velocity of movement is emphasized while the load lifted is not specifically the load that maximises power output (Harris et al., 2000). These training schemes are reported within the literature as a session consisting of three to seven sets of five to 15 repetitions of the corresponding loads as mentioned previously (Cormie et al., 2007; Wilson et al., 1993; Jones at al., 2001; Harris et al., 2000; Lyttle, Wilson, & Ostrowski, 1996).

Dynamic training protocols have consistently improved subject's strength performance as all of the reviewed literature reported magnitude of improvement between 2.0 (0.1 ES) and 15% (0.6 ES) (Cormie et al., 2007; Lyttle et al., 1996) (Table 3). The magnitude of improvement is less compared to the magnitude of change reported in the literature involving maximal strength (6.0 [0.2 ES] to 32% [1.6 ES]) and plyometric training (12 [2.5 ES] to 37% [1.9 ES]) protocols.

Dynamic training protocols have been found to be successful in improving power performance (Table 3). Untrained (Sayers, 2007), recreational (Lyttle, Wilson, Ostrowski, 1996; Cormie, McCaulley, & McBride, 2007), and trained subjects (Newton et al., 2006; Wilson et al., 1993; Harris et al., 2000; Jones et al., 2001) have benefited from dynamic training protocols. Training improvements in jumping ability were reported in recreational and trained subjects ranging from 7.9 (0.4 ES) – 19% and 2.6 (0.3 ES) – 17% (1.0 ES). Power output ranged from 18 – 29%, 9.0 (0.9 ES) – 27% and 2.4 (0.8 ES) – 11% (1.0 ES) in untrained, recreational and trained subjects respectively. From the reviewed studies, only two measured sprint performance (Harris et al., 2000; Lyttle et al., 1996). Non significant decreases of 0.6% (0.7 ES) (Harris et al., 2000), and 1.7% (0.2 ES) (Lyttle et al., 1996) were found in 30m and 40m sprint performance respectively.

From the reviewed dynamic training schemes, four utilised a Pmax (Newton et al., 2006; Lyttle et al., 1996; Wilson et al., 1993; Cormie et al., 2007) and three used high velocity with loads around 20 - 40% of 1RM (Harris et al., 2000; Jones et al., 2001; Sayers, 2007). Pmax training schemes improved CMJ HT between 2.6 (0.3 ES) – 17% (1.0 ES) (Newton et al., 2006; Wilson et al., 1993), whereas the high velocity training protocols improved VJ HT by 3.6% (0.5 ES) (Harris et al., 2000).

Table 3: Dynamic training protocols and their influence on lower body explosiveness.

Author	Subjects	Training Status	Study length	Tests	Results(Effect Size)
Cormie et al., 2007	26 M	Recreational	12 wk	1RM Squat	↑ 2.0%(0.1) 1RM Squat Strength
				JS HT PP	*↑19% (CC), *↑27% (CC) Jump Squat Height and Peak Power
Harris et al, 2000	51 M	Trained	9 wk	1RM Squat	*↑ 3.6%(0.5) 1RM Squat Strength
				VJ HT, PP, MP, 30m Sprint	*↑ 3.8%(CC), *↑ 2.4%(0.8), *↑ 2.1% (0.6) Vertical Jump Height, Peak Power, Mean power, #↑ ~0.6%(0.7) 30m Sprint
Jones et al, 2001	26 M	Trained	10 wk	1RM Squat	*↑ 12%(0.7) 1RM Squat Strength
				30 and 50% 1RM JS	*↑ 5.9(0.4) and *↑ 12%(0.6) 30 and 50% Jump Squat
Lyttle et al,, 1996	33 M	Recreational	8 wk	1RM Squat, CMJ HT	*↑ 15%(0.6) 1RM Squat Strength, *↑7.9%(0.4) Counter Movement Jump Height
				6 sec cycle, 40m sprint	*↑ 9.0%(0.9) Peak Power Cycle, #↑1.7%(0.2) 40m Sprint
Newton et al., 2006	14 F	Trained	4 wk	CMJ HT	↑2.6%(0.3) Counter Movement Jump Height
				MP PP	#↑11(1.0), *↑ 10%(0.9) Counter Movement Peak and Mean Power
				mRFD	*↑ 28%(0.8) maximum Rate of Force Development
Sayers, 2007	12 OMX	Untrained	12 wk	1RM LP	↑ 14%(CC) 1RM Leg Press
				KE PP at 40, 50, 60, 70, 80, and 90% 1RM	↑ 18 - 29%(CC) Knee Extensor Peak Power across ranges
Wilson et al., 1993	64 NM	Trained	10 wk	CMJ HT	*↑ 17% (1.0) Counter Movement Jump Height
				6 sec cycle PP	*↑ 5.0%(0.18) cycle Peak Power

M = Male; F = Female; MX = Mixed Gender; OMX = Older Mixed Gender; NM = Not Mentioned; wk = weeks; PP = Peak Power; MP = Mean Power; VJ = Vertical Jump; CMJ = Counter Movement Jump; HT = Height; KE = Knee Extension; JS = Jumps Squat; BM = Body Mass; RM = Repetition Maximum; mRFD = Maximum Rate of Force Development; ↑ = Increase; *↑ = Significant Increase; #↑ = Non Significant Increase; ↔ = No difference / No Change; *↓ = Significant Decrease; #↓ = Non Significant Decrease

Training frequency within the dynamic training protocols ranged from two (Lyttle et al., 1996; Wilson et al., 1993; Cormie et al., 2007; Jones et al., 2001), three (Sayers, 2007) and four (Harris et al., 2000) days per week. Training frequency resulted in differing results in reported jump height performance. Subjects who trained twice a week showed the greatest improvements in CMJ HT of 7.9 (0.4 ES) - 17% (1.0 ES) (Lyttle et al., 1996; Wilson et al., 1993).

Variations of the dynamic training protocols have been used within the literature including, linear periodisation (Jones et al., 2001; Wilson et al., 1993) and straight set designs (Sayers, 2007; Harris et al., 2000; Cormie et al., 2007; Lyttle et al., 1996). These protocols have also displayed varied improvements with no protocol being better than the other. For example Wilson and colleagues (1993) found a 17% (1.0 ES) increases in CMJ HT after 10-weeks of Pmax training whereas Lyttle and colleagues (1996) similarly found 7.9% (0.4 ES) in CMJ HT.

Over-Speed Training Protocols

The over-speed training protocols reported in the literature have involved five to 12 repetitions of various sprinting distances, 20 to 90 m (Kristensen et al., 2006; Tinning & Davis, 1978; Paradisis & Cooke, 2006; Majdell & Alexander, 1991). Over-speed training involves training at speeds that are greater than are possibly attainable by normal biological means by way of artificial help (Majdell & Alexander, 1991). Typical techniques include wind-assistance, downhill running, high speed treadmill running, the use of rubber tubing, and towing by either a winch type device or motor vehicle (Mero, Komi, Rusko, & Hirvonen, 1987; Girold, Calmels, Maurin, Milhau, & Chatard, 2006). Over-speed training protocols are also referred to as supra-maximal and assisted training. To date research utilizing over-speed stimulation has focused on sprinting performance (Mero & Komi, 1986; Mero et al., 1987; Majdell & Alexander, 1991; Tinning & Davis, 1978). The mechanisms behind adaptation to over-speed are unclear but theories include increased force output during ground contact, decreased ground contact, increased used of fast twitch muscle fibres, and enhanced firing of the nerves to the active muscles (Mero et al., 1987; Tinning & Davis, 1978).

From the five studies reviewed, all found significant improvements in speed performance via various sprinting distances (Table 4). The variation of improvement was between 0.5 – 3.0% (1.1 ES). Only two of the five researchers utilized a power measurement, power output. Of the five studies, three had recreational subjects (Hammett & Hey, 2003; Paradisis & Cooke, 2006; Kristensen et al., 2006), which included the studies that tested power and two used trained subjects (Majdell & Alexander, 1991; Tinning & Davis, 1978). Hammett and Hey (2003) were the only researchers to utilize a machine (Howse III Speed system) to generate specific hip and knee over-speed stimulation, whereas Kristensen et al., (2006), Tinning & Davis (1978), Paradisis & Cooke (2006), Majdell & Alexander (1991) all used strategies that allowed for subjects free range of movement during training, i.e. towing, pullies, or downhill running. Irrespective of the methods used for creating the over-speed stimulus, all appeared to improve speed of movement either through movement velocity (Kristensen et al., 2006) or sprint time (Hammett & Hey, 2003).

Table 4: Over-speed training protocols and their influence on lower body explosiveness.

Author	Subjects	Training Status	Study length	Tests	Results(Effect Size)
Hammett & Hey, 2003	38 MX	Recreational	4 wk	VJ P	#↑ 1.0%(0.04) Vertical Jump Power
				36.6m Sprint	*↓ 2.7%(0.4) 36.6m Sprint time
Kristensen, et al., 2006	19 MX	Recreational	6 wk	20m Sprint Velocity	*↑ 0.5%(CC) 20m Sprint Velocity
Majdell & Alexander, 1991	18 M	Trained	6 wk	40m Sprint	*↓ 1.7%(0.3) 40m Sprint Time
Paradisis & Cooke, 2006	35 NM	Recreational	6 wk	6 sec WG PP	#↓ 0.5%(0.01) in Wingate Peak Power
				35m Sprint Speed	*↑ 1.1(0.15) in 35m Sprint Speed
Tinning & Davis, 1978	10 M	Trained	5 wk	Flying 50m Sprint	*↓ 3.0%(1.1) 50m Sprint Time

M = Male; MX = Mixed Gender; NM = Not Mentioned; wk = weeks; P = Power; PP = Peak power; VJ = Vertical Jump; VEL = Velocity; ↑ = Increase; *↑ = Significant Increase; #↑ = Non Significant Increase; *↓ = Significant Decrease; #↓ = Non Significant Decrease; CC = Couldn’t Calculate

Power measures used in the reviewed literature included calculated vertical jump peak power and Wingate cycle test. There appears to be a lack of consistency of improvement of power output using over-speed sprint training as slight or no differences were found after four weeks (Hammett & Hey, 2003) or six weeks (Paradisis & Cooke, 2006) of training respectively. Measures of power output were scarce within over-speed training protocols. This highlights the need for further investigation into the effectiveness of over-speed training on power output. No measures of strength were used in any of the reviewed literature of this kind of training protocol.

Mixed Methods Training Protocols

Mixed method training protocols (combination training) are based on the idea that training with more than one type of training method at the same time (strength, plyometric etc) may improve more desired adaptations, therefore providing a more complete stimulus for changes in both muscle and nervous systems. In addition such training schemes have resulted in a greater transfer of the training effect to a wider range of performance skills, especially those relying on power and strength (Baker, 1996; Newton & Kraemer, 1994). Two major types of combination training exist within the literature: compound and complex training. Compound training schemes are where resistance and plyometric exercise are performed during separate sessions (Mihalik et al., 2008). For example, leg training is performed on one day and then depth jumps are formed on another day. This type of training is thought to improving the stretch reflex of a muscle while increasing contractile proteins (Fatouros et al., 2000; Kotzamanidis et al., 2005). Complex training differs by alternating between resistance exercises and biomechanically similar plyometric exercises within the same session (Mihalik et al., 2008). Complex training is thought to be more effective than other training schemes because of an enhanced neuromuscular environment (Masamoto, Larson, Gates, & Faigenbaum, 2003).

Compound training protocols have shown to improve power output following differing lengths of training from four to 12 weeks (Mihalik et al., 2008; Ingle et al., 2006) (Table 5). The training status of the subjects within these studies ranged from untrained (Fatouros et al., 2000), recreational (Newton et al., 2002), or trained (Harris et al., 2000; Mihalik et al., 2008). Two groups of subjects had no prior resistance training experience (Fatouros et al., 2000; Newton et al., 2002), one had a minimum of one year strength training (Harris et al., 2000) and one carried out regular plyometric training as part of their normal training (Mihalik et al., 2008). The less trained subjects improved to a greater extent than the more trained subjects during jumping tasks. Peak power output increased 39% (3.5 ES) during a VJ (Fatouros et al., 2000) and jump squat performance saw a 26 - 33% increased power output in younger males and 25 - 36% increases in older men (Newton, Hakkinen, Hakkinen, et al., 2002). Trained subjects were also able to improve their power output but to a lesser degree: 2.9%; 2.8% (0.5 ES); 2.6% (0.7 ES) in VJ HT, MP and PP respectively (Harris et al., 2000) and 9.1 (0.6 ES) and 7.5% (0.4 ES) increases in VJ HT and MP respectively (Mihalik et al., 2008). Interestingly both Fatouros et al., (2000) and Newton et al., (2002) both used a non linear approach, daily undulation periodised protocol, with their training programmes whereas Harris and colleagues (2000) and Mihalik et al., (2008) both used a straight set design. Moreover Fatouros et al., (2000) and Newton, et al., (2002) used the same training

Table 5: Mixed method training protocols and their influence on lower body explosiveness.

Author	Subjects	Training Status	Study length	Tests	Results(Effect Size)
Complex					
Ingle et al., 2006	47 M	Untrained	12 wk	10RM Squat, 30 sec WG PP	*↑ 49%(2.2) 10RM Squat Strength, *↑ 3.6%(0.2) Wingate Peak Power
				VJ HT, 40m Sprint	*↑ 5.2%(0.2) Vertical Jump Height, *↓ 3.1%(0.4) 40m Sprint
Lyttle et al., 1996	33 M	Recreational	8 wk	1RM Squat, CMJ, 6 sec cycle	*↑15%(0.8) 1RM Squat Strength, *↑13%(0.5) Counter Movement Jump Height
				PP, 40m Sprint	*↑ 7.8%(0.6) Peak Power, ↓ 0.8%(0.19) 40m Sprint
Marques & Gonzalez-Badillo, 2006	16 M	Trained	12 wk	4RM Squat, CMJ HT	*↑ 43%(2.4) 4RM Squat Strength, *↑ 13%(0.9) Counter Movement Jump Height
				30m Sprint	*↓ 3.1%(0.7) 30m Sprint
Mihalik et al, 2008	31 MX	Trained	4 wk	VJ HT MP	*↑ 5.4%(0.3) *↑ 4.8%(0.2) Vertical Jump Height and Mean Power
Compound					
Fatouros et al, 2000	41 M	Untrained	12 wk	1RM Squat VJ HT PP	*↑29%(9.1) 1RM Squat Strength, *↑ 39%(3.5) Vertical Jump Peak Power, *↑15%(2.1) Vertical Jump Height
Harris et al, 2000	51 M	Trained	9 wk	1RM Squat,	*↑ 12%(1.4) 1RM Squat Strength
				VJ HT, MP, PP	*↑ 2.9%(CC), 2.8%(0.5), 2.6%(0.7) Vertical Jump Height, Mean and Peak Power
				30m Sprint	*↑ 1.4%(0.7) 30m Sprint
Mihalik et al, 2008	31 MX	Trained	4 wk	VJ HT MP	*↑ 9.1%(0.6) , *↑ 7.5%(0.4) Vertical Jump Height and Mean Power
Newton et al, 2002	91 O and Y M	Recreational	10 wk	Iso Squat,	*↑ 23%(1.3) (Younger Men) and *↑ 40%(0.5) (Older Men) Isometric Squat,
				JS 30 and 60% 1RM	*↑ 33%(CC), and ↑ 26%(CC) (Younger Men), *↑ 36%(CC), and *↑ 25%(CC) (Older Men) 30, 60% 1RM Jump Squats

M = Male; MX = Mixed Gender; O = Older; Y = Younger; wk = weeks; PP = Peak Power; MP = Mean Power; VJ = Vertical Jump; CMJ= Counter Movement Jump; JS = Jump Squat; Iso = Isometric; RM = Repetition Maximum; HT = Height; WG = Wingate; ↑ = Increase; *↑ = Significant Increase; *↓ = Significant Decrease; CC = Couldn't Calculate.

frequency during their research of three days a week compared to either two days (Harris et al., 2000) and four day (Mihalik et al., 2008).

