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The Effect of Complex Training on Horizontal Power Production in Rugby Union Players.

A thesis presented in partial fulfilment of the requirements for the
degree of Master of Science at Massey University

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Abstract

The use of strength and power training regimes is common place among elite and recreational athletes. However, the application of such methods as direct determinants of improvement in sporting performance is a controversial and much debated topic because the degree of transfer from the training exercise to the sporting application is unknown. In recent years combining strength and sport specific training methods into one training session (complex training) has been promoted as a method to enhance training transfer. The purpose of this project was to examine the effect of complex training on horizontal power production in rugby players.

9 participants completed two four week phases of training (complex and standard) in a randomized order. Participant performance in 5RM squat, horizontal force and horizontal power was tested prior to and at the end of each training phase.

A number of significant improvements were observed following complex training: maximum slope of the horizontal force curve increased by 12.29 ±33.59%, maximum power increased by 15.13 ±7.49%, width of the power curve increased by 28.30 ±18.16%, and maximum velocity during the horizontal power test improved by 20.63 ±14.21%. The improvements were significantly different from the respective standard training measures ($p \leq .05$).

It is concluded that power gains were a product of an enhanced ability to produce force at higher velocities. No significant weight gain or significant improvement in 5RM force production was associated with the improvement in maximum power. Therefore it is inferred that neural mechanisms accounted for the difference following complex training. The results presented here suggest that complex training not only improves horizontal power production but also transfers performance improvements to an untrained task by improving the rate of force development in the horizontal force condition. It appears that the complex training regime has in some way created a persistent change in the control mechanisms regulating the performance of both the horizontal strength and power conditions.

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1 Introduction

Action in sport is a direct manifestation of the only function of muscle fibres, namely the generation of force. The ability to produce force is affected by numerous factors; a strength and conditioning training programme is one such factor.

Muscular strength and conditioning programmes and structured training programs have been used to enhance sporting performance since the ancient Olympic Games. This implies that some methods of strength and power development have been known for many years. However, the recognition of such methods as direct determinants of improvement in sporting performance is still in question. This is largely because the degree of transfer from the training application to the sporting situation is unknown. The following review discusses the methods of strength and power development, the mechanisms involved in them, and their applicability to the field of sport performance enhancement.

1.1 Muscular strength

1.1.1 Definition of strength

"Muscle fibres, the cells of skeletal muscles, have but one function: to generate force." (Billeter & Hoppler, 1992).

Muscular strength may be defined as the force or torque a muscle can exert against a resistance in one maximal effort (Potach & Chu, 2000; Wilson, 1994). The mechanism of muscular contraction is described by the sliding filament theory. In this context, force production is affected by several factors, including:

1) the release of calcium into the myofibril, which is governed by the innervation of the muscle;

2) the number of actin and myosin cross bridge interactions at a given position and time, determined by the length-tension and force-velocity relationships;

3) the physiological cross sectional area of the muscle; and

4) the anatomical structure of the muscle, that is the angle of muscle fibres relative to the tendon and line of force.

The sliding filament theory of muscular contraction proposes that, after stimulation of the muscle fibre via the motor neuron, calcium ions are released by the sarcoplasmic reticulum. The calcium binds to troponin, which in turn creates conformational changes in tropomyosin allowing binding of the myosin head to the actin filament. Once bound, the myosin head bends drawing the actin filament towards the centre of the sarcomere; this is the power stroke. This process is facilitated by the cleaving of a phosphate group from ATP within the myosin head, allowing binding to take place and leading to the power stroke (Billeter & Hoppler, 1992).

The amount of calcium released is related to the frequency of stimulation from the innervating motor neuron. It is recognised that motor neurons stimulate more than one muscle fibre, and so the term motor unit (MU) incorporating the motor neuron and all the fibres it innervates is used to describe the functional unit of muscle action. MUs are recruited in an all or none fashion, meaning that all fibres within the MU contract simultaneously to produce force. Each individual stimulation and contraction of the MU is referred to as a twitch. Each single twitch produces a force pulse, and if stimulation is repeated prior to relaxation of the MU the force pulses of the two twitches summate creating a greater force than the single twitch. By decreasing the interval between twitches summation of force is enhanced and when stimulation is at maximum frequency twitches become indistinguishable in the force trace. This is a fused tetanus, and produces the largest amount of force that the MU can develop. MUs themselves may be broadly categorised into two classes or types; type I or slow twitch, and type II or fast twitch. Each type is identified using physiological characteristics; type I by its aerobic qualities and relatively low force capabilities, and type II by its anaerobic qualities and its relatively high force capabilities. All fibres within a MU are of the same type.

The force that an individual sarcomere can produce is proportional to the number of actin and myosin filaments interacting at a given instant. The length-tension relationship indicates that the optimal position (optimal interaction of actin and myosin) for a sarcomere to produce maximal force is at its resting length; when the sarcomere is either shortened or lengthened its force producing capacity will be diminished (Edman, 1992).

This implies that the length of the muscle itself will have a direct bearing on the force production possible at any given instant. The force a muscle can produce is also governed by the force-velocity relationship which relates the velocity of concentric contraction to force production. Contraction velocity will be discussed at a later stage.

Muscle strength is proportional to the physiological cross sectional area (pCSA) of the muscle (Hunter, 2000; Roy & Egderton, 1992; Wilson, 1994). The greater the pCSA the greater number of sarcomeres in parallel and, consequently, the greater the maximum possible force production (Hunter, 2000). Speed of contraction of a muscle is proportional to the number of sarcomeres in series. Because type II muscle fibres have relatively short sarcomeres compared to type I, they will have more sarcomeres in series for a given length of muscle and consequently will contract faster than type I fibres. Therefore, type II fibres have the greatest potential for both maximal force production and velocity of shortening.

The morphology of muscle (such as pennation) affects the force that a muscle can produce. The term pennation refers to the angle between the line of action of the muscle fibres and the line of the tendon to which they attach. In general, it is considered that a pennate muscle will have a greater number of sarcomeres in parallel compared with a non-pennate muscle and so it will have the potential to produce greater force. However, the number of sarcomeres in parallel must be great enough to compensate for the reduction in muscular force as a consequence of the oblique alignment of the muscle to the tendon. Therefore, if a pennate muscle has a sufficiently large pCSA it will allow the development of greater force than a non-pennate muscle of similar size. The morphology of muscle, such as fibre arrangement, origin and insertion, appears to be a genetic predisposition and so is unable to be modified by training. Consequently, variation in muscle structure may account for differences in strength seen in individuals of similar physical stature with a similar proportion of type II MUs within a given muscle (Hunter, 2000; Roy & Egderton, 1992).

Therefore, we may conclude that muscular strength is dependent on the proportion of high force producing MUs within a muscle, the neural activation of those MUs, the muscle pCSA, and the structure of the muscle. As a result, hypertrophy of muscle, increasing the number of MUs recruited, and increasing the rate of MU recruitment will enhance muscle strength. Hypertrophy and neural adaptation account for strength gains when muscle is subjected to a training stimulus. These two categories of adaptations occur within well documented time frames. It is reported that in the first 6-8 weeks of training neural adaptation precedes muscular adaptation; following this, muscular adaptation accounts for the majority of strength improvements. However, it appears possible that our ability to gain strength via muscular adaptation may be limited by genetic factors and so performance improvements beyond a certain point may only be gained by neural adaptations; that is learning to use what we have more effectively.

1.1.2 Muscular adaptation to strength training.

By adhering to the general principles of training, such as progressive overload, which allow muscle to be repeatedly and appropriately stimulated, muscle may be made to adapt and become stronger. The primary mechanism of muscular adaptation is hypertrophy. Because Type II muscle fibres have a greater ability to hypertrophy they have a greater potential for strength adaptation than Type I muscle fibres (Goldspink, 1992; Goldspink & Harridge, 2003). When considering the method of recruitment of MUs (the size principle), training loads applied should be sufficiently heavy to allow full recruitment of all type II MUs in the muscle being trained.