Compound training protocols have also provided greater improvements in performance measures, when compared to single focus training protocols. For example, Harris et al., (2000) found subjects performing a combination of high force and high velocity training improved equally or better in VJ HT (2.9%), MP (2.8% [0.5 ES]), and PP (2.6% [0.7 ES]), compared to either a high force (2.0, 3.0 [0.6 ES], and 3.0% [0.6 ES] respectively), or high power groups (3.8, 2.4 [0.8 ES), and 2.1% [0.6 ES] respectively). Similarly Fatouros et al., (2000) found significant differences in their compound group between both a plyometric and strength training groups of 15% (2.1 ES) and 39% (3.5 ES) in VJ HT and VJ PP respectively compared to 11% (2.6 ES) and 17% (1.7 ES), and 9.0% (3.3 ES) and 25% (2.9 ES) improvement of the plyometric and strength training groups respectively.

Researchers investigating the benefits of complex training protocols on power output have also found favourable results from training in this manner (Table 5). The training age of the subjects ranged from untrained (Ingle et al., 2006), recreational (Lyttle et al., 1996) and trained (Mihalik et al., 2008; Marques & Gonzalez-Badillo, 2006). The trained subjects improved their jumping ability by 5.4 (0.3 ES) -13% (0.9 ES) during CMJ and VJ jumping while the less trained subjects improved similarly between 5.2 (0.2 ES) – 13% (0.5 ES) during CMJ and VJ performance. Cycle PP was also improved in the less trained subjects between 3.6 (0.2 ES) – 7.8% (0.6 ES).

Training frequency seemed to have little effect on performance, as those researchers that reported the greatest gains (Lyttle et al., 1996; Marques & Gonzalez-Badillo, 2006) trained both twice, and three times per week. Untrained subjects appeared to improve their performance when a straight set design was utilised (Lyttle et al., 1996), whereas more trained subjects benefited more from a mixed linear and undulating training protocols (Marques & Gonzalez-Badillo, 2006).

Comparisons between complex training protocols and other methods have found favourable results. Complex training has been shown to be just as effective as both maximal power training (Lyttle et al., 1996) and compound training (Mihalik et al., 2008). However within the current studies complex training was not seen as superior to these other methods with increases of 13% (0.5 ES) CMJ, and 7.8% (0.6 ES) 6-sec cycle PP in complex training compared to 7.9% (0.4 ES) CMJ and 9.0% (0.9 ES) 6-sec cycle PP after maximal power training (Lyttle et al., 1996). Compared to compound training increases in power performance after complex training was found to be similar and these improvements increased at similar rates, VJ 5.4% (0.3 ES), MP 4.8% (0.2 ES) for complex and VJ 9.1% (0.6 ES) and MP 7.5% (0.4 ES) after compound training (Mihalik et al., 2008).

Summary

Many types of training protocols have been shown to be beneficial for improving lower body explosiveness, including: maximal strength, plyometric, dynamic, over-speed, complex, and compound. From these reviewed training methods all but one training method, maximal strength, was shown to clearly improve power output. Therefore speculating on which method of training protocol is best for developing lower body explosiveness would be premature. The type of training protocol implemented by the conditioning professional should by specific to the goals / needs of the athlete. For example, if strength needs to be improved then a maximal strength protocol should be used but if the athlete wants to jump higher, a plyometric protocol maybe more appropriate.

There are many combinations, from the reviewed literature, that are possible within combined method training including; strength and plyometric, strength and dynamic, and strength and over-speed protocols. However, no research was found on the effects of a strength and over-speed training protocol. Moreover the research related to over-speed training has only been investigated in a horizontal plane and mainly on the effect on sprint speed. What effect might there be of a vertical over-speed protocol or a combined strength and over-speed protocol on various performance measures?

Another issue found within the current literature is the wide use of non active control groups. Using controls of this nature in essence is like comparing the active against the inactive or less active versus the more active. In order to compare the effectiveness of different training protocols future training studies should measure training interventions against controls of similar training volumes and against another training protocol/s.

Introduction

The ability to generate force quickly (power) is paramount during actions involving changes in direction, sprinting, and jumping (McClenton et al., 2008). As such, power training has received intense investigation over the years to aid athletes in running faster, jumping higher and throwing further. As illustrated by the force-velocity-power relationship, maximal power output is obtained when an optimal combination of force and velocity have been reached (Kraemer & Newton, 2000). Researchers have used this principle to improve power output by designing training strategies that either maximizes strength (force) (Brown et al, 2007) or the speed of the contraction (velocity) (Cormie, McCaulley & McBride, 2007) or both (Marques & Gonzalez-Badillo, 2006). However, the load, and therefore the velocity, that maximizes power output has been inconsistent, with loads ranging between 0-70% of one repetition maximum (1RM), (Cormie et al., 2007; Siegel et al., 2002) and appears to be movement specific.

In the pursuit of improving lower body power output, many forms of training have been utilized and proven successful. These include; slow velocity (Brown et al, 2007) and fast velocity training (McClenton et al., 2008), ballistic/plyometric protocols (Kotzamanidis, 2006; Markovic et al., 2007), over-speed training (Kristensen, Tillaar, & Ettema, 2006; Hammett & Hey, 2003), as well as complex (Marques & Gonzalez-Badillo, 2006), and compound training protocols (Mihalik et al., 2008; Fatouros et al., 2000). These training methods aim to improve either singular (slow / fast velocity, ballistic/dynamic, or over-speed) or multiple (Baker, 1996; Newton & Kraemer, 1994) (complex and compound) power variables, i.e. slow velocity strength, high velocity strength, rate of force development, the stretch shortening cycle, and inter-muscular co-ordination and skill (Newton & Kraemer, 1994). Researchers are in agreement on the effective use of combined protocols, compound or complex, as a means to improve power output (Newton, Rogers, Voleck, Hakkinen, & Kraemer, 2006; Markovic et al., 2007; Fatouros et al., 2000). However, since many protocols are used, researchers have not yet determined the “ideal” training stimulus in which power production is best improved by combined protocols, and furthermore, whether there is indeed a “ideal” stimulus or simply a plethora of combinations dependant on the athlete, phase, and competition specific variables (e.g. implement, bodyweight etc).

It has been stated that if athletes want to improve high-velocity force (power) then they should perform exercises at high movement speeds (Blazevich & Jenkins, 2002). Faster than “normal” movement velocities can be achieved when artificial assistance is given from either, towing, bungee apparatuses etc (Majdell & Alexander, 1991). This assisted speed stimulation has been shown to improve athlete velocity during sprinting (Hammett & Hey, 2003; Kristensen et al., 2006) and swimming activities (Girold, Calmels, Maurin, Milhau, & Chatard, 2006). Sporting activities are not only limited to the horizontal plane, but can also occur in the vertical plane as well, e.g. jumping. To date no attention has been given to an assisted velocity stimulus in the vertical plane.

Since many sporting codes require a degree of both strength and velocity and high movement speeds are desirable for the development of power, the investigation of a combined strength and high-velocity stimulus is warranted. Therefore the aim of this investigation was to compare the effectiveness of a combined strength and assisted jumping stimulus (fast) against a similar training stimulus, i.e. combined strength and plyometric vertical jumping (slow). Moreover, this study will aim to build upon previous research within the area of combined training methods, which are associated with greater improvements in power output and functional performance compared to single method designs. If encouraging results are observed, this may provide an alternative or compliment the standard training practice of a traditional combined strength and plyometric exercise stimulus.

Methods

Design

This randomized longitudinal study comprised of seven weeks training split into one, three week base strength phase and one, four week intervention phase (figure 1). Subjects were pair – matched (as practically possible) with respect to their 3RM squat strength, 20-metre sprint, and vertical jump test results of the second testing session (see below). Subjects were then randomly allocated to either a strength and plyometric jumping (SVJ) or a strength and assisted plyometric jumping (SAJ) group.

Subjects were tested during a familiarization session before the commencement of the study (PRE1), during week three of the baseline strength phase (PRE2), and at the completion of the training intervention during week nine (POST1). The tests comprised of a vertical jump (power), a 20m sprint assessment (speed), and a 3RM squat test (strength), in that order. Each test was separated by 10 minutes of rest. The protocols and methods used in this study were approved by the Waikato Institute of Technology's (WINTEC) Human Ethics Research Committee prior to the commencement of this study (see Appendix 1).

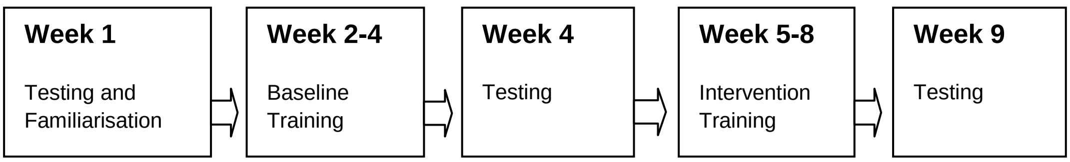

Figure 1: Research design in chronological order outlining testing, baseline and intervention phases.

Subjects

Seventeen male athletes were recruited from local sports clubs, gyms and students from WINTEC and agreed to participate in this study. Subjects were recruited through either an advertisement flyer (see Appendix 2) or via recruitment presentations. Subject characteristics are displayed in Table 6. All subjects had at least six months prior weight training experience and currently training regularly using heavy loads, i.e. ≤8RM. Subjects were excluded if they had current injuries to the lower back, hip, or knees and screened via a health screening form (see Appendix 3). Moreover subjects not completing 80% or more of the intervention were excluded from statistical analysis. All subjects were informed of the procedures of the study, through an information sheet (see Appendix 4), and gave their written informed consent prior to the studies commencement (see Appendix 5). During the course of the study 17 subjects withdrew for various reasons; 12 from non compliance, three from individual sport injuries, and two from aggravating old injuries. The 17 recruited subjects participate in a variety of sports including; rugby (7), recreational resistance training (7), martial arts (2), parkour (1).

Table 6: Characteristics of subjects (means ± SD).

	No of subjects	Age (years)	Weight (kg)	Height (cm)	Training Experience (months)
SVJ	8	20 ± 2	80 ± 14	177 ± 11	26 ± 17
SAJ	9	22 ± 4	88 ± 17	177 ± 8	20 ± 24

Training Protocols

Strength Training Protocol

All subjects completed the same strength training protocol during the seven week training period. Subjects completed two supervised lower body resistance training sessions per week and on average two other training sessions with their sporting code. Each supervised training session was separated by a minimum of 48 hours to ensure recovery between trainings. All sessions, both training and testing, began with a standardised warm up consisting of five minutes of light jogging and self directed stretching. Each training session comprised of four of the following exercises;

Back Squats – as outlined by Earle and Baechle (2000) this exercise began with placing an Olympic bar in a high bar position (position at the base of the neck resting on the posterior deltoids). Subjects positioned their feet approximately shoulder width apart. Whilst maintaining a neutral spine (neither hunched nor excessively extended), chest up and out, and head looking slightly up subjects began to flex at the hips and knees to lower themselves to a parallel position (thighs parallel to floor) whilst maintaining heel contact with the floor. Once subjects reached the parallel position or the heels of their feet lifted off the ground they began to extend their hips and knees to raise themselves to a full standing position.

Box Squats – This exercise was performed the same as Back Squats except at the bottom of the movement (parallel position) subjects sat on a box. The box height was set approximately 90^0 knee flexion. During the time subjects were sitting on the box they were instructed not to relax their neutral spin and not to rock back to gain momentum for the lifting of the load.

Front Squats - as outlined by Earle and Baechle (2000) this exercise is similar to the Back Squat with one difference. The bar was placed on top of the anterior deltoids, instead of the posterior deltoids, using either using a parallel (hands were placed on the bar in an pronated grip slightly wider than should width and upper arm parallel to floor) or crossed (arms crossed in front of chest using an open grip on the bar to maintain placement and elbows parallel to floor) arm position.

½ Squats - this exercise was similar to the Back Squat with one difference. While lowering the bar and themselves, instead of lowering to a parallel thigh position, subjects only needed to lower to a knee angle of approximately 90^0.

Static Lunges – as outlined by Earle and Baechle (2000) this exercise began by placing an Olympic bar in a high bar position and taking a large step forward into a split stance. Subjects then lowered the trailing leg until both knees were approximately 90^0. Once the 90^0 had been reached subjects extended the front knee to return to the split stance position. Subjects were instructed to keep the front knee over the front foot and maintain a perpendicular body position to the floor. Once the desired repetitions were completed on one leg subjects changed the lead leg to the trailing leg.

Deadlift - as outlined by Earle and Baechle (2000) this exercise began with subject's feet in a shoulder to hip width stance approximately 1/3 under the bar. Subjects began with their knees and hips flexed in a forward facing position with a neutral back, chest up and out, head in line with spine, heels flat on floor, shoulders over the bar, arms were in a fully extended position with hands slightly wider than shoulder width on the bar. Subjects began to lift by extending the hips and knees while keeping elbows fully extended, head looking slightly up, and back in a neutral position. Subjects were instructed to keep the bar close to the shins and as the bar moved passed the knees to move the hips forward. At the top position, standing, subjects were also instructed not to excessively extend the back but to maintain a normal erect position. Subjects then lowered the bar under control to the beginning position. Those subjects with poor hand grip were allowed to used hand grips in order to lift maximally.

Clean Pulls - as outlined by Newton (2006), this exercise begins in a Deadlift starting position. The movement is the same for the Deadlift except towards the end of the movement subjects “jumped” explosively, maintaining toe contact with the floor. Subjects were also instructed to maintain “stiff arms” with as little flexion as possible. Subjects with poor hand grip were allowed to use hand grips.

Clean Pulls from a Hang – as outlined by Newton (2006), this exercise is the last part of the Clean Pulls, beginning from a semi upright (hanging) position. The bar was positioned atop of boxes to make it easier for subjects to initially lift the bar to begin the exercise. The exercise began after subjects lifted the bar from the boxes and positioning the bar mid-way up the thighs. Subjects were instructed to explosively extend their hips, and knees to effectively jump maintaining toe contact with the floor. Subjects were also instructed to maintain “stiff arms” with as little flexion as possible. Subjects with poor hand grip were allowed to use hand grips.

The training protocol and exercise order is outlined in table 7. The volume of training completed by the subjects over the seven week study period ranged from three to four sets of a three to five RM (repetition maximum) load. The sets and repetitions were completed using an undulating periodised training model (see table 7). This was chosen because undulating type programmes have shown greater increases in power and strength adaptations compared to straight sets and linear type periodised protocols (Rhea, Ball, Phillips, & Burkett, 2002).

During the baseline training phase subjects were instructed not to perform exercises to failure but instead to lower training loads to approximately 80% effort. However during the intervention phases, subjects were instructed to lift maximally and to failure. Throughout this study subjects were still permitted to continue with their normal upper body training but no lower body training was allowed.

Interventions

Plyometric Group Training

Eight subjects completed the strength and vertical jumping protocol (SVJ). The subjects completed their resistance and jumping exercises in a contrasting manner (refers to a workout that involves the use of alternating sets between heavy and light resistances [Duthie, Young, & Aitken, 2002]). Six jumps were performed after the first three sets (for a total of six sets of jumps for each day) of the back squats and lunges during day 1 and after box squats and dead lifts during day 2.

Table 7: Training exercises, intensities and rest for the two protocols over each of the seven week periods.

	Day 1			Day 2			
Exercises	Clean Pulls			Clean Pull from Hang			
	Back Squats			Box Squat			
	Front Squats			½ Squats			
	Static Lunges			Dead Lifts			
	Base Strength Phase			Intervention Phase			
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Intensity for exercises	3 x 4RM	3 x 3RM	3 x 4RM	3 x 3RM	3 x 5RM	4 x 4RM	3 x 4RM
Rest periods	3 min	3 min	3 min	3 min	3 min	3 min	3 min

Subjects were instructed to jump as high and as quickly as possible with a countermovement and minimal rest between jumps. The rest period between a strength set and the plyometric jump set was 90 seconds. Although researchers have investigated the optimal rest length between complex training sets (4 minutes) (Comyns, Harrison, Hennessy, & Jensen, 2006), in "real life" this is unrealistic. That is, if a strength training session comprising of four exercises with alternating power exercises with three sets of six repetitions, it would take in excess of 70 minutes (not including a warm up, warm down, and exercise time). Therefore performing the jumping exercise mid-way through a typical strength training rest period i.e. 3-mins, makes a training session that is approximately 55 min long and more appropriate in "real life".

The SVJ protocol served as the control for this study. The decision to use the plyometric jumping group as the control was due to the combination of strength and plyometric training being common practice when developing explosive power in activities involving the SSC, such as jumping and sprinting (Newton et al., 2006; Markovic et al., 2007; Fatouros et al., 2000). The authors want to test the experimental procedures (assisted jumping) against more traditional procedures of power development.

Assisted Group Training

While completing the strength and assisted jumping protocol (SAJ), subjects (n=9) completed the same contrasting training programme as outlined in the plyometric jumping protocol section, i.e. six jumps performed after each of the first three sets of core exercises only. The jumping procedure was identical to the SVJ group differing only by the subjects wearing a climbing harness / weight belt attached to a 41inch long strength band (Iron Woody LLC, Montana) via karabiners. The karabiners were attached to the harness at each leg strap just behind the adjusting buckle and also attached to the strength band. The strength bands were attached to a power rack in the middle of the top support beams at a height of 2.1 m. An assistance level of -25% bodyweight was chosen for the SAJ group. To reach a 25% level of assistance subjects were weighed at the commencement of each training session to determine the type of strength band required. For heavier and taller subjects a heavier/stronger tensioned band was needed (medium #4 band) and a lighter/weaker tensioned band was needed (super mini #2 or small #3 band) for shorter or lighter subjects. If the assistance was too great or not enough the leg straps of the climbing harnesses were adjustable and could be loosened off (lessening the assistance) or tightened (increasing the assistance) in order to reach the desired -25% body weight of assistance.

Testing Procedures

Vertical Jump Test

An adjustable vertical jump board, measuring to the nearest cm, (Vertech Inc, Questtek Corp., Northridge, CA) was positioned next to a piezoelectric force plate (Kistler Instruments Inc, Winterthur, Switzerland.) (Mihalik et al., 2008). After subjects marked their starting heights, by reaching as far as they could up the vertical board and keeping their heels flat on the ground, they performed three warm-up jumps at a sub maximal effort. Subjects then performed three maximal effort jumps (with counter movement and arm swing) using a 2-foot take off and landing. Each effort was separated by three minutes of rest and the highest jump was used for analysis (Potteiger et al., 1999, and Mihalik et al., 2008) (see Appendix 6).

Sprint Test Procedures

A 20m sprint test was used to measure horizontal speed and acceleration prior to and after experimental procedures. Subjects ran the 20m sprint distance in an indoor facility without the use of spikes. Subjects began from a standing static starting position and measured by infra red light cells (Speedlight, Swift Performance Equipment, Lismore, Australia) (Blazevich & Jenkins, 2002). The timing lights were placed at 0, 10, and 20m intervals to gather speed data of the sprint test. Before the maximal sprint test subjects were give three sub-maximal trials at self estimated intensities of 50, 75 and 90% efforts. After which subjects completed three maximal effort trials separated by five minutes rest and the fastest time was used for analysis (Harrison, Keane, & Coglan, 2004) (see Appendix 6).

3RM Squat Test

The squat assessment was performed using procedures reported by Anderson, Sforzo, and Sigg (2008) for 1-3RM squat testing. After the standardised warm up, subjects performed the back squat exercise in a power rack. An Olympic bar was placed upon the upper back approx around the C-7 vertebrae. Subjects performed the downward phase of the squat until the knee reached a 90^{o} angle and then returned to a standing position. The depth of each subject's squat was marked with tape. For the lifts to be deemed successful, the subjects needed to lower the bar to the position of the tape when an audible cue from the tester was heard. The foot placement was at shoulder width and then marked, with tape, for each additional lift. Subjects were given up to six attempts and progressively increasing their load during each set until their 3RM was reached (see Appendix 6). Subjects were given three (minimum) to five minutes (maximum) rest between attempts.

From the 3RM squat strength test a predicted 1RM value was attained using the Epley formula. This method has been reported to correlate well compared to 1RM tests, r = 92 (Wood, Maddalozzo, & Harter, 2002). Testing the exact 1RM would be more accurate over predictive methods, however applying maximal loads to subjects who may not be accustomed to such intensities may result in injury, therefore this predictive method (using lighter loads) was used to minimise the injury risk while still acquiring accurate 1RM values (McIntosh, 2005).

Data Analysis

The resultant ground force reaction (GFR) data was collected at 500 Hz, from a 15 second capture time, and passed through a AC/DC converter (Type 5606A, Kistler Instruments Inc, Winterthur, Switzerland.) and analysed using force interpreting software (Bio Ware 2, ver 3.06c, Kristal Systems Inc, Switzerland). The force data was imported into a spreadsheet (Microsoft Office Excel 2007, Microsoft Corporation) for further analysis (see Appendix 7). From the force data, subject's body weights were calculated by averaging the vertical force trace over 200 samples during a period of motionlessness prior to the vertical jump. The GFR data was used to determine the various variables of interest, including: total and average force, rate of force development (RFD), velocity (peak, average, and takeoff), and power (peak and average).

The process for calculating power and velocity from the force-time data is outlined in Bartlett (1997). Firstly the original force-time curve was normalized by subtracting subject's body weight from the force data. This was then converted into an acceleration-time curve by dividing the normalized force by subject's body mass (body weight / 9.81 (gravity)). Secondly, the acceleration-time curve was numerically integrated to find the velocity-time curve using the formulae, $\int_{t1}^{t2} a \blacktriangle t = v_2 - v_1$ for each data point. Finally power was calculated from multiplying the initial force by velocity (see Appendix 7).

Rate of force development was calculated from the peak force developed during the concentric phase of the jump (from the point at which the change in velocity becomes positive (i.e., end of the countermovement) to the point at which peak concentric force occurred before takeoff [Cormie, McBride, & McCaulley, 2007]) and determined as the change in force divided by the change in time taken to develop the force. Peak force (PF), peak power (PP), peak velocity (PV), were determined as the maximal value achieved during the concentric phase of the jump. Mean force (MF), power (MP), and velocity (MV) were calculated as the average values during the concentric part of the jump, i.e. point where change in velocity becomes positive to the point of take off. Relative force (RF) and power were calculated from dividing the PF and PV by the subject's body mass (from the averaged 200 force plate samples). Take off velocity was deemed to be the first point where the force-time record from each jump zeroed.

Statistical Analysis

To make inferences about the effect being true about the population, the uncertainty has been expressed as 95% confidence limits (CL) and as the likelihood of the true value of the effect represented a beneficial, trivial, or harmful change (Hopkins, 2002).

In order to assess the magnitudes of the effect between the two experimental training protocols with respect to VJ, 20 m sprint, 1RM, and kinetic variables, a spreadsheet for the analysis of a pre-post controlled trial with adjustment for a predictor (Hopkins, 2006) was used. The spreadsheet was used to log transform the raw results into a standardized effect unit and interpreted using the Cohen scale of magnitudes for standardized differences in the mean. The Cohen scale is represented by 0.2 (small), 0.6 (moderate), 1.2 (large), 2.0 (very large), and 4.0 (extremely large) effect sizes (ES) (Hopkins, 2009) and have been used to quantify the differences between conditions.

When results were not unclear, the probabilities of the reported effects were qualitatively quantified using the following descriptors developed by Hopkins (2002):

- <1%, almost certainly not
- <5%, very unlikely
- <25%, unlikely / probably not
- <75%, possibly / possibly not
- >75%, likely / probably
- >95%, very likely
- >99%, almost certain

A result was deemed unclear if its confidence interval overlapped the threshold for substantiveness (i.e. the smallest worthwhile effect); that is, if the effect could be substantially positive, trivial and negative, or beneficial and harmful (Batterham & Hopkins, 2006). The smallest worthwhile standardized change was set at 0.20 (Cohen, 1988), therefore changes below this threshold were interpreted as trivial.

In order to assess the magnitude of the effect within both training protocols with respect to vertical jump, 10 and 20m sprint performance, and 1RM squat strength a spreadsheet for the analysis of a post-only crossover trial, with adjustment for a predictor was used (Hopkins, 2006). The interpretation of the results was conducted in the same manner as mentioned above.

In order to compare the training effects between the groups with respect to the difference within subject ability (i.e. was there a greater training effect between the groups in subjects who were better performers, i.e. subjects who could jump higher, sprint faster, or lift more etc), trend lines between changes in post and baseline values were plotted. The above mentioned spreadsheet did this automatically. From the trend lines various point of interest were identified. The spreadsheet was then adjusted to the point of interested and analyzed in the same manner as above.

Correlations between improved jump height and the improvements in the measured variables of peak force, peak velocity, peak power, predicted 1RM squat strength, and maximum rate of force development were calculated using the Pearson's product moment method (Hopkins, 2000). Correlation values were represented by 0 – 0.1 (trivial), 0.1 – 0.3 (small), 0.3 – 0.5 (moderate), 0.5 – 0.7 (large), 0.7 – 0.9 (very large), and 0.9 – 1.0 (nearly perfect) (Hopkins, 2000) relationship and have been used to quantify the relationships between variables.

Results

Training Protocols

There were some clear differences between the SVJ and the SAJ jumping protocols. The SAJ protocol was found to have a mean maximum velocity during a jump of 3.1 $m.s^{-1}$ (± 0.4 $m.s^{-1}$ SD) compared to the SVJ protocol of 2.6 $m.s^{-1}$ (± 0.2 $m.s^{-1}$ SD). The difference between the two jumping protocols was very large at 18% (± 12% SD). Similarly, the difference in take off velocity between the two jumping protocols was also very large, 20% (± 13% SD). The SAJ protocol had a mean take off velocity of 3.0 $m.s^{-1}$ (0.5 m.s-1 SD) compared to the SVJ protocol of 2.5 (± 0.2 $m.s^{-1}$ SD). There were unclear differences in the two jumping protocols with respect with maximum force output. The SAJ protocol had a mean maximum force output of 1013 N (± 180 N SD) compared the SVJ protocol maximum force output of 1091 N (± 362 N SD). The between protocol difference was 4.6% (± 25% SD).

Vertical Jump

There were trivial differences in the SVJ and SAJ groups between their vertical jump ability before the training intervention (pre-2), 51 cm (± 7.9 cm SD) (SVJ) and 49 cm (± 7.6 cm SD) (SAJ). At the completion of the training both training groups improved their mean jumping performance by 1.6 cm or 3.9%; ±6.6% (SVJ) and 3.3 cm or 6.8%; 3.5% (SAJ) (figure 2). This was seen as a possible small and a likely small effect with the SVJ and SAJ groups respectively. However the qualitative analysis of the difference between the groups was unclear.

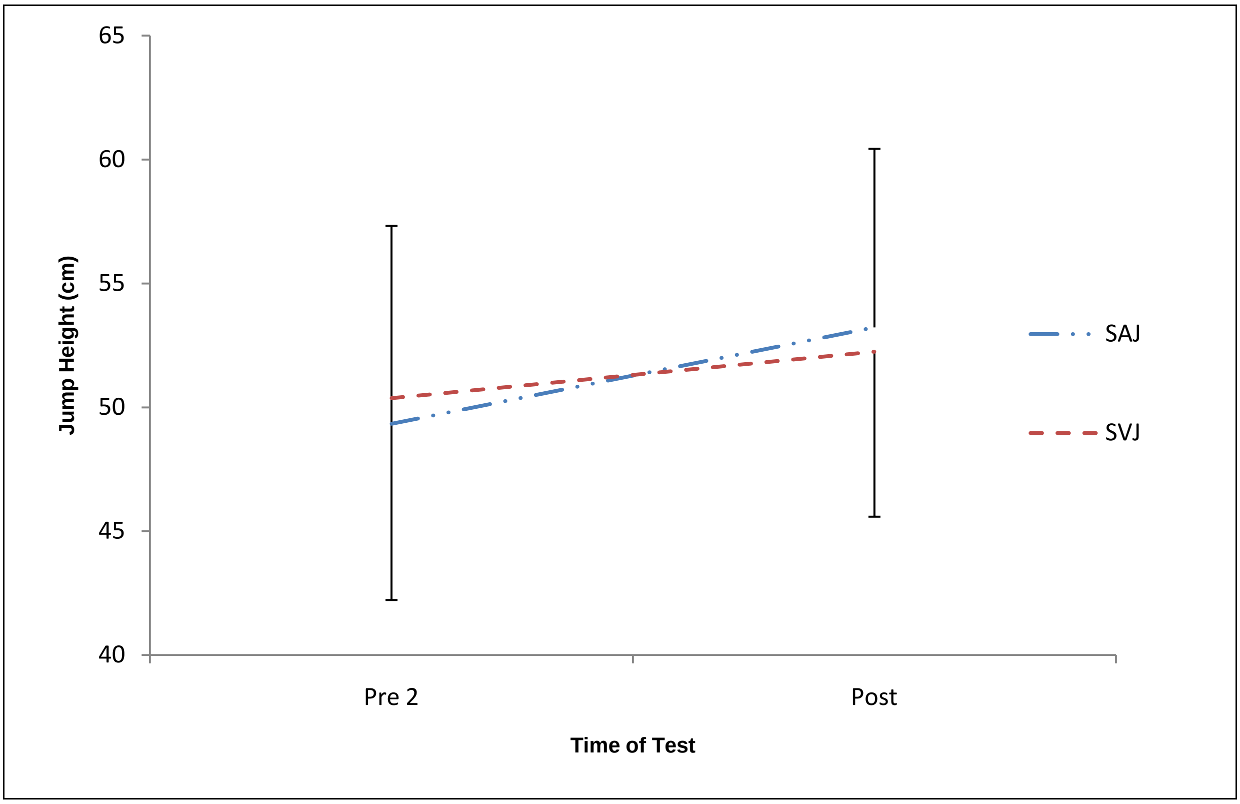

Figure 2: Mean (±SD) vertical jump performance of recreationally trained subjects before (pre-2) and after (post) four weeks of either a strength and vertical jump (SVJ) or a strength and assisted vertical jump (SAJ) training intervention.