1.1.2.1 Hypertrophy

As the mechanisms of muscular hypertrophy are well known they will only be briefly discussed here; for a more detailed description see Goldspink (1992). Increase of fibre CSA is reported to be associated with a large increase in the myofibrillar content of the fibre as a consequence of myofibrils undergoing longitudinal splitting into two or more myofibrils (Goldspink, 1992). This process is reported to be stimulated by micro trauma within the muscle fibre caused by overload (performing heavily loaded contractions to fatigue). Repair of this micro trauma proceeds by two mechanisms; an increase in the rate of protein synthesis, or a decrease in the rate of protein breakdown (Goldspink, 1992; Goldspink & Harridge, 2003). The myofibril increases in size because of the increased volume of the myofilaments actin and myosin, this increases the ability of the sarcomere to produce force and, at some stage, the force produced is large enough to create a "snap" of the z-discs effectively subdividing the myofibril. Hypertrophy of the muscle fibre may take place independent of any change in the size of the entire muscle because the increase in fibre CSA occurs at the expense of extra-cellular space (Goldspink & Harridge, 2003). It is important not to confuse myofibrilar proliferation with an increase in the number of muscle fibres (hyperplasia).

1.1.2.2 Hyperplasia

Hyperplasia is an increase in the number of muscle fibres and has not been reported to take place in human muscle as a result of training interventions. This is not to say that the mechanism for hyperplasia is not present. The presence of satellite cells, which appear to function as reserve muscle cells, could provide such a mechanism (MacDougall et al., 1992). Cadaver studies have shown that the muscles of dominant limbs contain a greater number of muscle fibres than those of the non-dominant limb (McCall et al., 1996; Sjostrom et al., 1990). This implies that chronic training or use of musculature induces hyperplasia as a means of increasing pCSA. The lack of support for hyperplasia in the current literature may be a consequence of the mismatch between the time course of hyperplasia and the average training intervention (Sjostrom et al., 1990). That is, the typical duration of training interventions used in scientific research is approximately 12 weeks, but the time course required to observe hyperplasia may be years rather than weeks or months. This then limits our means of enhancing pCSA in the short to medium term to the mechanisms of hypertrophy, which, in turn indicates that the principles of hypertrophy (muscular adaptation to resistance training) must be considered in any discussion of strength adaptation.

1.1.2.3 Morphological Changes

Strength training is reported to induce shifts in fibre type composition (Tesch & Alkner, 2003). To understand this concept we must consider the Type II muscle fibres to exist as two sub-types or isoforms. One method of determining the isoform of muscle is to measure the myosin heavy chain (MHC) content. The isoforms are usually labelled Type I, Type IIa and Type IIb. Strength training induces a shift from the expression of the Type IIb isoform towards the Type IIa (Goldspink & Harridge, 2003; Kraemer, 2000; Schiaffino & Reggiani, 1994). However, there is no report of change in fibre type (Type II to Type I, or Type I to Type II) following resistance training. It is suggested that the Type IIb isoform may be the default Type II fibre expression in unconditioned/untrained muscle, therefore, any training will promote a shift away from the Type IIb isoform (Tesch & Alkner, 2003). This is supported by an investigation into detraining that shows an isoform shift back towards Type IIb following a period of detraining (Anderson & Aagaard, 2000). This implies that the shift towards the Type IIa isoform following training may be an adaptation to allow more efficient force production. Therefore, the individual becomes more efficient a lifting an absolute load following resistance training. Another way to think of this is to consider that the absolute load which was once maximal becomes sub-maximal, a greater load must now be lifted to achieve maximal activation of MUs. The physical outcome of this is increased strength. There may be implications of this shift for strength and power performance, however, these are yet to be explored and are beyond the scope of this study.

1.1.2.4 Cardiovascular Changes

The two most commonly reported cardiovascular changes following strength training are increased left ventricular wall thickness and decreased capillary density. There are other cardiovascular changes that occur as a response to strength training, but they appear to have little effect on strength or power performance (Fleck, 2003).

When considering strength training regimes it is clear that improvement in strength as a function of muscular adaptation is a product of muscular hypertrophy and therefore, increase in pCSA.

1.1.3 Neural component of strength adaptation

Although strength is proportional to pCSA, increasing pCSA alone does not account for all strength gains; the non-hypertrophy gains are partly attributable to neural adaptation. Therefore, strength of a muscle is determined both by muscle size and the ability of the nervous system to activate the muscle appropriately. There appears to be a complex interaction of neural drive to the agonists, synergists, and antagonists involved in a movement (Sale, 2003; Wilson, 1994). Whatever interactions are present MU recruitment appears to be controlled, in the first instance, by the size principle.

1.1.3.1 Recruitment of Motor Units

The size principle that governs the recruitment pattern of MUs may be described as follows; as the demand on muscle to produce muscular tension increases, MUs are recruited in order of increasing size. As described previously type I MUs tend to be smaller, low force producing MUs, while type II MUs tend to be larger, higher force producing MUs. Consequently, increasing muscle force is produced by initially recruiting small, low threshold MUs, then increasing the firing rate of those MUs, followed by the progressive recruitment of larger MUs, and finally by increasing the firing rate of the large MUs. Theoretically a voluntary contraction that incorporates the maximal number of MUs (high and low threshold) will produce the largest force possible. However, research has shown that maximal voluntary contraction (MVC) does not produce the maximum force possible from a given muscle (Belanger & McComas, 1981). By superimposing electrical stimulation over MVC (known as the interpolated twitch method) additional force can be produced (Belanger & McComas, 1981). This suggests that improvement of MU recruitment could enhance strength. This is supported by observations of increased agonist activation and decreased difference between MVC force and force produced with stimulation superimposed over MVC following a training protocol (Hakkinen et al., 1992; Moritani & deVries, 1979). This suggests regulatory mechanisms are present governing the magnitude of voluntary production of force, and that training modifies these mechanisms allowing increased activation of MUs involved in producing the intended movement (agonists), and decreased activation of MUs inhibiting the intended movement (antagonists).

1.1.3.2 Disinhibition

Movement is essentially the sum of force produced in the line of the intended action by the agonist and any opposing force produced by the antagonist, that is, the true expression of agonist force may be inhibited by the level of antagonist force. Exposure to high levels of tension has been reported to reduce the sensitivity of Golgi Tendon Organs (the receptors which regulate muscle tension). This creates a disinhibitory effect allowing greater agonist activation and, consequently, greater force production. Disinhibition can occur in the absence of muscular hypertrophy (Wilson, 1994). Decreasing antagonist co-activation allows a truer expression of agonist force. Although the concept of reduced sensitivity of Golgi Tendon Organs appears to be widely accepted some authors reject it as an adaptation to strength training citing lack of evidence (Chalmers, 2002). Disinhibition theoretically allows increased agonist activation and increased muscle force which may, in some instances, be brought about via the synchronization of MU recruitment.

1.1.3.3 Motor Unit Synchronization

Synchronization of MUs refers to the coordination of different MUs within a muscle creating a synchronised firing pattern. Strength training reportedly increases synchronization of MUs resulting in increased force production (Wilson, 1994). This coordination enables greater force to be expressed through the combined effect of numerous MUs contracting simultaneously. Not only is the force of a contraction increased but also the Rate of Force Development (RFD) is enhanced.

1.1.3.4 Rate of Force Development (RFD)

In many situations it is not necessarily the magnitude of force that can be produced that determines sporting success, rather it is the rate at which force is developed. In theory two identical athletes who produce identical peak force in opposing directions (such as a scrummaging situation in rugby) would achieve zero net movement; this suggests that the only means for athletes of similar size and force producing potential to gain advantage over the other is to reach peak force in a shorter time. In this situation the athlete with more rapid RFD would be superior. This concept was explored in a comparison of untrained men and ski jump athletes (Komi, 1984). The author showed there was no difference between groups in peak force production during a leg extension exercise between groups. However, the defining attribute of the ski jump athletes was superior RFD.