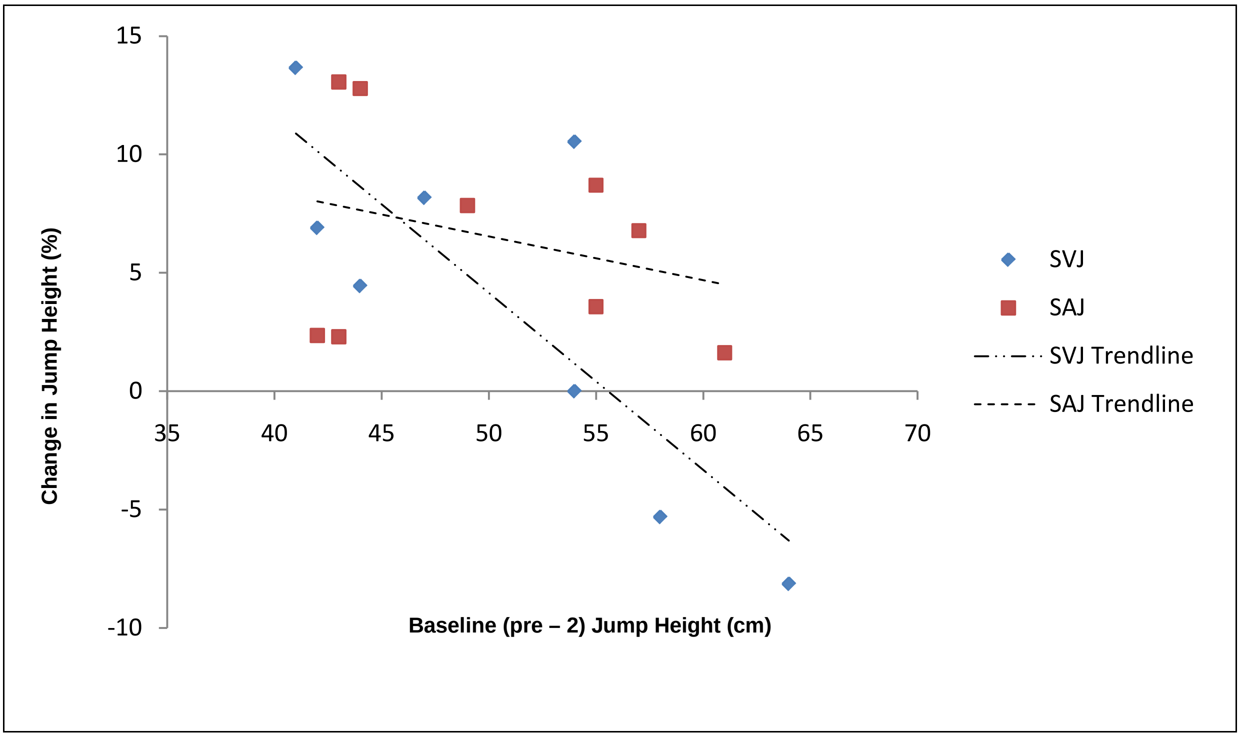

Figure 3: Percentage change (%) in jump height following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted trend lines.

Using the fitted trend lines (figure 3) we investigated the difference between the groups at 43, 50, 55, and 60 cm jumping ability. An unclear effect was found at 43 cm but at 50.0 cm we found a small possible effect of 1.5% (± 2.7%). At 55.0 cm we found a likely moderate effect of 3.1% (± 3.2%), and at 60 cm we found a likely moderate effect of 4.8% (± 4.5%) of the SAJ group compared to the SVJ group. In addition the point at which results become clear between the groups was at a 50 cm jump height. These data suggest that the SAJ protocol was better suited to subjects who could already jump in excess of 50 cm and was seen to be more effective than the SVJ protocol to improve jump height in subjects who could already jump well (≥ 50 cm).

Kinetic Variables

The mean baseline (pre – 2) performance measures of peak, average, relative force and power, peak, mean and take off velocity, and maximal rate of force development for the two training groups are presented in table 8. The analysis and between group differences of these variables are shown in table 9.

Although no meaningful differences were found between the groups with respect to force measures there were however clear differences when analyzed with trend lines (figures 4, 5, 6). When peak force was investigated at 900, 1000, 1100, 1200, and 1300 N between the groups unclear results were found at 900 and 1000 N. However at 1100, 1200, and 1300 N there were likely large effects of 26% ± 30%, very likely large effects of 30% ± 25%, and very likely very large effects of 35% ± 23% respectively. Mean force was further analyzed at 700, 750, 800, 850, and 900 N and found unclear results between 700 and 800 N.

Table 8: Baseline (pre – 2) performance (mean ± SD) (pre-2) and differences between the strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ), of peak (Max), mean, and relative peak force and power, peak, average, and take off velocity, and maximal rate of force development (mRFD).

	SVJ	SAJ	Between Group Difference (SAJ to SVJ)
Force			
Max (N)	1097 (188)	1411 (240)	29%
Mean (N)	751 (126)	975 (141)	30%
Relative Peak Force ($N.kg^{-1}$)	13.66 (2.6)	16.42 (4.2)	20%
Velocity			
Max ($m.s^{-1}$)	2.92 (0.3)	2.85 (0.3)	- 2.4%
Mean ($m.s^{-1}$)	1.62 (0.2)	1.64 (0.2)	1.2%
Take off Velocity ($m.s^{-1}$)	2.73 (0.3)	2.68 (0.3)	- 1.8%
Power			
Max (W)	4587 (822)	5172 (929)	6.9%
Mean (W)	2327 (419)	2733 (429)	17%
Relative Peak Power ($W.kg^{-1}$)	57.01 (10)	59.27 (9.5)	3.9%
Rate of force development			
mRFD ($N.s^{-1}$)	2262 (1419)	2830 (1745)	25%

There were however clear likely very large effects of 24% ± 27% and 25% ± 27% at 850 and 900 N respectively. Moreover relative peak force was further analyzed at 12, 13, 14, 16, and 17 $N.kg^{-1}$ and found unclear effects at 12 and 13 $N.kg^{-1}$. Likely large effects were found at 14 and 16 $N.kg^{-1}$ of 19% ± 21% and 23% ± 25% respectively and a likely very large effect was found at 17 $N.kg^{-1}$ of 25 ± 30%. There was no meaningful difference between the groups in terms of kinetic responses although the SAJ group did show trends of greater improvement or at least not worsening as much as the SVJ group.

Table 9: Changes within the mean, difference between the groups, confidence limits, and qualitative outcomes between the strength and vertical jump (SVJ) and strength and assisted vertical jump (SAJ) training groups in various kinetic variables.

	Mean % change (± SD)				
	SVJ	SAJ	Difference between the groups	Confidence limits (%)	Qualitative outcome
Force					
Max (N)	-10% (20)	-2.3% (23)	8.6%	-12 to 34	unclear
Ave (N)	-10% (16)	-4.8% (23)	6.0%	-13 to 29	unclear
Relative Peak Force (N/kg)	-9.9% (21)	-3.7% (24)	6.9%	-14 to 33	unclear
Velocity					
Max ($m.s^{-1}$)	1.6% (3.3)	3.4% (9.4)	1.9%	-5.2 to 9.4	unclear
Ave ($m.s^{-1}$)	-0.2% (5.5)	1.2% (5.9)	1.4%	-4.6 to 7.7	unclear
Take off Velocity ($m.s^{-1}$)	1.9% (3.6)	3.1% (9.6)	1.2%	-6.1 to 9.0	unclear
Power					
Max (W)	-1.5% (9.3)	4.4% (12)	6.0%	-5.0 to 18	unclear
Ave (W)	-4.0% (10)	0.5% (13)	4.6%	-6.8 to 18	unclear
Relative Peak Power ($W.kg^{-1}$)	-1.4% (10)	2.9% (11)	4.4%	-6.6 to 17	unclear
Rate of Force Development					
mRFD ($N.s^{-1}$)	9.1% (167)	15% (52)	5.0%	-59 to 168	unclear

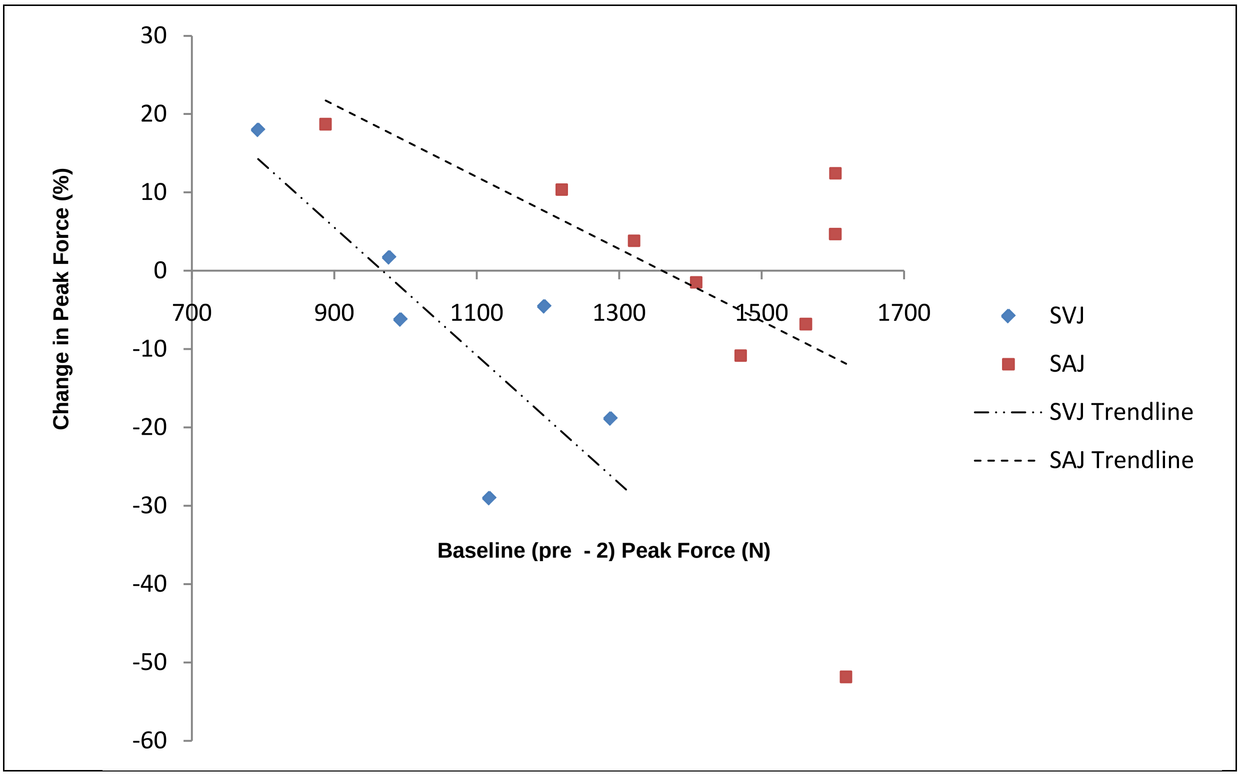

Figure 4: Percentage change (%) in peak force following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted regression lines.

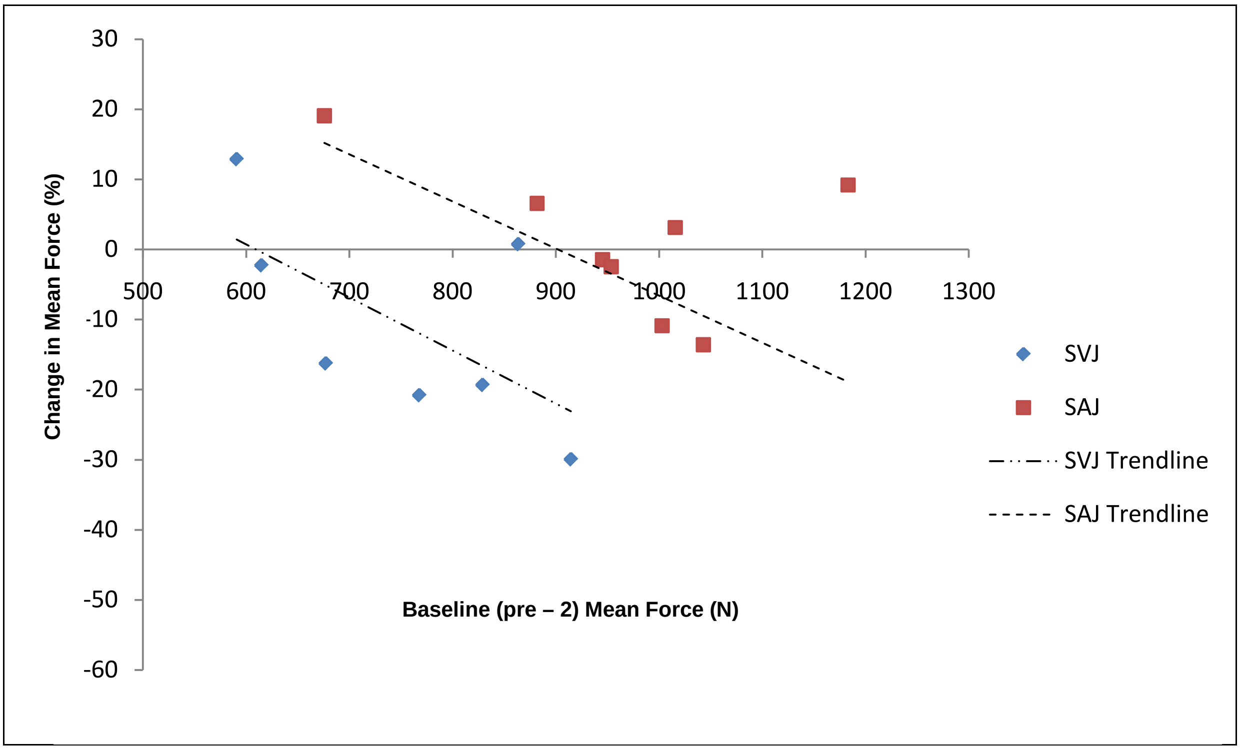

Figure 5: Percentage change (%) in mean force following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted trend lines.

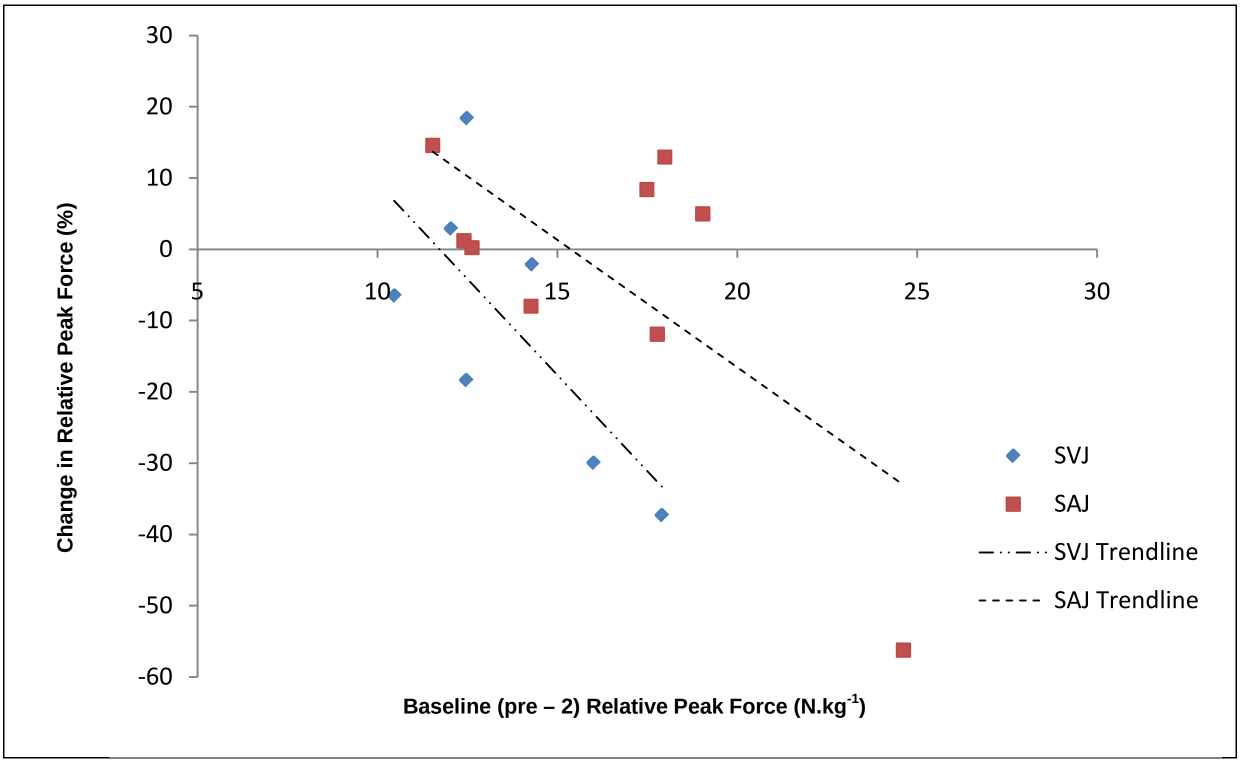

Figure 6: Percentage change (%) in relative maximum force (Rel) following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted trend lines.

The magnitude of difference between the groups with respect to power variables was found to be unclear but further analysis using trend lines revealed clear trends within peak power (figure 7). Upon further analysis at 4000, 4500, 5000, 5500, and 5750 W, we found likely large effects at 4000, 4500, and 5500 W of 12% ± 15%, 11% ± 12%, and 10% ± 13% respectively, while only a likely moderate effect was found at 5000 of 11% ± 10%. Analysis at 5750 W revealed an unclear effect. No other trends were found between the groups with respect to mean and relative peak power.

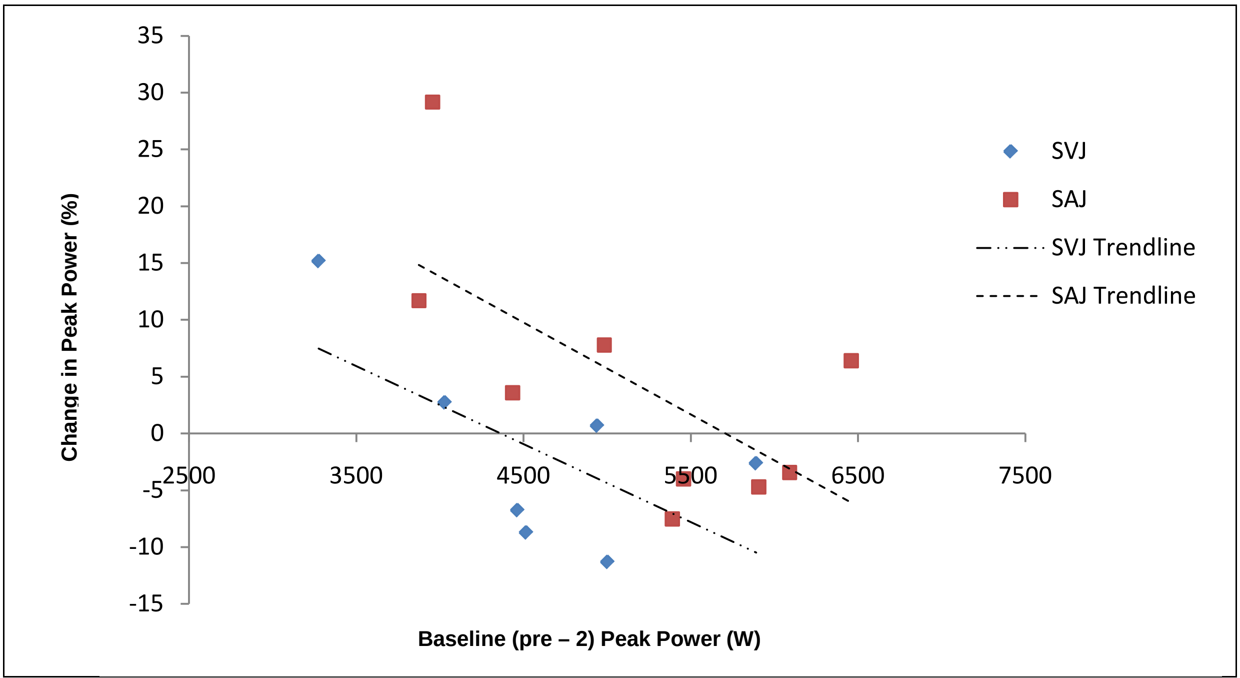

Figure 7: Percentage change (%) in peak power following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted regression lines.

We plotted trend lines (figure 8) to examine the difference between the groups at various points of mRFD, 1200 $N.s^{-1}$, 2000 $N.s^{-1}$, 2800 $N.s^{-1}$, 3600 $N.s^{-1}$, and 4400 $N.s^{-1}$. The magnitude of the difference at 1200, 2000, and 2800 $N.s^{-1}$ was unclear but at 3600 and 4400 $N.s^{-1}$ the difference was seen as a likely very large effect of 116% (± 134%) and a very likely very large effect of 224% (± 208%) respectively in favour of the SAJ group. No other trends were seen in the other kinetic variable using trend lines. These data suggest that those subjects who had a greater mRFD improved more so than those subjects who couldn't.

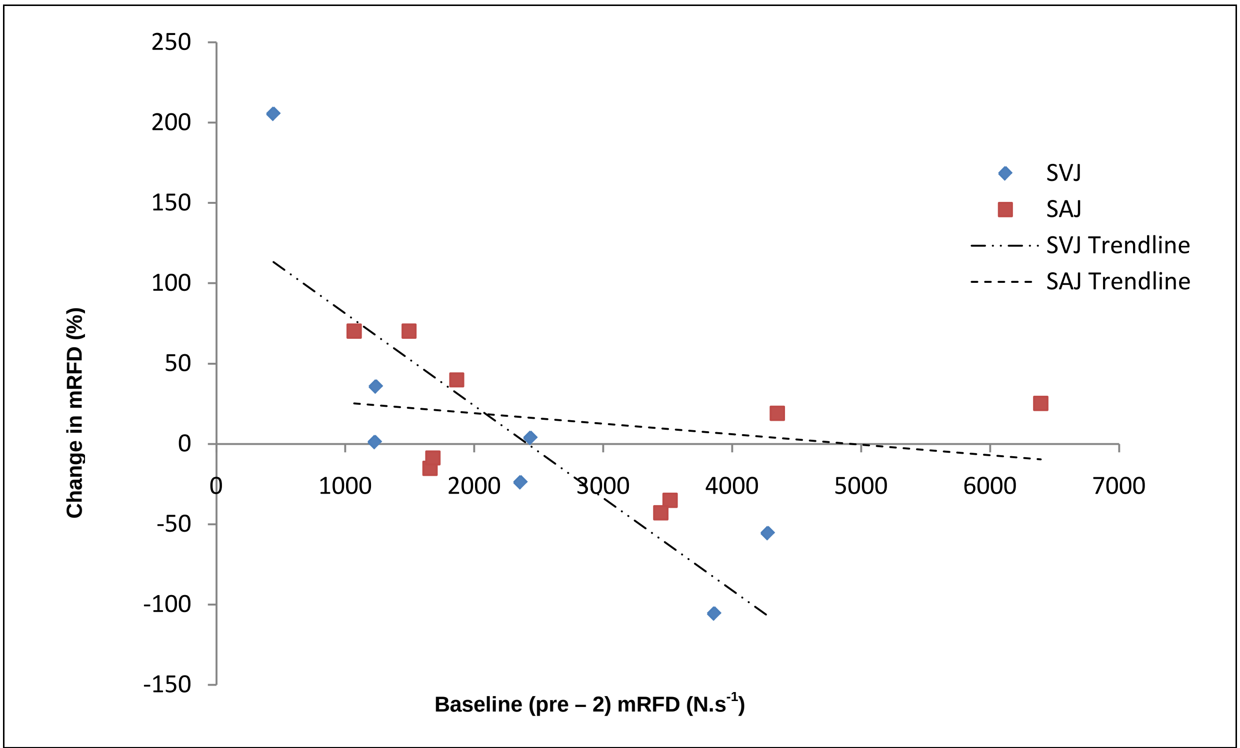

Figure 8: Percentage change (%) in maximum rate of force development (mRFD) following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted regression lines.

Sprint Performance

The SVJ and SAJ groups had trivial differences between them before the commencement of the intervention (pre-2) in 20 m sprint ability, 3.2 sec (± 0.1 SD) and 3.2 sec (± 0.2 SD) in the SVJ and SAJ groups respectively. The mean 10 and 20 m sprint times at pre 2 and post intervention are depicted in figure 9. At the completion of the intervention (post) both groups improved their 10 m times by 0.03 sec or 1.6%; ±2.0% (SVJ) and 0.02 or 1.2%; ±0.9% (SAJ). The groups also improved their 20 m sprint performance by 0.03 sec or 0.9%; ±1.8% (SVJ) and 0.04 sec or 1.3%; ±1.2% (SAJ). There were likely moderate and an unlikely small magnitude of effects within the SVJ and SAJ respectively, in 10m sprint performance from baseline (pre – 2) to post testing and possible small effects in 20m performance within both the SVJ and SAJ groups between baseline (pre – 2) and post testing.

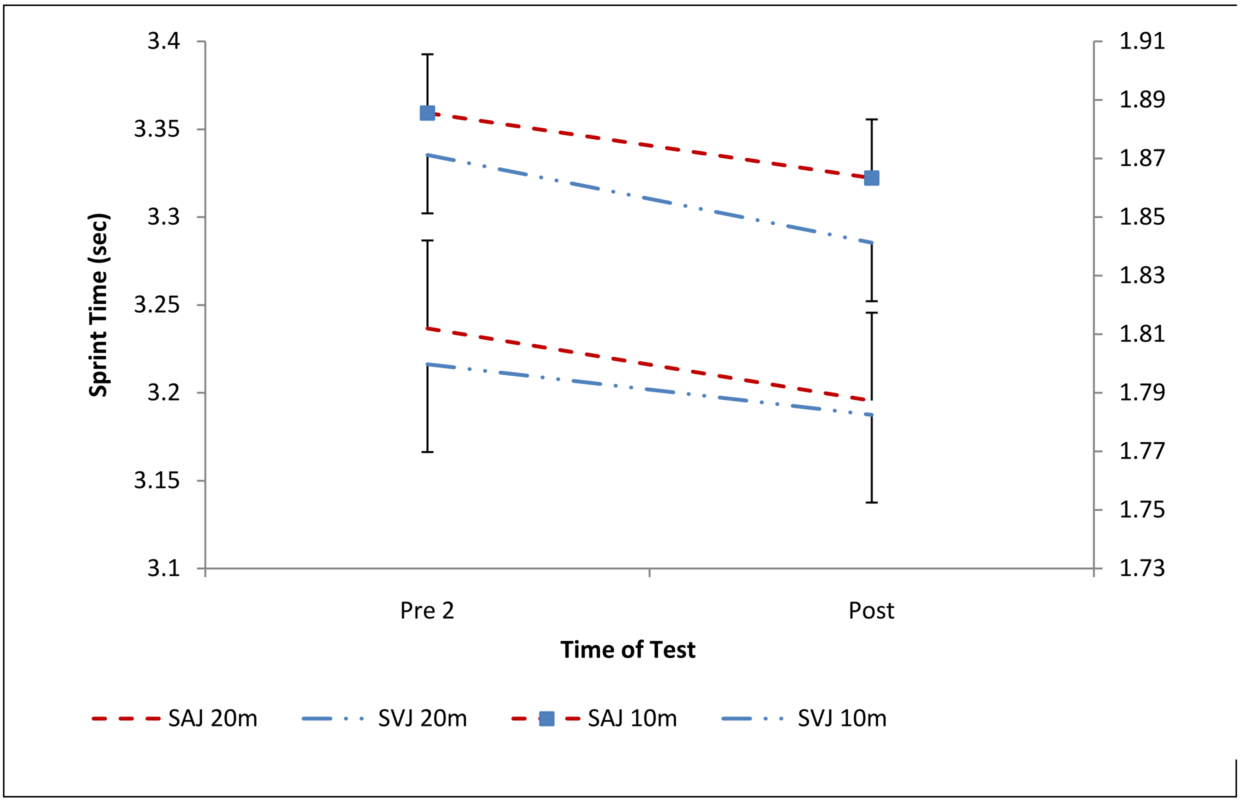

Figure 9: Mean (± SD) 10 and 20m sprint times of recreationally trained subjects before (pre-1) and after (post) four weeks of either a strength and vertical jump (SVJ) or a strength and assisted vertical jump (SAJ) training intervention.

There was a 0.4% (± 2.1%) and 0.3% (± 2.0%) difference between the groups in 10 and 20m performance respectively. The qualitative outcome between the two training protocols was unclear and demonstrated no real differences between the groups at both distances. No differences were found between the SVJ and SAJ groups when trend lines were used.

1RM Squat Strength

The SVJ and SAJ groups had moderate to large differences between their 1RM prior to the intervention period (pre-2) with a mean load of 147 kg (± 22 kg) (SVJ) and 164 kg (± 33 kg) (SAJ). The mean predicted 1RM squat loads for both groups before (pre-2) and after the training intervention (post) are presented in figure 10.