The type of training has also been shown to effect RFD. Hakkinen et al. (1985) showed that both explosive jump training and heavy resistance training improved peak force (11% and 27% respectively). However, only explosive jump training was able to significantly alter RFD (24% improvement following explosive jump training compared to 0.4% improvement following heavy resistance training). It is suggested that increased motor neuron firing rates, selective recruitment of high threshold MUs, or both, account for this adaptation (Aagaard et al., 2002; Sale, 2003).

Therefore, it is clear that neural mechanisms exist that allow greater expression of force and RFD independent of muscular adaptation. It is also clear that strength training methods are able to induce neural adaptations.

1.1.4 Summary of Strength Adaptation

Strength is the ability of the muscle to produce force. MUs are the functional units of the neuromuscular system and because they are composed of motor neurons and muscle fibres strength may be increased by inducing both muscular and neural adaptations.

Muscular adaptation is primarily a consequence of muscular hypertrophy which is a result of increased net accumulation of protein within the myofibril; this ultimately causes myofibrilar proliferation and hypertrophy of the muscle fibre. Hypertrophy of the muscle fibre may occur without increasing pCSA of the muscle. An increase in the number of muscle fibres, hyperplasia, is not believed to contribute to increasing pCSA in short term interventions.

Neural adaptations that enhance strength include increased agonist activation, decreased antagonist activation, increased MU synchronization, increased firing rates and increased rate of force development. Neural adaptations are not limited by the time course associated with structural and metabolic repair/recovery processes seen in muscular adaptation; consequently, neural adaptations can occur more rapidly than muscular adaptation

Therefore, it appears clear that optimisation of muscular strength requires optimisation of the muscle pCSA, and optimisation of the neural components of muscle action. In the absence of any of these adaptations maximal strength will not be fully realised. Furthermore, for those who have already achieved significant muscular adaptation, neural adaptation may be the only means of further improvement. This suggests that interventions may not need to be as long as those intended to induce muscular adaptation because it is recognised that the time frame associated with neural adaptation is shorter.

1.2 Muscular Power

1.2.1 Definition of power

Muscular power may be considered as a combination of an individual's strength and speed. The external power may be determined from the force exerted on an object and the speed of the object in the direction in which the force is exerted (Harman, 2000).

Force = Mass x Acceleration

$$\underline{F} = m.\frac{d\underline{v}}{dt}$$

Work done = Force x Distance moved in the line of application of the force

$$W = \int \underline{F}.d\underline{s} \quad \text{and since} \quad \underline{V} = \frac{d\underline{s}}{dt}$$

$$W = \int \underline{F}.\underline{V}.dt$$

Power is defined as work done per unit of time

Power = Work/Time

$$P = \frac{dW}{dt}$$

Or we can rewrite as

Power = Force x Distance/Time

$$P = \frac{d}{dt}\int \underline{F}.\underline{V}.dt$$

Power = Force x Velocity

$$P = \underline{F}.\underline{V}$$

Therefore creation of a powerful movement requires muscle force and velocity to be optimised. The force-velocity relationship indicates the relationship between muscle force and movement speed (i.e. shortening velocity).

1.2.2 Force-Velocity Relationship

The Force-Velocity relationship indicates that, as speed of concentric contraction increases, the muscle's ability to produce force decreases. This relationship is maintained for eccentric contractions if they are considered as concentric contractions with negative shortening speed, and so, as the eccentric speed increases (i.e. the speed of concentric contraction becomes more negative) force production increases. The relationship is not valid for infinitely increasing eccentric speeds, at some stage maximal force is reached and any further increase in eccentric speed does not produce greater force. The maximum force producing capabilities of muscle are reported to be 120-160% of isometric strength in eccentric contraction (Edman, 1992; Hunter, 2000; Wilson, 1994).

1.2.3 Power-Load Relationship

It is obvious from the force-velocity relationship that muscle force and contraction speed are inversely related. Therefore, force and speed cannot be maximally expressed at the same instant during concentric contraction. Research has shown that maximal power is produced when utilising loads between 30% and 63% of maximum (Baker et al., 2001; Wilson et al., 1993). That is, use of moderate load and appropriate velocity combine to produce the optimum power-training environment. Consequently, the actual load for power training would depend on whether power is required in a light load or heavy load situation. It would seem inappropriate to train a volleyball player for lower body power using the same percentage of 1RM as a front row forward in rugby because their respective sport settings require different loading patterns and speeds of movement. There are other arguments surrounding the selection of load for power training, such as using heavy loads with the intention to move rapidly (Behm & Sale, 1993). This, and other arguments, will be discussed at a later stage.

1.2.4 Strength as the basis for power

Although power is dependent on both force and velocity, strength should be recognised as the foundation for enhancement of power because ultimately MUs are the causative agents of movement. Consider that an individual begins with a base level of strength; they would exhibit a relationship between force and velocity that could be fitted with a curve. Theoretically, any improvement in strength should result in an upward shift of this relationship showing that greater force could be produced at a given velocity of contraction. This line of reasoning would appear to be especially appropriate if the exercise mode used to test power was the same as the exercise used during training. However, this may not hold true when considering the transfer of any effect of training to a different task.

1.2.5 Methods of power development

In the first instance, strength is the basis of power, but once the required strength for a given task is realised, it may be more pertinent to increase velocity of contraction rather than force of contraction.

Behm & Sale (1993) state that the development of power is largely a result of training of the neural system once prerequisite strength has been attained. That is, enhancement of MU recruitment, rate of recruitment, and rate of force production are the main sources of power gains once absolute strength is adequate for the task. Consequently, to maximise power enhancement, the appropriate load should be used to optimise velocity and training should cease prior to muscular exhaustion. That is, to express force at high velocities, high velocities must be used during training.

Power development has traditionally been carried out in activity specific settings such as sports training in practice sessions. Most often, this type of power training does not employ methods utilising significant external load (resistance exercises such as power cleans etc.), but uses methods such as specific plyometrics and dynamic medicine ball training using body weight or 2-8kg medicine balls to provide the load. While such methods are sport specific with respect to movement, they fail to utilise the loads (between 30% and 63% of maximum) that have been shown to maximise power. Currently methods that do use optimal loading states tend to be based on gym equipment and so are non-specific in outcome. Two further disadvantages of gym techniques are the requirement to have a prerequisite strength level and to have learned techniques to enable their safe use. Therefore, the potential benefits of optimising both load (and therefore force) and velocity by working with gym based exercises may not be fully realised given the non-specific results and difficulty of use. As a consequence neither methodology (field based or gym based) has succeeded in producing optimal power adaptation. Therefore, a methodology that optimises both load and velocity in a sport-specific situation is required to maximise the effects of power training.

1.2.6 Summary of Power

Power in a sport setting is the expression of a combination of strength and speed. However, a trade off must be made because the two parameters are inversely related and so cannot be maximally expressed at the same instant. A prerequisite level of strength is often required prior to power training because it is the foundation upon which velocity of movement is built. Consequently, development of power is usually attributed to neural mechanisms, e.g. learning to use strength qualities rapidly and specifically. Although traditional power training methods do produce significant gains in power, they do so predominantly in the exercise used during training, and so transfer to sporting tasks is often limited. Consequently, questions are often raised regarding the value of non-specific power training exercises because of the learning requirement of such activities when compared with sport-specific methods used in an applied situation.

1.3 Transfer of Training Effect: Training Specificity

There is a substantial volume of research available on strength and power training methods and the degree to which the training stimulus transfers to real world or performance tasks (Anderson & Kearney, 1982; Hetzler et al., 1997; Housh et al., 1995; Kluckhuhn et al., 1997; McBride et al., 2002; Morrissey et al., 1995; Sale & MacDougall, 1981; Sleivert et al., 1995; Treiber et al., 1998; Weiss et al., 2000). This literature supports the notion that strength and power are trainable variables and that, if the increase in either strength or power is appropriate and specific to the task, performance may be enhanced.

In a comprehensive review of strength and power training Morrissey et al. (1995) found support for the notion of specificity of the training stimulus in the following categories:

Contraction type (Concentric, Eccentric, Isometric, Isotonic),

Contraction velocity,

Exercise type, and

Joint angle/ROM.