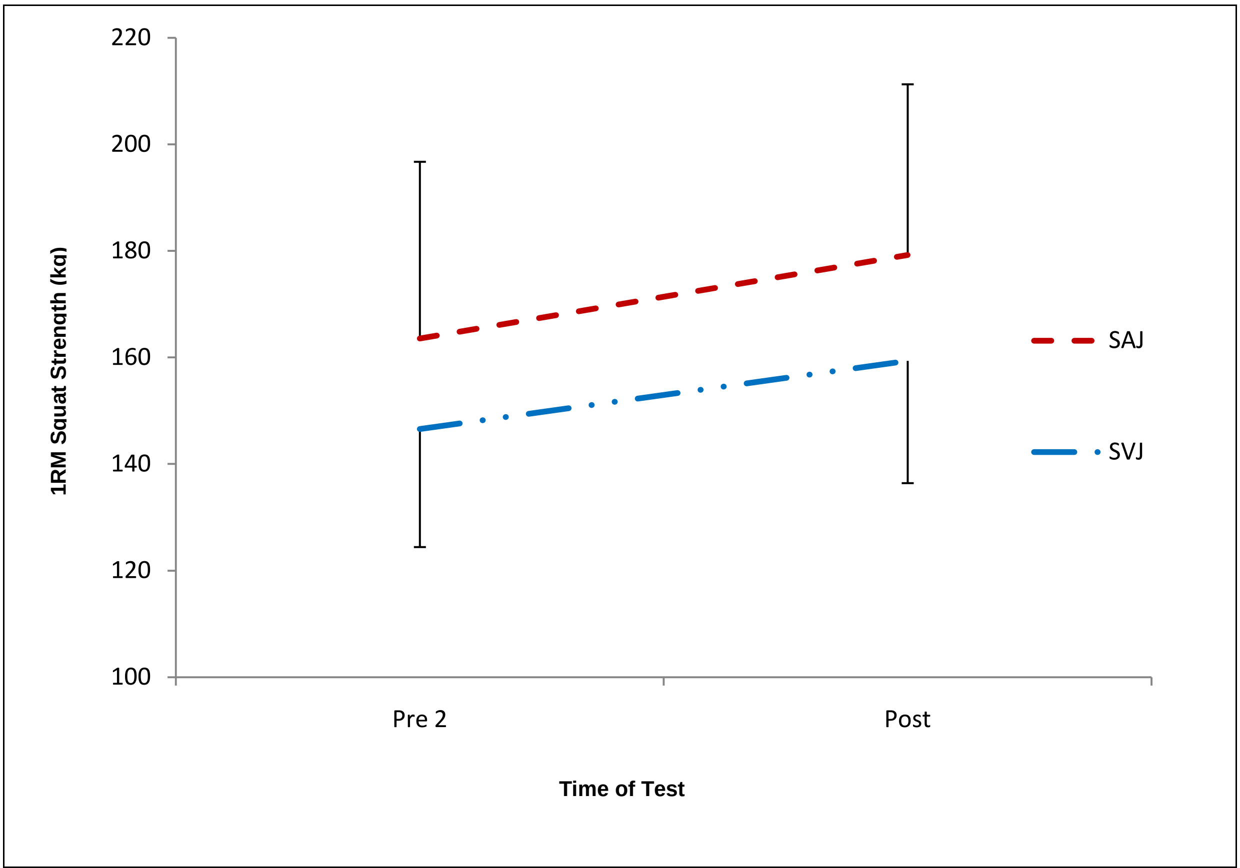

Figure 10: Mean (±SD) predicted 1RM squat strength of recreationally trained subjects before (pre-1) and after (post) four weeks of either a strength and vertical jump (SVJ) or a strength and assisted vertical jump (SAJ) training intervention.

The SVJ group improved their predicted 1RM squat strength from 147 kg to 159 kg or 8.9%; ±5.6%. The SAJ improved from 164 kg to 179 kg or 10%; ±5.6%. There was a likely small effect in the 1RM squat strength in the SVJ group and a very likely moderate effect in the SAJ group between baseline (pre – 2) and post testing. However there was an unclear magnitude of effect between the groups of 1% (± 6.9 %). When we plotted our trend lines (figure 11) and investigated the difference between the groups at 120, 130, 140, 150, and 160kg we found a surprising trend. At points of 120-140kg there were unclear magnitudes of difference but at 150 and 160 possible small effects were found of 2.8% (± 6.8%) and 3.2% (± 7.5%) in the SAJ group compared to the SVJ group. These results indicate that stronger subjects using a SAJ stimulus may improve more so than the similar subjects using a more traditional stimulus of SVJ training.

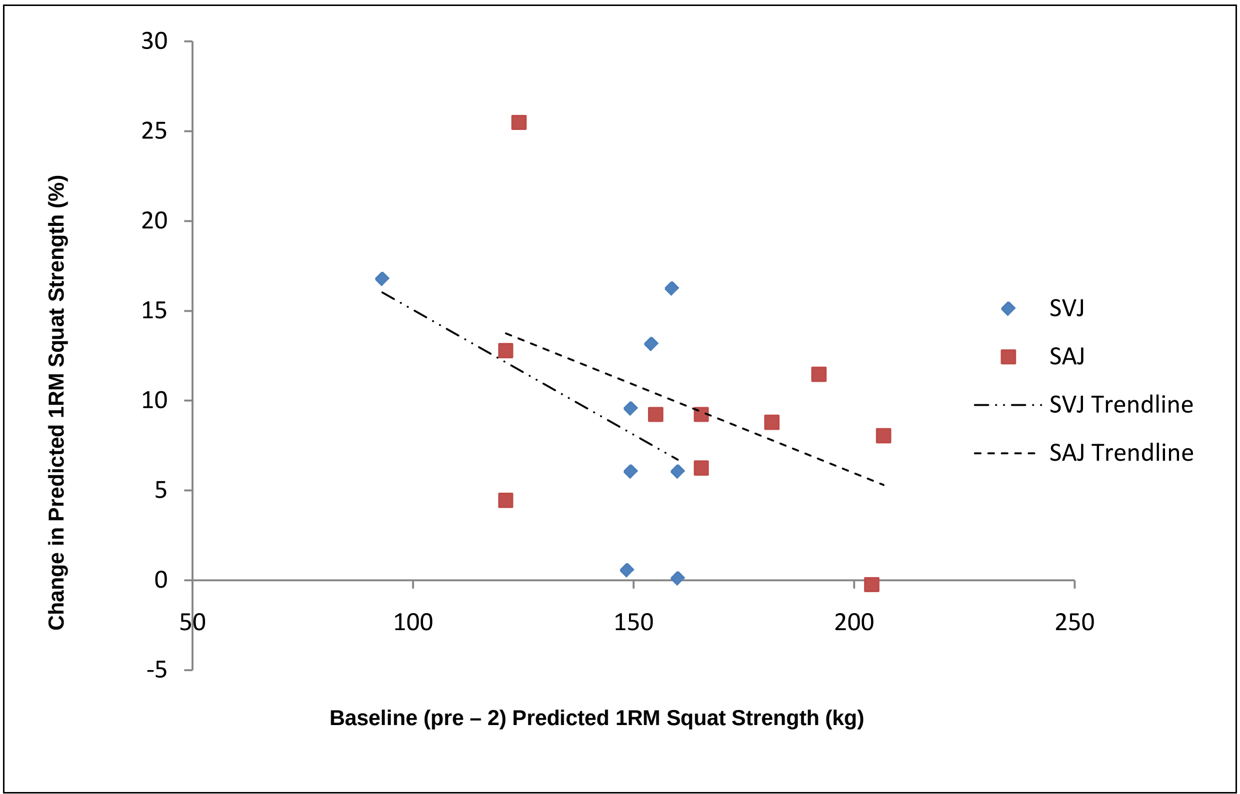

Figure 11: Percentage change (%) in maximum predicted 1RM squat strength following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects with fitted trend lines.

Relationships between Variables

There were trivial correlations between the improvements in vertical jump height and the change in peak force (r = 0.06), peak velocity (r = -0.07), and peak power (r = -0.07). There was however a moderate correlation between the change in predicted 1RM squat strength and VJ height improvements (r = 0.47) and a large correlation of r = 0.54 between the change in mRFD and the change in VJ height.

Summary

Vertical jump, 20m sprint, and predicted 1RM squat strength were improved to similar magnitudes following SVJ and SAJ training in recreationally trained athletes when training twice a week (76 repetitions of jumping per week) over a four week period. The strength and assisted jump stimulus was found to be as effective as the traditional strength and vertical jump stimulus to improve strength, power and speed performance. The main findings of this study have been summarized in table 10.

Table 10: Summarised results of subjects following four weeks of either a strength and vertical jump (SVJ) or strength and assisted vertical jump (SAJ) training protocol intervention in recreationally trained subjects.

	Means percent change (± SD)		
	SVJ	**SAJ**	**Qualitative outcome**
Vertical Jump	↑ 3.9% (6.6)	↑ 6.8% (3.5)	Unclear
Peak Force	↓10% (20)	↓2.3% (23)	Unclear
Peak Velocity	↑1.6% (3.3)	↑3.4% (9.4)	Unclear
Peak Power	↓1.5% (9.3)	↑4.4% (12)	Unclear
Maximum Rate of Force Development	↑9.1% (167)	↑15% (52)	Unclear
20m Sprint Time	↓ 1.6% (2.0)	↓ 1.2% (0.9)	Unclear
Predicted 1RM Squat Strength	↑ 8.9% (5.6)	↑ 10% (5.6)	Unclear

Discussion

Summary

To the authors knowledge this is one of the first studies to evaluate and compare the effects of a novel complex training stimulus utilising an assisted vertical jumping stimulus against a more traditional complex training stimulus on strength, power and speed variables. The main findings of this study were that the SVJ and the SAJ training protocols were successful in inducing small effects in vertical jump, 20m sprint in the SVJ and SAJ groups and small and moderate effects in 1RM squat strength in the SVJ and SAJ groups respectively. However, neither training protocol was more beneficial than the other. The unclear effects when comparing the difference of the two groups indicates the need for further data collection. In addition, trends found within the data of the present study indicated the more trained subjects benefited more from the SAJ protocol than the SVJ protocol. Further research is needed to clarify and validate these trends.

The current study differed from previous research, in the area of mixed method training, in two main ways. Firstly, the current study utilised a short intervention period of four weeks. Four weeks is short intervention period compared to the reviewed literature but it is representative of a typical training cycle within a pre-season training programme (Hammet & Hey, 2003). The four week intervention period used in the current study was long enough to elicit positive substantial improvements in the performance of our subjects. Previous studies utilising a four week intervention have also reported substantial improvements (Newton et al., 2006; Mihalik et al., 2008).

Other studies have utilised longer intervention periods of up to 12-weeks (Ingle et al, 2006; Newton et al., 2002; Lyttle et al., 1996). In the studies of Lyttle et al., (1996), Marques and Gonzalez-Badillo (2006), and Fatourus et al., (2000) larger increases in their primary power test, vertical jump were found, ~ 20, 13, and 39% respectively. The intervention period in these studies were 8, 12, and 12 weeks respectively. Does this mean that the longer the intervention period the greater the improvement? Not necessarily as Ingle et al., (2006) found after 12 weeks, smaller comparable (to the current study) results of ~ 4% improvements in vertical jump performance.

Secondly, the current study only used one type of plyometric exercise and a small amount (36) of foot contacts per session. Marques and Gonzalez-Badillo (2006), Lyttle et al., (1996), and Fatourus et al., (2000), reported larger improvements of 13, 20, and 39% in vertical jump height respectively. These researchers utilised a greater number of foot contacts per training session. For example, Fatourus and colleagues (2000) began their training with 80 foot contacts per session for the first two weeks and then 220 contacts the first session and between 150-170 for the second weekly session and continued for the remainder of the training intervention (10 weeks). In contrast Mihalik et al (2008) found a similar (5.4%) improvement in vertical jump height, compared to the current study, and used a similar amount of foot contacts, 54 contacts per session.

One of the main findings in the present study was a 3.9% (SVJ group) and 6.8% (SAJ group) improvement in vertical jump height after only four weeks of training. Although a greater improvement was found in the SAJ group the difference between the groups was unclear. The magnitude of our findings are consistent with the previous research of Mihalik et al., (2008) and Ingle and colleagues (2006) who found 5.4% and 3.9% improvements respectively in vertical jump height after either a four (Milhalik et al, 2008) or 12 week (Ingle et al., 2006) complex training protocol. In addition, the magnitude of our vertical jump improvements were approximately one half found by Marques and Gonzalez-Badillo (2006) (13%) and one third of the reported increases of and Lyttle and colleagues (1996) (20%).

The increased vertical jump performance may be explained by several possibilities. Firstly, within the current study the improvement of vertical jump height (3.9 and 6.8% in SVJ and SAJ respectively) was accompanied by increases in maximal predicted squat strength of 8.9% and 10.0% in the SVJ and SAJ group respectively. Increases in vertical jump height with slow movement velocity strength training have been reported to improve, decrease, or not change vertical jump ability by ~-2 to 5% (Neils et al., 2005; Wilson et al., 1993) with concurrent increases in strength of ~6 to 9% (Neils et al., 2005; Wilson et al., 1993). These studies indicate that if the increases in strength were responsible for the observed improvements in vertical jump, the observed strength increases would need to be on average three times the increase of vertical jump. Based on this, the improvements of strength in the current study would have to have increased on average by 12 and 21% in the SVJ and SAJ groups respectively. However, these estimated strength improvement were not observed in the present study and would suggest that other mechanisms are in part responsible for the increases in vertical jump performance.

Secondly, from a biomechanical standpoint, kinetic variables of force, velocity, power, and mRFD were measured in order to help explain the observed changes of the two group's vertical jump performance. We observed no differences between the group's changes in any of the kinetic variables and improvements in vertical jump performance. Both of the groups decreased their peak force, 10% and 2.3% in the SVJ and SAJ group respectively. Both groups also improved their peak velocity, 1.6% and 3.4% in the SVJ and SAJ group respectively. We also found a decrease in peak power in the SVJ of 1.5% and an increase in the SAJ of 4.4%. The observed decrease in force is speculated to be from a shift in the force-velocity relationship. This relations states, when velocity of a movement increases the amount of applied force decreases and when velocity slows, the applied force is greater (Kawamori and Haff, 2004; Kraemer and Newton, 2000). This was seen within the current study with both of the training groups decreasing their amount of applied force by 10% (SAJ) and 2.3% (SVJ). The decrease in force was associated with an increase in movement velocity of 3.4% (SAJ) and 1.6% (SVJ).

Rate of force development (RFD) has been touted as an important factor to improve jumping performance (Behm & Sale, 1993). Therefore athletes with a greater RFD may jump higher compared with athletes with a lower RFD. This was demonstrated within the current study with subjects in the SAJ group increasing their mRFD by 15% with a concurrent 6.8% improvement in their vertical jump performance, compared to subjects in the SVJ group only improving their mRFD by 9.1% and vertical jump performance by 3.9%. These data suggest that vertical jump improvements seen in the present study were more likely to be due to increases in strength (r = 0.47) and an increase in mRFD (r = 0.54) than changes in force (r = 0.06), velocity (r = -0.07), and power (r = -0.07) outputs.

Neils et al, (2005) stated that a short concentric contraction phase (fast movement velocity) was important for explosive activities. Indeed the SAJ did in fact improve to a greater degree than the SVJ but was not deemed to be different compared to the SVJ group. The training between the two training groups in the current study only differed by differences in movement velocity within the plyometric jumping exercise. The peak movement velocity during vertical jumping utilised within the SAJ group was measured 19% faster than the movement velocity during traditional vertical jumping. The lack of a clear difference may be a result of small sample size and large variations within change scores. In order to clarify any possible difference between the two types of training used within this study further research is needed.