1.3.1 Evidence of Velocity Specificity

Faster training speeds appear to favour improvement in faster movements in athletic activities (Morrissey et al., 1995). This appears to be related to a preferential development of fast-twitch muscle fibres and a neural component involving learning rapid muscle contractions (Sale, 2003). Liow & Hopkins (2003) reported velocity specific effects with regard to strength training and kayaking performance. Experienced male and female kayakers (N = 39) were matched by sex and sprint time and randomly assigned to a slow weight training, explosive weight training, or control (normal training) group. Weight training using sport-specific exercises was performed twice a week for six weeks. Performance effects were measured using a 15m sprint. The authors found that during the first portion of the 15m, when movements were slow, the slow-training group improved most (6.9%), followed by the fast group (3.2%), and the control group (1.4%). Over the last 3.75m the fast training group improved most (3.0%), followed by the slow group (2.1%), and the control group (-0.8%).

Anecdotally, some coaches and trainers suggest that heavy weight training usually causes movements to decelerate throughout their action. This statement is mechanically incorrect because all discrete weight training movements must have both an acceleration and deceleration phase (Wilson, 1994). A more correct statement would be that heavy weight training movements tend to have longer deceleration phases compared with lighter load weight training. Therefore, heavy weight training produces adaptation that is specific to slower velocities. Because heavy weight training is more specific to slow velocities it seems logical to expect little improvement during movements of greater velocity. This is supported by Mayhew et al. (1995) who examined the effects of heavy-resistance training on measures of bench press power, using absolute loads, and seated shot put performance. College men (N = 24) trained twice weekly for 12 weeks. Bench press power was measured by timing free weight actions at 30%, 40%, 50%, 60%, 70%, and 80% of 1 RM. While 1 RM performance increased significantly (9.1%) after training, there was no change in shot put performance. Peak power was produced at 40-50% of 1 RM both before and after training. There was no relationship between changes in shot put performance and changes in resistance-training strength.

However Behm & Sale (1993) suggest that the results could change if participants attempted to maximally accelerate the load. The authors (Behm & Sale, 1993) state that the rate at which force is developed may be more critical for improving the ability to exert force at high movement speeds than the absolute speed of the movement itself. However, in an investigation into training load on velocity specific adaptation Jones et al. (2001) found that lighter load, higher velocity training was superior to heavier load training that employed an "intent to maximally accelerate" technique.

The characteristic common to all training methods recommended to stimulate power improvement is that movements are performed as explosively as possible, whether or not weights or resistances are used. A typical total-body explosive movement (e.g., vertical jump) requires force to be developed over a time period of 200ms to 350ms. This is supported by Young et al. (1995) who state that the best predictor of sprinting speed is force produced 100ms from the initiation of a vertical jump. Most of the increases in force-producing potential induced by heavy strength training cannot be realized over such a short time. This also suggests that heavy strength training may be of little benefit to already strong individuals who wish to perform powerful movements (Mayhew et al., 1997). Consequently, training exercises that produce rapid rate of force development are to be preferred to exercises that spread force development over longer intervals.

Some researchers suggest that moderate-load, higher velocity weight training may provide the greatest stimulus for power development (Kluckhuhn et al., 1997; Treiber et al., 1998). Treiber et al. (1998) investigated the use of light resistance training in female tennis players. They found improvement in both slow and fast shoulder rotational torque as well as improved peak and average speed of the serve. In an investigation of high speed isokinetic training and baseball fast pitching Kluckhuhn et al. (1997) reported that force at high velocity (power) and acceleration accounted for 99% of all variation in fastball pitching, and that strength was not related to speed of movement. They suggested that training should incorporate velocities close to those seen in actual performance and implied that any training that did not allow high velocities could be detrimental to performance. Plyometric exercises which incorporate the stretch-shorten cycle are often used for this reason.

1.3.1.1 Stretch-shorten Cycle

Most jumping and power activities as used in many sports involve a counter movement (e.g., wind-up, backswing, crouch) during which the muscles involved are first stretched rapidly and then shortened to accelerate the body or limb. This type of muscle action is known as a "plyometric contraction" and takes advantage of the stretch-shorten cycle (SSC).

The counter movement involves muscles acting both eccentrically to slow the body or limb and concentrically to initiate the reverse movement required. As the muscles are activated, the internal force on the tendon-muscle complex is increased. As the tendon stretches, its stiffness or resistance to stretching increases, and the result is storage of elastic energy in the tendons that is recovered in the subsequent "release" movement. A suddenly imposed stretch also increases neural stimulation to the muscles as muscle spindles sense this stretch and create a reflex contraction that couples with the voluntary contraction and the stored elastic potential energy to create greater resultant force (Potach & Chu, 2000). Walshe et al. (1998) reported significantly better concentric contractile performance when preceded by a SSC compared with either an isometric preload or concentric only movement. Because actions without a sudden, or ballistic, preparatory movement are less effective, training for explosive power should include movements incorporating a SSC.

1.3.2 Mode Specificity

Mode specificity refers to the likelihood of strength and power training adaptations transferring from the training exercise to another exercise that differs in loading pattern, body orientation, velocity, or contraction type. There are two general lines of thought evident in the literature. The first of these proposes that the exercise used should mimic the performance activity as closely as possible, and the less alike the exercise is in mode, contraction type, or contraction velocity the smaller the transfer will be (Wilson et al., 1996). The second line of thought suggests that only a portion of the components from the performance activity need to be included in the training activity (Morrissey et al., 1995), e.g. the training exercise need only be specific in velocity but not body orientation. This could be a product of the difficulties encountered in measuring sport-specific performance, and so only measurable components of the action have been investigated in an attempt to heighten methodological control. In a more recent investigation participants were trained using a horizontal leg press resisted either by a bungy or a weight stack, and improvement in vertical jumps and lunges was measured (Cronin, J. et al., 2003). Cronin et al. (2003) concluded that the body orientation of the training exercise limited the transfer of power gains to the performance measure. This supports the argument presented by Wilson et al., (1996) and implies that training should be specific to the body orientation used in the sporting task.

Explosive power training, employing a combination of plyometrics and light-load explosive weight work, would seem to be a more appropriate form of auxiliary training for many sports than the more popular traditional heavy resistance training. The latter is aimed at developing strength and may not be appropriate when transfer to sports is required. However, it should be noted that non-specific training may be required initially in the case of baseline hypertrophy and strength development or in the case of rehabilitation. Table 1 briefly outlines the application and appropriateness of various forms of strength and power training. The sequential arrangements of training methods, will, if done correctly bring about a change in performance. This arrangement of training demands is termed Periodisation.

Table 1. The utility of training type on improvement in muscular performance.

	Heavy Load Weight Training	**Light Load Explosive Training**	**Plyometrics**	**Isokinetic Training**
Maximal Strength	Excellent	Fair	Poor	Good
Rate of Force Development	Good	Excellent	Good	Fair
Stretch-shorten Cycle	Poor	Good	Excellent	None
High Velocity Force Production	Poor	Excellent	Poor	Good
Maximal Mechanical Power	Good	Excellent	Fair	Good
Skill & Muscular Coordination	Poor	Good	Excellent	Poor

extracted from Kraemer and Newton (1994)

1.3.3 Periodisation

Various authors have described the interaction of training stimuli and the methods by which we incorporate the various stimuli and demands into a progressive training program (Bompa, 1999; Fleck & Kraemer, 1996). This combination of training demands is termed periodisation. It is defined by Fleck and Kraemer (1996) as "a planned, variegated training program where changes are made to ensure long-term fitness gains". It attempts to progress base line, non-specific training into sports specific, in season peaks in performance. Various periodisation schemes are used by the strength and conditioning fraternity ranging from:

> Sequential training plans (train for hypertrophy, followed by strength, followed by power); to
>
> Concurrent plans (many fitness components trained concurrently in the plan with an emphasis placed on the component of greatest importance); to
>
> Hybrid plans (a combination of sequential and concurrent plans).

Periodisation is one means of attempting to develop baseline, non-specific fitness into optimal sport specific fitness.

1.3.4 Combining the Training Stimuli

Evidence has begun to emerge suggesting that an integrated training method may be a better approach to overcoming the problems faced with regard to specific power adaptation and may be a means to transfer non-specific strength more rapidly to sport specific power (Cronin et al., 2001; Harris et al., 2000). Cronin et al. (2001) reported significant improvement in chest pass velocity when strength training was combined with a sport specific motion. Similarly Harris et al. (2000) reported that a combination training protocol produced significantly better results when compared with a protocol in which the training variables were trained independently.

A logical progression from the preceding discussion would be to seek to combine training stimuli to take advantage of appropriate loading to maximise both strength and power. This would also attend to the principle of specificity of training i.e. training in a similar plane of motion to that of the applied sporting task. In addition, it may be possible to take advantage of Post-activation Potentiation (PAP), a phenomenon known to acutely improve performance.

1.3.4.1 Post-activation Potentiation

Post-activation Potentiation refers to enhanced performance characteristics (muscular power) following a maximal voluntary contraction (MVC). It is based on the contention that during a MVC the greatest proportion of high threshold MUs is activated within a given muscle or muscle group. The head of each myosin molecule in skeletal muscle contains a subunit known as the regulatory light chain. Skeletal muscle force production is regulated by Ca^{++} concentration, which mediates the rate at which cross bridges make the transition from resting to force-generating states (Vandenboom et al., 1995). It has been proposed that regulatory light chain phosphorylation, facilitated by maximal contraction, modulates the nature of actin-myosin interactions (Grange et al., 1993). Vandenboom et al. (1995) report that phosphorylation of the myosin regulatory light chain increases sensitivity to Ca^{++} and so following the MVC, MUs are believed to have a lowered threshold (Hamada et al., 2000). Therefore, reactivation of those MUs could be induced during contractions that would not normally reach sufficiently high threshold to activate them. Consequently, performance (typically assessed using a vertical jump) is acutely improved and PAP may be a potential mechanism for the maximisation of muscular strength and power.

PAP is an acute phenomenon that is reported to persist for up to 5min post MVC (Hamada et al., 2000; Jensen & Ebben, 2003). Its direct use in sporting application may be limited, although there are anecdotal reports of athletes (sprinters) performing maximal lifts (squats) immediately prior to competition in an attempt to improve performance by recruiting a greater number of high threshold MUs during competition. The goal of training would be to create a persistent change in performance. However, if learned patterns of movement are represented in the cortex, then training may be just another pattern of movement and so any strength gain through non-specific training may not be represented in the original (sporting) movement pattern (Hellebrandt, 1972). This line of thought would certainly account for the lack of transfer seen in much of the current strength and conditioning literature. As previously stated PAP has only acute performance benefits, but structured training using PAP where non specific lifts are used in conjunction with specific sporting tasks may provide a learning environment facilitating the long term maintenance of performance benefits. Therefore the methodology of combing non-specific, maximally heavy exercises and sport specific exercises may enable the optimisation of strength and power, while still maintaining mode, contraction type and velocity specificity of the sporting task.

1.3.4.2 Combined Training Methods Defined

There are many ways that training modes can be combined; each may be assigned to one of three categories; namely Concurrent, Contrast or Complex training.

> Concurrent training involves the use of two or more training modes during the one phase of training. However, each of the training modes is performed independently of the other. Examples of concurrent training are seen in Nicholson & Sleivert (1999) and Paavolainen et al. (1999). In both investigations resistance training was employed concurrently with running training. Traditionally, concurrent training methods have been considered less desirable than methods that emphasise only one form of training as it was

assumed that each mode would negatively effect the adaptation stimulated by the other. Nicholson & Sleivert (1999), report that concurrent resistance training did not negatively affect adaptation to running training, rather, it improved running performance (running time) and other parameters associated with running performance (VO_2 max and lactate threshold speed).

Contrast training uses one training mode with contrasting movement velocity. During the training session the load and/or the velocity of the movement are manipulated (Baker, 2003). For example, the first set of a squat exercise would be performed with a relatively heavy load (70-90% 1RM) at a slow velocity. The second set would be performed with a lowered load (30-60% 1RM) at the fastest velocity possible. The proposed benefit of contrast training is that the use of near maximal force and high movement velocities allows both strength and power to be improved. Harris et al. (2000) show that contrast training improves more strength and power parameters than either strength or power training alone. However, based on the preceding discussion of specificity, the transfer of training effects to sporting performance is likely to be low because the mode specificity of the exercise is low.

Complex training uses one or more training modes within a single training session (Ebben et al., 2000). The training modes range from non-specific movements to sport-specific movements that are similar in their general movement qualities e.g. the bench press exercise and a netball chest pass (Cronin et al., 2001). Burger et al. (2000) compared complex training (resistance training exercises superseted with plyometric exercises that had biomechanical similarities) with concurrent training (resistance exercises were performed separately from plyometric exercise). Both groups improved performance (vertical jump); the complex group improved significantly more when compared to the concurrent group. Therefore, research indicates the benefit of complex training is to provide high force adaptation, high velocity adaptation while maintaining mode specificity.

1.3.5 Summary of Specificity

Gains in strength and power are specific to the exercise used to train strength and/or power, and so any enhancement of strength and power will be expressed most readily in the task utilised for training. Additionally, enhancement will be most noticeable when utilising the velocities and ROM of the training exercise. Transfer of enhanced strength or power to other tasks is limited, which has lead to scepticism about the validity of auxiliary training methods. However, when the training stimulus incorporates a close representation of the movement pattern used during sport and attempts are made to accelerate loads maximally, transfer is enhanced. Recent research examining more contemporary training methods has suggested that combined training methods will provide greater enhancement of sport specific strength and power than those achieved using traditional non-specific methods such as squats, bench press, and power cleans that only loosely represent the sporting movement. The most potent of these methods is likely to be complex training as it utilises methods (PAP) known to produce acute performance enhancement as well as incorporating mode, contraction, and velocity specificity.

1.4 Aim

Strength and power are determinants of performance in many sports situations. Therefore, the training and improvement of these qualities should provide substantial benefit for athletes. Although strength and power are readily trainable qualities, the lack of support in the literature for direct sport performance improvements from strength and power training indicates that specificity of training is important. The proposed benefit of physical conditioning in a non-specific setting (e.g. the gym) is a subject of continuing debate and, as a consequence many conditioning practitioners prefer sub-optimal loading states to maximise specificity of training. However, the lack of transfer observed in non-specific settings may be attributed to lack of utilisation of neural learning or adaptation. Resent research has examined the benefit of combined methods of training that combine specific and non-specific stimuli in the one training session (Cronin et al., 2001; Harris et al., 2000). The initial results suggest that the resulting transfer of the training effect is possibly greater than previously thought.

When considering the sport of rugby, power tasks occur in both horizontal and vertical directions. The specificity principle implies that, for training to effectively transfer to the required task, it should mimic the task as closely as possible. Of particular importance in the sport of rugby is the ability to apply force rapidly in the horizontal plane. Activities such as scrummaging, mauling and tackling all require force to be produce in a horizontal plane. However, many of the conditioning programmes currently in use train rugby athletes predominantly in the vertical plane. Therefore, this study investigated the effect of a complex training regime, which includes both vertically and horizontally orientated exercises, on power production in simulated scrummaging and mauling, and training transfer from a vertically orientated non-specific exercise to a horizontal sport specific task.

2 Methods

2.1 Development of the Training and Testing Protocol

The development of the protocol used in this study required the consideration of a number of factors: firstly, the consideration of appropriate exercises, exercise load and exercise volume; and secondly, the specific limitations associated with the participants and the training facility.