Using the trend analysis we found that subjects who could already jump ≥ 50 cm benefited more from the increased movement velocity of the SAJ protocol compared to the SVJ training protocol. This may be due to trained subjects have the ability to activate a greater proportion of their motor units (Del Balso & Cafarelli, 2007; Higbie et al., 1996; Pensini et al., 2002) compared to less trained subjects. In addition the activation of the motor units can be enhanced by increasing the velocity of movement in similarly trained subjects (Aagaard et al., 2000). The SAJ groups mean training age was greater than the SVJ by three months and trained using greater movement velocities. These data offer a possible insight to why there were slightly greater improvements in the more trained SAJ subjects compared to the more trained SVJ subjects.

The concurrent use of the force plate and Vertec as used in the current study may have restricted the full potential of the subjects. A few subjects did mention the Vertec was not in a good position and was awkward to perform the jumping task. This may have influenced the kinetic response results by some subjects not able to perform to their potential. However this possible limitation was the same for all subjects during each testing session.

Another finding in the present study was improved 20 m sprint times. The SVJ and SAJ groups improved their 10 m times by 1.6% and 1.2% respectively. The groups also improved their 20 m sprint performance by 0.9% (SVJ) and 1.3% (SAJ) respectively. However the magnitude of the difference between the two group's performance at the 10 m distance and 20 m was unclear. The magnitude of improvements in the present study were approximately half of the magnitude found by Marques and Gonzalez-Badillo (2006) who reported 2.4% increases in 15 m sprint time and 3.1% over a 30 m distance. In contrast Lyttle and colleagues (1996) found a decrease in 20 m sprint times of 0.4% after an intervention of complex training.

The relatively small improvements found by the researchers in the current study may be due to a lack of training specificity towards sprinting. Indeed the training protocol used within the current study were vertical in nature, both in the resistance and plyometric exercises, and no emphasis on horizontal movements were made. Previous research involving predominantly vertical movements, both plyometric and resistance training, have resulted in either no significant difference or small decreases in sprinting ability (Wilson et al., 1993; Lyttle et al., 1996). However when a combination of both vertical and horizontal training has been used (Marques & Gonzalez-Badillo, 2006) larger significant changes have been reported.

The third finding in the present study was an increased predicted 1RM squat strength. The SVJ group improved their predicted 1RM squat strength by 8.9% (small effect), whereas the SAJ improved by 10% (moderate effect). Once again the magnitude of the difference between the groups was unclear. Our results are comparable with those of Lyttle and colleagues (1996) who found increase of 14.8%.

In addition our results were a quarter of those found by Marques and Gonzalez-Badillo (2006) who found their subjects improved 43% in squat strength.

Because of the four week intervention training period used in the current study it is likely that improvements in 1RM squat strength were due to mainly neurological improvements. Indeed neural adaptations have been reported to play a major role in the early stages of resistance training (Gabriel, Kamen, & Frost, 2006). The improvements in muscular strength may be a result of but not limited to increased muscle fibre recruitment, inhibition of antagonists, increased co-contraction of synergists, increased motor unit firing rate, increased motor unit synchronisation (Lyttle et al, 1993; Bassa et al., 2005; Milner-Brown et al., 1975; Kamen & Knight, 2004; Potteiger et al., 1999). Although body composition was not measured in the present study the recent work of Seynnes and colleagues (2006) and Blazevich and colleagues (2003) who have found significant growth in muscle fibres, in as little as three to five weeks of resistance training, the contribution of morphological mechanisms such as hypertrophy cannot be overlooked.

Limitations

Although there were improvements within the two training groups in their explosive performance measures there were no clear effects of the training interventions between the two training groups. However, the SAJ training group improved to a greater extent in the vertical jumping and 1RM squat strength test than the SVJ training group. The unclear results found within the current study may have resulted from the following limitations.

- The length of the training intervention
- The number of subjects
- The number of foot contacts

Practical Applications

- We found small – moderate improvements in a number of explosive performance measures in the SAJ group. These improvements were of a similar magnitude to that of the SVJ group. The results found in the current study indicate that the SAJ training protocol is an effective means to improve explosive performance and therefore could be used by the conditioning professional as tool to train his/her athletes.

- We found trends towards a greater improvement in the more skilled performers, those who could jump higher. If the conditioning professional were to use a combined strength and assisted jump training protocol then the use of such a protocol should be limited to those athletes who can jump ≥50 cm and/or be able to squat ≥ 150kg or 1.7 times body weight.

Future Directions

- Due to the relative infancy of this novel training stimulus further research is warranted to further explore the potential benefit of a strength and assisted jumping stimulus on various performance measures. Future research in this area should focus on but not limited to the following aspects:
    - The effectiveness of assisted jump training alone
    - Examine the differences between trained and untrained subjects
    - Explore a dose response, e.g. number of foot contacts and level of assistance

- Explore the differences in kinetic and kinematic responses of assisted and non-assisted jumps
- Explore the effect of the periodization of the level of assistance
- Explore the effects of assistance during different jumping techniques, i.e. depth jumps, bounding etc.

Conclusion

Complex training utilising assisted vertical jumping is an effective training stimulus to improve a variety of performance measures. The strength and assisted vertical jump protocol was as effective compared to a more traditional complex training stimulus of strength and plyometric jumping. The results from this current research provide the conditioning professional with an alternative, fun method in which to aid the development of their athletes. However, the use of this novel training protocol should be restricted to more experienced athletes.

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Appendices

Appendix 1: Letter of Ethical Approval

16 May 2008 email: research@wintec.ac.nz

Paul Croucher

56 Spinnaker Drive

Flagstaff

Hamilton

Dear Paul

Human Ethics Research Application

Can vertical over-speed training improve explosive performance?

Thank you for your application which was considered at the Human Ethics in Research committee meeting held on 15 May 2008 and it is with pleasure I advise ethics approval for your project was granted.

The Human Ethics Committee wishes you every success with this project. The committee would also like to congratulate you on the quality of your application,

Kind Regards

Pamela Tait

C/o Hon Katherine O'Regan QSO JP

Chairperson

Wintec Human Ethics in Research Committee

C.c. Katherine O'Regan

Research leader or HOS

Appendix 2: Subject Recruitment Flyer

Want To Get Stronger, Faster, or Jump Higher?

I am looking for some resistance trained males to volunteer to take part in this investigation of a new exciting and fun method to increase explosive performance (jumping, sprinting etc).

<u>PROJECT TITLE</u>

"Can Vertical Over-Speed Training Improve Explosive Performance?"

The basics of what you will do:

- **Complete 3 laboratory based strength, jump and sprint assessments.**
- **Train twice a week, at your convenience, over seven weeks that will comprise of strength and jump exercises at WINTEC.**

If you are interested and would like further details please contact the principal investigator Paul Croucher (Master of Sport and Exercise Science student)

<u>Contact Details</u>

Ph. 854-6482 or 027-443 2384

Email: paulc@windowslive.com

Appendix 3: Subject Information Sheet

Can vertical overspeed training improve explosive performance?

Principle Investigator

Paul Croucher

Masters of Science Research Student

Waikato Institute of Technology

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Project Supervisor

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Senior Lecturer in Exercise Physiology

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Introduction

You are invited to be part in a study to find out whether vertical overspeed training can improve explosive performance. If you decide to participate you will be asked to participate in a set training programme for seven weeks attending two sessions per week at WINTEC. During this seven week period you will be tested three times for vertical jump height, 20m sprint ability and 3RM squat strength.

You will have several days in which to decide whether you want to be part of this study. In this time you can talk things over with your family, your coach, your G.P, and any one of us (Paul or Nick).

If you do agree to take part you are free to withdraw at any time for any reason. Withdrawal from the study will not affect the quality of the help you receive from your sports club nor affect your relationship with WINTEC should you study there currently or decide to study there in the future.

Who will be in the study?

There will be approximately 30 participants in the study.

How will I know if I am suitable for the study?

If you are male with at least 6 months resistance training experience and regularly train with between four and eight reps then you may be able to participate or if you regularly train in a sport that jumping is part of your training. You should also be free of any injury to the lower body.

Where will the study be held?

The study will be conducted at the Centre for Sport and Exercise Science, Wintec, Avalon Drive Campus. The School of Sport and Exercise Science is a Sport and Exercise Science New Zealand accredited laboratory, which means all equipment, and protocols are of an approved standard.

How long will the study take?

The study will last seven weeks. We will require you to travel to Wintec two times per week to conduct training session which will last approximately one to one and a half hours.

Will everybody be treated the same?

Yes. Everybody participating in the study will do the same training and tests. The only difference will be some of you will be doing normal vertical jumping and some will be doing assisted vertical jumping.

What will I do in a testing session?

During a familiarization period the overall procedure will be explained to you and any questions answered that you may have. After this is done and if you decide to participate and informed consent form will be filled out and signed. Next will be the tests.

The three tests will follow a standard warm-up consisting of a 5min jog and self selected lower body stretches. After the warm up the tests will include a 20m sprint test in an indoor stadium, a vertical jump test, and a 3RM squat strength test. These tests will be conducted three times over a nine week period (week 0, week 3, week 8).

What measurements will be taken?

Measurements that will be taken are 10 and 20m sprint times via infra red timing lights.

Vertical jump height will be collected via a vertical slap board positioned next to force plate. The force plate will measure the forces used during the jump and will also be used to calculate other information (total and net force, impulse, mRFD, and take off velocity)

Predicted 1RM will be estimated via a 3RM squat test. The 1RM will be calculated using a mathematical formula (Epley equation). The 3RM test will use free weights (barbell and weight plates) and be performed in a power rack for your safety.

Weight, height, age, and training age will also be measured.

What should I wear during testing?

Make sure you wear comfortable clothes for training i.e. the same as you would for a normal weight training session.

What does the training involve?

The training protocols involve a strength component where you will train twice a week on non consecutive day with at least 48 hours between. The exercises and training plan for the study is outlined below.

	Day 1			Day 2			
Exercises	Clean Pulls Back Squats Front Squats Static Lunges			Clean Pull from Hang Box Squat ½ Squats Dead Lifts			
	Base Strength Phase			Intervention Phase			
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Intensity for exercises	3 x 4RM	4 x 5RM	3 x 4RM	4 x 3RM	4 x 5RM	5 x 4RM	3 x 4RM
Rest periods	4 min	3 min	4 min	4 min	3 min	3 min	4 min

During each intervention period you will be assigned to either a plyometric jumping or assisted plyometric jumping group. The plyometric jumping protocol (PJ) involves vertical jumping after the core exercises only (see table). Six jumps were performed after the first three sets (for a total of six sets of jumps for each day) of the core exercises. During the jumping, you will be instructed to jump as high and as quickly as possible with a countermovement and minimal rest between jumps. The rest period between a strength set and the plyometric jump set will be 90 seconds.

The assisted jumping protocol (AJ) differs only by you will wear a climbing harness / weight belt attached to bungee cords via karabiners. The karabiners will be attached to the harness at each leg strap just behind the adjusting buckle and also attached to a power rack at the top support beams at a height of 2.1 m. During pilot work in our laboratory it was found that using the bungee and harness assisted each subject by aiding the subject during the jump by effectively reducing the mass of the subject by 25%, which will increase the velocity of which each jump is performed compared to velocities that could be produced by normal jumping.

Are there any risks associated with the procedures?

There are minimal risks associated with this study. These risks that are present are common with normal resistance training i.e. torn / pulled muscles, stress fractures dropped weights, muscle soreness etc. These risks have been minimized by limiting subject participation to those persons who currently are involved with weight training, moreover those that regularly use high loads. This will minimize the possibility of injury as these subjects should already be accustomed to the forces and stress involved with type of training. Familiarization of all procedures, exercises etc, will be given to all subjects.

The possibility of tearing a muscle during the explosiveness of the different tests will be reduced by ensuring adequate warm up and preparation prior to the commencement of the test.

Will I be able to take supplements during the study?

During this study no supplement will allowed to be taken. This is to ensure that any gain in explosive performance is associated with the training and not from other sources.

Will I be able to continue training and participate with my sport?

You will be able to continue your upper body training and continue with week end games without any problems. However you will not be able to conduct any further training to the lower body. This will interfere with results when analyzing results, in addition you will run the risk of over training and possible injury.

Will I suffer any inconvenience from participating?

There will be some inconvenience from participating in this study. You will have to travel to Wintec twice a week for trainings. We would like to conduct these training sessions at convenient times for you and are flexible in this.

What benefits will I gain from participating?

By being a participant in this study you will undergo three different physiological tests which will be repeated three times over the course of the study. These tests will provide you will information on the effectiveness of the training you are completing. Since one type of training is experimental (not widely practiced) you will be one the first to see how this new training could benefit your sport.

Will the information be kept confidential?

Any and all information collected about you will be kept in a secure filing cabinet that only us will have access to. To protect your identification you will be identified as a number rather than a name. This information will be kept on site at Wintec.

What will happen when the study is finished?

When the study is finished (which could be months after the final test date) We will hold an information evening at a beneficial time for all, to inform you of results we have found as a result of this study. During this session we will answer any questions that you may have. The results from this study may be presented at a national conference for sport. Your identification will still be kept confidential.

What are my rights as a participant?

If you have any queries or concerns about your rights as a participant you may wish to contact a Health and Disability Advocate.

Telephone: 0800 11 22 33

You can stop participating at any time for any reason. Please let Paul or Nick know of your decision.

Has this study been approved?

This study has received ethical approval from the Wintec Ethics Committee.

Appendix 4: Subject Health Screening Form

Pre-exercise Screening Questionnaire

Name		
Address	**Occupation**	
	Day Phone	
	Evening Phone	
Contact Person	**Contact Person Phone**	
Today's Date	**Doctor**	
Date of Birth		
Gender	**H/R**	**BP**

Please answer the following questions by indicating yes or no next to the questions.

I Have you ever had a stroke or heart condition?

2 Have you ever had high blood pressure?

3 Have any family members had heart problems before age 60?

4 Have you experienced chest pain when engaged in physical activity?

5 Have you experienced chest pain when not engaged in physical activity?

6 Have you ever had, or do you currently have, high blood cholesterol?

7 Have you ever suffered from asthma or breathing difficulties?

8 Have you ever smoked cigarettes, pipes or cigars?

9 Have you been hospitalised within the last six months?

10 Are you currently taking any medication(s)?

11 Have you ever had, or do you currently have, diabetes, epilepsy, hernia, dizziness or loss of consciousness?

12 Have you ever had any disease or injury of the back, joints, bones or muscles that may be aggravated by exercise?

13 Are you aware of any other health-related issues that may affect your participation in physical exercise?

Pre-exercise Screening Questionnaire (part two)

<table>
<tr><td colspan="6">Name</td></tr>
<tr><td colspan="6">Details of “Yes” answers, medications, possible contraindications to exercise, etc.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Please answer the following questions by placing a tick in the appropriate box.</td></tr>
<tr><td colspan="4">Exercise Participation</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="4">I Have you been participating in regular physical activity’? If yes what type?</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">How would you describe your current physical condition? (Tick one or more boxes).</td></tr>
<tr><td>Unwell</td><td>Overweight</td><td>Unfit</td><td>Healthy</td><td colspan="2">Fit</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">I have understood all the questions and have answered them to the best of my knowledge.</td></tr>
<tr><td colspan="6">I certify that I have disclosed fully any conditions that may affect my participation in physical exercise.</td></tr>
</table>

Date

Staff Name

Client Signature

Staff Signature

Appendix 5: Subject Informed Consent

Participant Informed Consent

"Can Vertical Over-Speed Training Improve Explosive Performance?"

The purpose of this study is to compare two different training schemes on power parameters. To date there has been no published research into the effects of vertical over-speed training to improve explosive performance. This study aims to identify whether vertical over-speed training has the potential to elicit increases in power adaptation.

In choosing to participate in this study you understand that:

- You have read and understood the information sheet.
- You have the right to decline to participate and to withdraw from the research once participation has begun at any stage without having to give reason.
- You will not suffer any foreseeable negative consequences as a result of declining participation or withdrawing from participation including discrimination from either The Waikato Institute of Technology or your club or training provider.
- You understand that there are potential risks, discomforts, and adverse effects associated with participation which has been explained to you in full and minimized to a thorough and practicable level for your safety.
- Your confidentiality is maintained at all times via a numbering system, a locked filing system and password protected computer, all of which is contained in a locked room at WINTEC. You understand that records of data will be kept on file for 5 years before being destroyed and you may request access to these at any stage.
- You are free from medical contraindications or physical injuries that would deem you ineligible to participate in this study.

I……………………..(please print name) have read, clarified and understood the information sheet and above consent information and hereby give consent to participate in the study entitled "Can Vertical Over-Speed Training Improve Jumping Performance?". I understand all inherent risks, requirements and rights that I have in regards to being a participant in this study.

Signed……………………………Date……/…../…. Print name:…………………….....

Appendix 6: Raw Subject Data for Pre – 2 and Post Testing for Vertical Jump, 10 and 20m Sprint, and Squat Strength

Vertical Jump

SAJ	Pre - 2	Post
Subject a	61	62
Subject b	55	60
Subject c	49	53
Subject d	43	49
Subject e	44	50
Subject f	55	57
Subject g	42	43
Subject h	57	61
Subject i	43	44

SVJ	Pre - 2	Post
Subject 1	54	54
Subject 2	47	51
Subject 3	41	47
Subject 4	42	45
Subject 5	58	55
Subject 6	44	46
Subject 7	54	60
Subject 8	64	59

10 and 20m Sprint

	Pre - 2		Post	
SAJ	10m	20m	10m	20m
Subject a	1.81	3.1	1.82	3.12
Subject b	1.93	3.28	1.89	3.22
Subject c	1.95	3.35	1.91	3.3
Subject d	1.69	2.95	1.64	2.88
Subject e	1.94	3.33	1.94	3.35
Subject f	1.83	3.08	1.8	3.03
Subject g	2.06	3.61	2.03	3.46
Subject h	1.77	2.99	1.75	2.96
Subject i	1.99	3.44	1.99	3.44

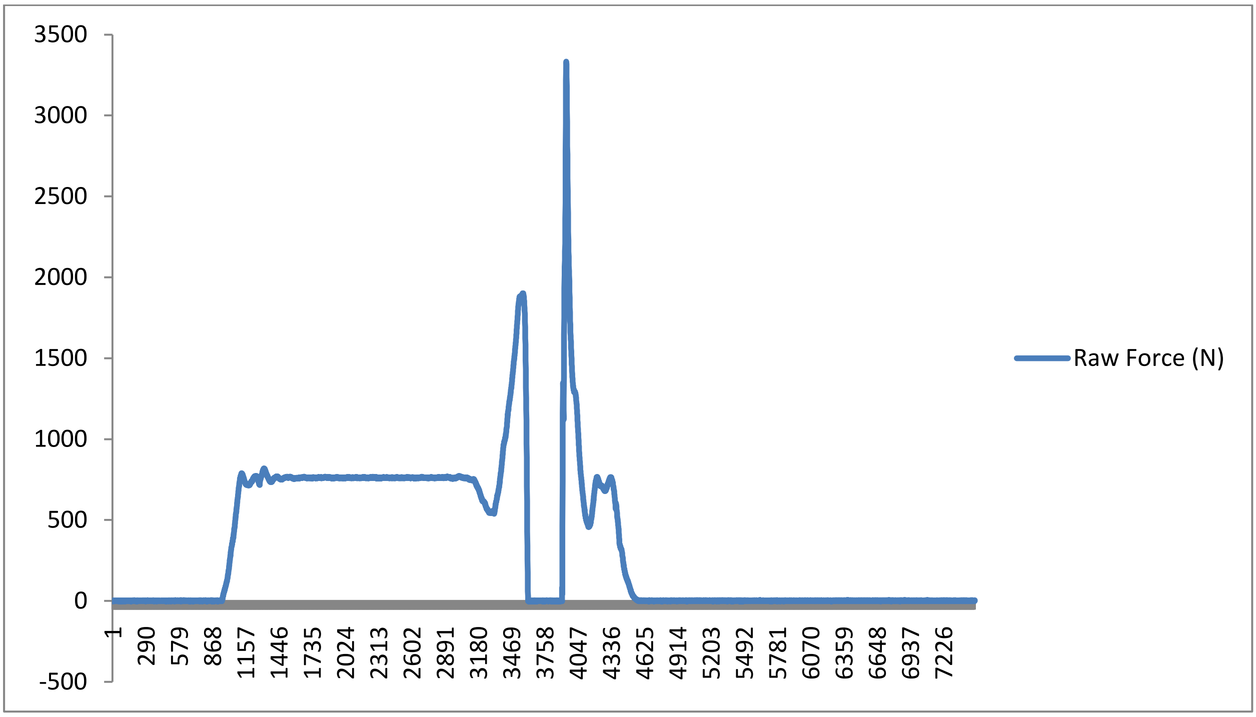
	Pre – 2		Post	
SVJ	10m	20m	10m	20m
Subject 1	1.84	3.15	1.85	3.17
Subject 2	1.88	3.26	1.85	3.23
Subject 3	1.98	3.37	1.91	3.31
Subject 4	1.87	3.18	1.86	3.14
Subject 5	1.98	3.43	1.94	3.45
Subject 6	1.77	3.04	1.76	3.06
Subject 7	1.84	3.14	1.86	3.15
Subject 8	1.81	3.16	1.7	2.99

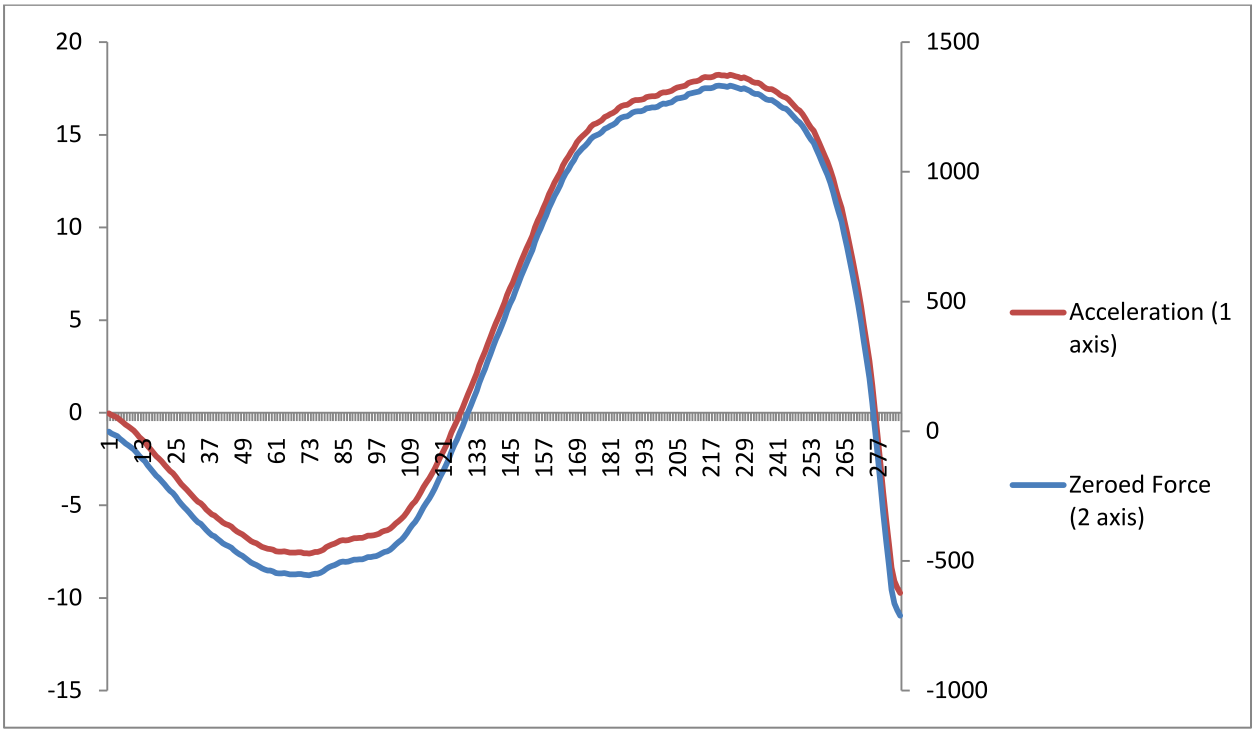
Squat Strength

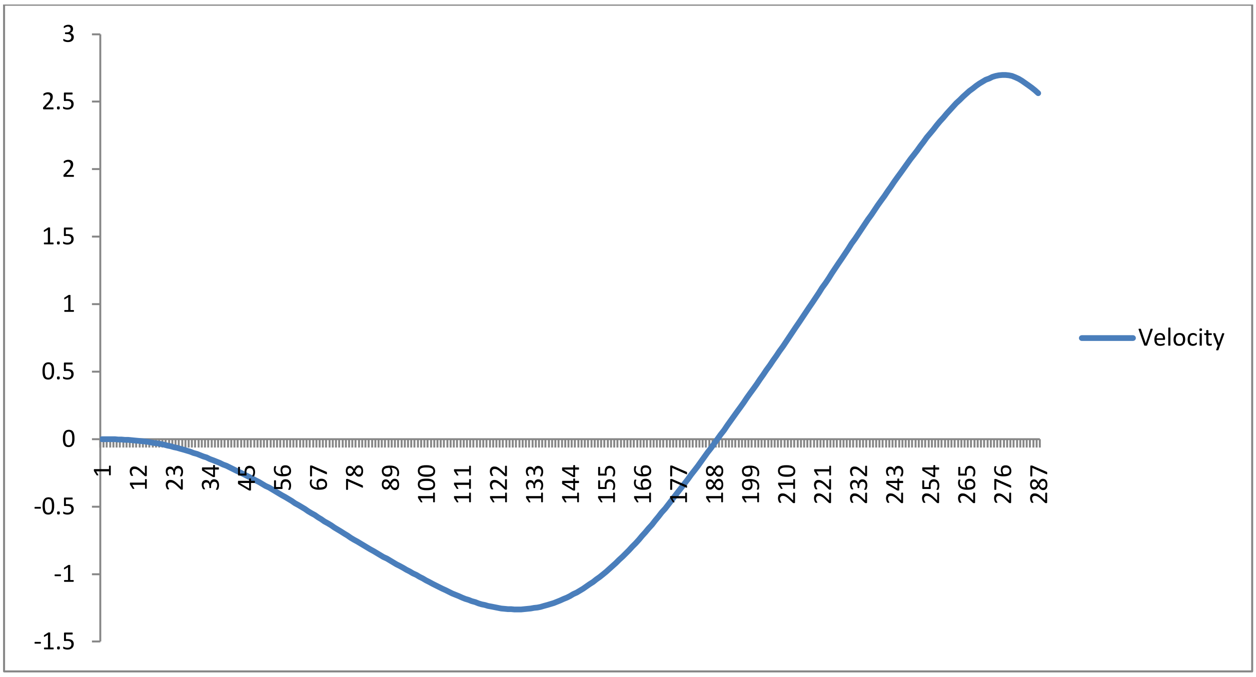
SAJ	Pre - 2	Post
Subject a	192	215
Subject b	124	160
Subject c	121	137
Subject d	121	126
Subject e	165	176
Subject f	165	181
Subject g	181	198
Subject h	204	203
Subject i	207	224

SVJ	Pre - 2	Post
Subject 1	159	187
Subject 2	149	164
Subject 3	148	149
Subject 4	93	110
Subject 5	160	160
Subject 6	160	170
Subject 7	149	159
Subject 8	154	176

Appendix 7: Sample Raw Force, Zeroed Force, Acceleration, Velocity, and Power Graphs



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0.5
0
-0.5
-1
-1.5
1
12
23
34
45
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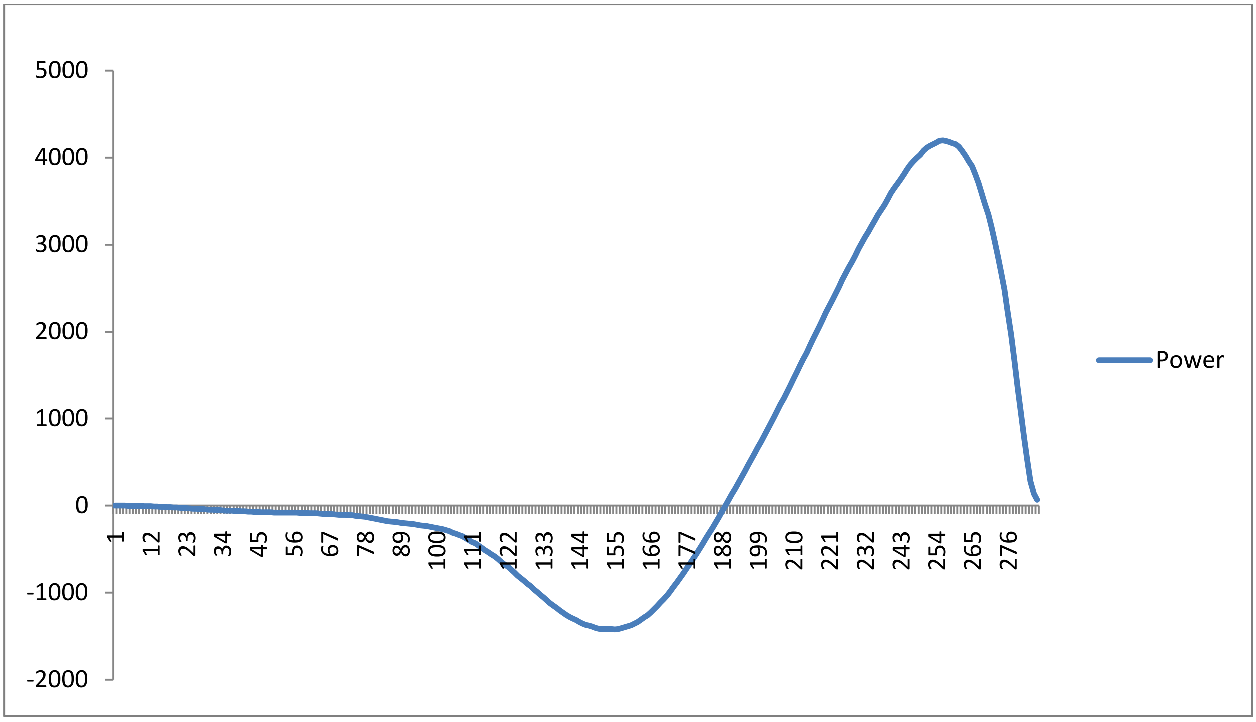
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
276
287
Velocity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3000
2000
1000
0
-1000
-2000
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
276
Power