2.1.1 Exercise selection

Previous investigations into the effect of complex training have used a heavily loaded non-specific lift combined with either a sport specific task or a plyometric/power exercise as the training protocol (Cronin et al., 2001; Ebben, 2002). I considered this approach to complex training was not ideal, firstly, because the non-specific lift and sport specific task were too disparate in movement characteristics to allow the PAP effect to be useful, and secondly, because the plyometric exercise was not sufficiently sport specific to enable significant transfer. Therefore, both the plyometric/power exercise and sport specific task were incorporated into the complex training regime. Therefore, complex training included a heavy non-specific lift, a lightly loaded plyometric/power exercise and a sport specific task. It was initially envisaged that the complex training exercises would be the Squat, the Power Reverse Hack Squat, and the Dynamic (mauling) Grunt 3000 exercise. The Alternating Lunge was later substituted for the Power Reverse Hack Squat because of unavailability of this piece of equipment. Because of the limited volume of previous research associated directly with complex training many of the decisions regarding the performance of exercises were based upon observation of the tasks required in mauling and scrummaging in rugby union and observation of performance of the simulated mauling task. For example, the decision regarding the number of repetitions of lunges to perform was based on the number of foot contacts made when performing the dynamic Grunt 3000 exercise. The decision regarding the appropriate load to use during the squat exercise was determined by the general recommendations with respect to MU activation in the literature (Hamada et al., 2000; Jensen & Ebben, 2003), and ability of the participants to safely complete all sets of the exercise in each training session. The selection of rest periods was largely based on the general recommendations within the National Strength and Conditioning Association's manual for power training (Baechle et al., 2000) in concert with the recommendations from previous investigations (Hamada et al., 2000; Jensen & Ebben, 2003). All rest periods between sets of exercise were passive. However, in retrospect rest between sets of complex training could be have been prescribed as light active recovery periods to enable clearance of metabolic by-products, such as lactic acid, which are known to inhibit forceful contraction(Kraemer, 2000). This would ensure maximal performance in subsequent sets of exercise. These points will be covered in greater detail in later sections.

2.1.2 Limitations

The major limitations of the study were a result of unforeseen events. The ideal training and testing facility was unavailable and so a less optimal location for training and testing was used. Furthermore, the unavailability of the original facility ruled out the original target population as participants and so a sample largely made up of Colts and University Senior rugby players, was used.

This presented various issues in the design of the intervention. Firstly, the selection of exercises had to be modified. For example, the reverse hack squat could no longer be included because the machine was not available at the testing facility; therefore, alternating lunges were included as a replacement exercise.

Secondly, the second cohort was more variable in playing history, resistance training history, and training status, and so in the interest of safety the load of the squat exercise was modified to accommodate these participants.

Thirdly, the change of both facility and participants disrupted the intervention timeline. This meant that the intervention was run throughout the competitive rugby season rather than prior to season commencement. Furthermore, the intervention period was reduced to ensure that all participants completed the intervention under the same conditions i.e. prior to season end. This effectively eliminated the inclusion of a washout period between conditions. However, this was not seen as a significant limitation as all players were resistance training prior to starting the intervention and so no order effect was expected.

2.2 Ethical approval

An application was submitted to the Massey University Ethics Committee in October 2002. The application was approved in November 2002 and assigned the protocol number 02/132.

2.3 Participants

Participants for the study were recruited from the local (Manawatu) senior and colts club rugby competitions. Participants were required to:

Be healthy males over the age of 16; have been playing competitive club rugby for at least one season; and have trained with weights, specifically squatting and lunging exercises during the past 12 months.

For the purpose of this study the term healthy included (but was not limited to):

Free from acute injury of the musculoskeletal system that impaired a participant's ability to exercise safely; and free from any pre-existing condition that contraindicated high load training exercises (80% of 5RM squats), e.g. scoliosis of the spine or high blood pressure.

In total 28 players volunteered to participate in the research project. All participants were informed of the nature of the study by a written information sheet (Appendix 1) and personal discussion with the researcher. Participants completed written informed consent prior to participation. Participants were required to complete a standardised Physical Activity Readiness Questionnaire (PAR-Q) (Appendix 1) and their individual ability to complete both squat and lunging exercises to a satisfactory standard was assessed.

A satisfactory standard was deemed to be

a) Squats: Squatting to a depth where the thigh was between 45deg and 90deg from vertical; during the squat there was no significant lateral deviation of either the knees or the hips; the barbell (carried on the shoulders) travelled posterior and parallel to an imaginary line drawn from the toe vertically upwards.

b) Lunges: lunging to a depth where the knee of the rear leg was 5cm from the ground, there was no significant lateral deviation of the knee or the hips, and the hip of the non support leg did not drop during the exercise.

The 45-90° range was implemented because participants had widely different training histories with the squat exercise and so had different abilities to perform the exercise. Consequently it was impossible to determine a set squat depth that was appropriate for the entire cohort. To allow the investigation to continue and to ensure the safety of the participants a range for squat depth was implemented. The individual variation in range of squat depth could impact the results if squat depth was not consistent for each individual. Therefore, the depth achieved by an individual during familiarisation was recorded and set as the standard for each subsequent training and testing session.

Four participants were excluded from participation because they presented contraindications to training in the PAR-Q, had insufficient weight training history, or had poor lifting ability. The remaining 24 participants were deemed healthy, and able to complete the required exercises satisfactorily.

2.4 Equipment

The following equipment was used for training and testing:

Squat training and testing took place within a Standard Squat Rack (with safety bars) using a Standardised Olympic Barbell (20kg) with rotating sleeves (Fitness Works Ltd) and Rubberised Olympic Weights of masses between 1.25kg to 20kg (Fitness Works Ltd). Standardised dumbells (Fitness Works Ltd) ranging between 10kg and 13.5kg mass were used for the shoulder press exercise during standard training. All weight plates were assayed; any plate exhibiting a difference in mass greater than ±5% from nominal was excluded.

A Grunt 3000 rugby ergometer and computer interface (SportsTec International) was used for both training and testing. Testing required the use of both the dynamic and static versions of Grunt 3000 exercises. The dynamic version required the use of an 18 wrap bungy cord (AJ Hacket Ltd) to provide dynamic resistance. The static version required the use of a wire cable strop in place of the bungy cord. A Toshiba Satellite 2180cdt laptop computer (AMD-K6(tm) 3D Processor, 474MHz) running Chart for Windows (AD Instruments) was used to record both force and velocity signals from the Grunt 3000. Force and velocity signals were amplified using a Grass differential amplifier and were sampled at 1000Hz using a Power Lab Data Acquisition device (AD Instruments). The force channel was calibrated by suspending a known load (981N) from the load cell and the velocity channel was calibrated by spinning the instrumented wheel of the Grunt 3000 at a rate equivalent to a constant speed of 2.8m/s. Both signals were captured in Chart for Windows (AD Instruments) and appropriate calibration constants assigned.

2.5 Experimental Design

The experiment was designed as a cross over intervention. Participants were required to complete a familiarisation period (two familiarisation sessions over the course of one week) followed by two consecutive 4 week phases of training including:

a) A complex training regime
b) A standard training regime

Participants were divided into two groups, a complex-standard group and a standard-complex group. The complex-standard group completed 4 weeks of complex training followed by 4 weeks of standard training while the standard-complex training group completed 4 weeks of standard training followed by 4 weeks of complex training. Figure 1 depicts the arrangement of familiarisation, testing and training.

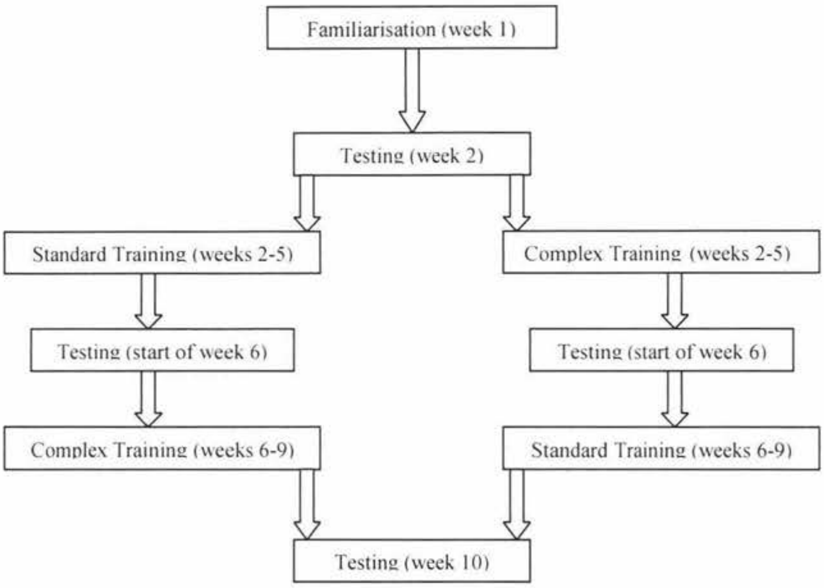

Figure 1. The experimental design

2.5.1 Complex Training

Complex training was defined for the purpose of this research as a training regime that utilised three distinct modes of exercise within the one exercise session. The three modes were:

a) Non-specific resistance training; an exercise that trained the musculature related to the performance of rugby union scrummaging and mauling actions, but was not specific in body orientation or movement pattern. The non specific exercise chosen for this experiment was the barbell squat. Five repetitions of 80% 5RM squat were used. It would have been preferable to use 5RM rather than a percentage of 5RM to ensure maximal effort was achieved. However, this was not possible because of the limited training history of a number of the participants. Therefore, in the interest of participant safety, 80% was identified as a safe load to be used within all 3 sets.

b) Semi-specific resistance training; an exercise that trained the musculature related to the performance of rugby union scrummaging and mauling, and loosely mimicked the body orientation and movement patterns seen during performance. The semi specific exercise chosen for this experiment was the alternating lunge exercise. Although the reverse hack squat is arguably a better semi-specific exercise the lunge was used because of the unavailability of such a piece of equipment. It was observed that approximately 10 foot contacts were required to perform the dynamic mode of the Grunt 3000 exercise in familiarisation. Therefore, 10 repetitions were chosen for the performance of the lunge exercise.

c) Sport specific exercise; an exercise that trained the musculature related to the performance of rugby union scrummaging and mauling which utilised body orientation and movement patterns seen in performance. The sport specific exercise chosen for this experiment was the dynamic (mauling) mode of the Grunt 3000 rugby ergometer (see Figure 2).

Complex training was structured in the following way:

Participants completed a non specific warm up consisting of 5 min of low to moderate intensity exercise on a Monark cycle erometer (ergometer load was self selected, low to moderate intensity was deemed to be that which allowed the continuation of a conversation). Participants then performed a brief stretching regime. Five static stretches were utilised targeting the calves, hamstrings, quadriceps, lower back and chest/shoulders. Each stretch was performed twice and held for a duration of 15-20 seconds as recommended by Holocomb, (2000). Participants then performed a specific warm up consisting of 2 sets of 8 repetitions of squats at 60% 5RM and 1 set of 3 low intensity repetitions on the Grunt 3000. Each warm up set was separated by 1 min passive rest. The function of the specific warm up was to prepare the individual for the particular demands of the upcoming exercises and was considered especially important given the dynamic nature of the training (Holocomb, 2000).

Participants then completed 3 sets of complex training per session. One set of complex training consisted of:

5 repetitions of squats at 80% of 5RM

Rest (90sec)

10 repetitions of alternating lunges holding either a 10, 15 or 20 kg mass

Rest (90esc)

3 maximal repetitions of the Grunt 3000 (dynamic mode)

Rest (150sec)

At the completion of each mode of exercise within the set participants rested passively for 90sec, at the completion of the 90sec period participants were instructed to prepare to perform the next mode of exercise within the set. This typically increased the total rest between modes within a set to 120sec. Participants rested passively between sets for 150sec. The rest period chosen was at the shorter end of the rest period range for power which is 2-5min (Baechle et al., 2000) but was approximately the mid-point of rest times used in other investigations of PAP (Ebben, 2002; Jensen & Ebben, 2003). This duration was chosen in an attempt to be specific to the repeated power demands of rugby union. At the completion of each training session participants warmed down at a self selected pace on a Monark cycle ergometer for 5-8min.

2.5.2 Standard Training

Standard training was composed of 4 exercises. The four exercises were relatively non-specific to the performance of rugby union scrummaging and mauling, i.e. they trained the musculature involved with performance but were either non-specific or semi-specific in nature with reference to body orientation and movement pattern. The 4 exercises chosen for the standard training regime were:

Barbell Squats at 80% 5RM
Alternating Lunges holding either a 10, 15 or 20kg mass
Upright Barbell Rows at 8-10RM
Seated Dumbell Shoulder Press at 8-10RM

The upper body exercises were included in the standard regime in order to replicate the typical programme the participants would have been using at this stage of the season. While most participants would normally have completed a larger volume of exercises, only 4 exercises were utilised in the standard regime to equalise training volume between the standard and complex conditions. Standard training was structured in the following way:

Participants completed the warm up previously described for complex training excluding the low intensity Grunt 3000 exercise. Three sets of each exercise were performed per session. Standard training was arranged in a sequential pattern i.e. 3 sets of squats were performed, followed by 3 sets of alternating lunges, followed by 3 sets of upright rows, followed by 3 sets of dumbell shoulder press. Participants rested passively for 60sec between each set regardless of mode.

At the end of each session participants warmed down on a Monark cycle ergometer for 5-8min at a self selected pace.

2.5.3 Frequency and Duration

Participants trained twice per week for eight weeks. The eight week duration was split into two 4 week phases of complex and standard training.

2.5.4 Testing

Participants were tested at the start of intervention, at the end of the 4th week (prior to cross over), and at the completion of the intervention. Height and weight were measured at each testing session.

Participants were then required to perform the following tests:

Horizontal Power (dynamic mode on the Grunt 3000)

Horizontal Strength (static mode on the Grunt 3000)

Barbell squat strength (5RM)

2.5.4.1 Testing Protocol

Prior to beginning the testing regime participants followed the warm up procedure described previously for training.

Following the warm up height was measured to the nearest 0.5cm and Body Mass was measured to the nearest 0.1kg.

Three repetitions were then completed in the dynamic mode of the Grunt 3000. Participants were asked to walk the Grunt to its start position; once any slack was removed from the bungy participants were asked to assume the position shown in Figure 2. Stance was standardised with feet parallel at shoulder width for each participant. For each repetition participants were instructed to drive the Grunt forward as rapidly as possible and a countdown was given to initiate each trial. Special care was taken to ensure participants did not "charge" the Grunt i.e. move back from the start position to allow an impact to occur as force was applied, this was done by ensuring the appropriate stance (lightly leaning on the Grunt) was taken before the initiation command was given. Eliminating the "charge" was essential because the mass of the

Grunt was far in excess of the mass of any participant and so any impact with the Grunt and would act to decelerate the participant. Spotters shadowed the Grunt throughout the entire repetition and assisted in control of the Grunt as it was returned to its start position. Participants rested for 30sec between each repetition.

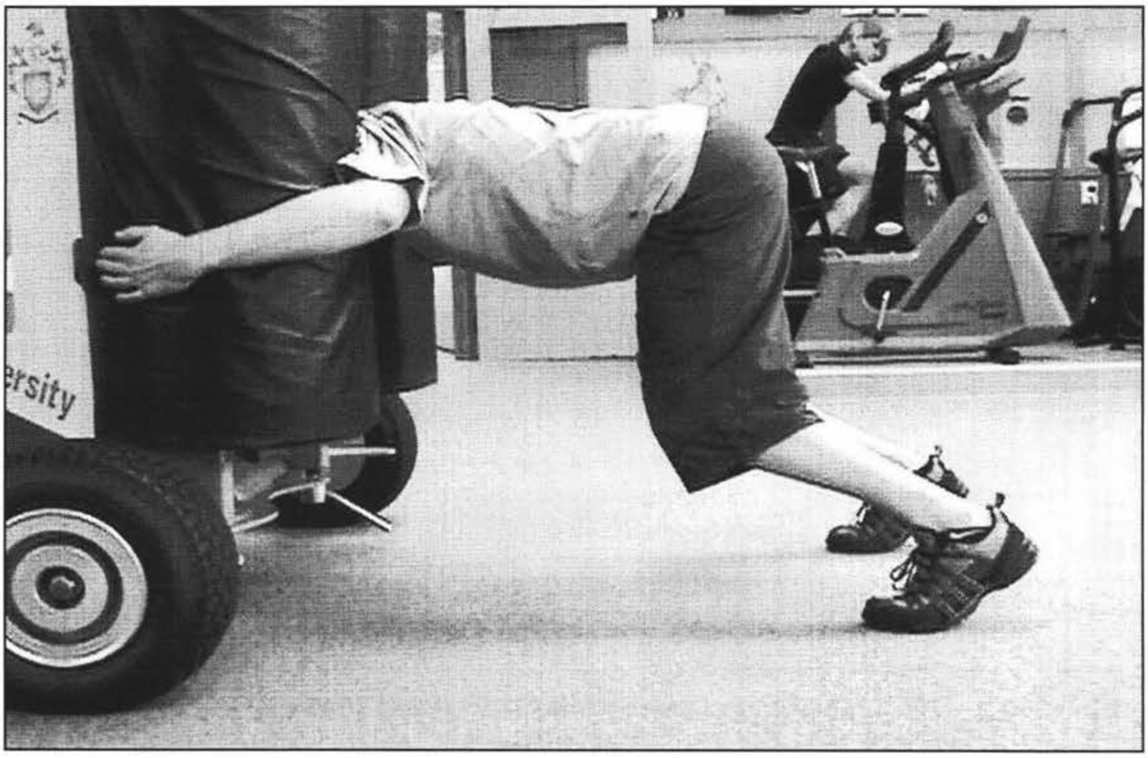

Figure 2. Standardised start position for both modes of Grunt exercises.

Three 5sec repetitions were then completed in the static mode, each separated by 30sec of passive rest. This could be perceived as limited rest, but because the exertion phase of the exercise is 5sec it represents a work:rest ratio of 1:6 which is similar to the repeated strength demands of rugby union. Participants were asked to assume the position described for Horizontal Power (Figure 2). In the static mode the bungy was removed and replaced by a wire cable. Participants were asked partly support their body weight on the Grunt prior to initiation to reduce the incidence of "charging" as described previously. Upon initiation participants were instructed to drive the Grunt forward and maintain the highest constant force possible. Instruction was given to ensure minimum elevation of the torso during the repetition.

The final performance test was the 5RM squat. The 5RM squat was defined as successfully completing 5 repetitions with satisfactory form but not a 6th. Satisfactory form was derived from the standard each participant set during screening and familiarisation. Participants were required to adhere to this standard during each 5RM attempt. Sets of squats were performed until each participant completed a 5RM set. The number of sets required to produce 5RM ranged between 2 and 5 sets. Participants were allowed as much rest as required between sets (minimum of 2min).

2.6 Data Treatment and Statistical Analysis

Force and velocity data from the Grunt 3000 were sampled at 1000Hz via the Grass Amplifier and Power Lab Data Acquisition system. Once collected the raw data were treated to allow examination of parameters associated with force and power production. The following parameters were defined.

Maximum Slope:

The value selected was the maximum slope of the leading edge of the force time curve. This represented the maximal rate of force development for any given trial.

Area under the force-time curve:

A point was selected on the leading edge of the force-time curve (departure from baseline) that represented onset of force development. A similar point was selected on the trailing edge that represented the end of the trial (return to baseline). The area under the force-time curve between onset and end was taken as the Integral, this represented total work done during each trial.

Mean Force:

Mean force was calculated as the mean value between the selected onset and end points of the force-time curve used for the area under the curve.

Force and velocity data were multiplied in Chart for Windows to display a power-time curve. The following parameters were derived from this curve.

Maximum Slope and Minimum Slope:

The greatest positive value from the leading edge of the power curve was taken as the Maximum Slope. The greatest negative value from the trailing edge of the power curve was taken as the Minimum Slope.

Maximum Power

The peak value from the power curve was taken as the Maximum Power.

Area under the power-time curve:

A point was selected on the leading edge of the power-time curve (departure from baseline) that represented onset of power development. A similar point was selected on the trailing edge that represented the end of the trial (return to baseline). The area under the power-time curve between onset and end was taken as the Integral, this represented total impulse during each trial.

Curve Width:

The width of the power curve was expressed in time (sec), and was taken to be the time between the maximum and minimum slope of a given trial.

Time to Peak Power:

The time from first departure from baseline to Peak Power was taken as the Time to Peak Power.

Figure 3 shows a generalised curve as an indication of the above parameters.

Frequency Analysis:

A Fast Fourier Transform (FFT) analysis was performed on the power curve and the force and velocity components of the curve. The FFT analysis was performed using Chart for windows on a 8192 point sample from the beginning of the trial.

Values for all parameters were generated from each individual trial. Mean values were calculated and then expressed as relative measures (percentage change from the previous testing session).

Data Analysis:

Descriptive statistics were generated for the participants who completed both phases of training. All data are presented relative to baseline measures (i.e. as a percentage difference from baseline). It was evident that there was a large variation between participants across a number of parameters, for example body mass ranged from 71kg to 129kg and 5RM squat ranged from 90kg to 160kg. Similar large variations were observed across the force parameters. There was also variation in training history between participants, and so it was considered necessary to use ratiometric differences to make meaningful comparisons of data.

Relative measures (percentage change) representing the post complex change and post standard change in variables were compared using a commercial statistical analysis package (SPSS). Paired t tests were performed to compare the two conditions with significance set at $p \leq .05$.

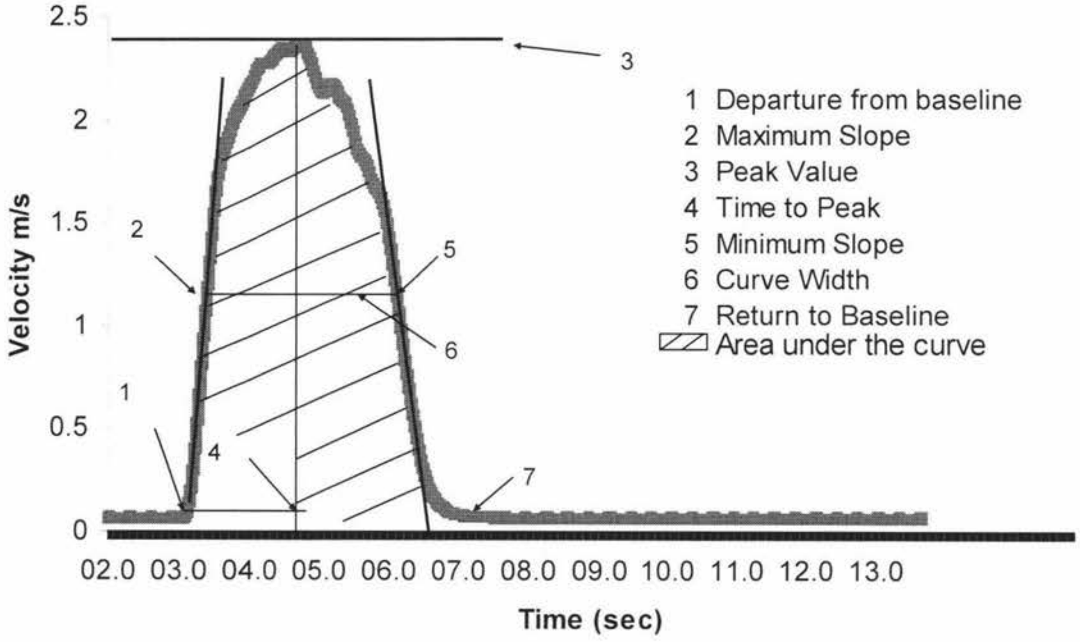

Figure 3. A generalised curve showing derived parameters.

3 Results

Of the 24 participants who volunteered to participate in the study only 9 completed all requirements. Reasons for participant drop out ranged from acute injury associated with rugby competition to poor adherence to the training program and consequent exclusion from the study. Data (mean ± SD) for these 9 participants are presented below; a complete set of data is presented in Appendix 2.

3.1 Body mass

There was no change in body mass following training. Body mass post standard increased on average by 1.36 ±1.31%, Body mass post complex training decreased by 0.05 ±1.61%.

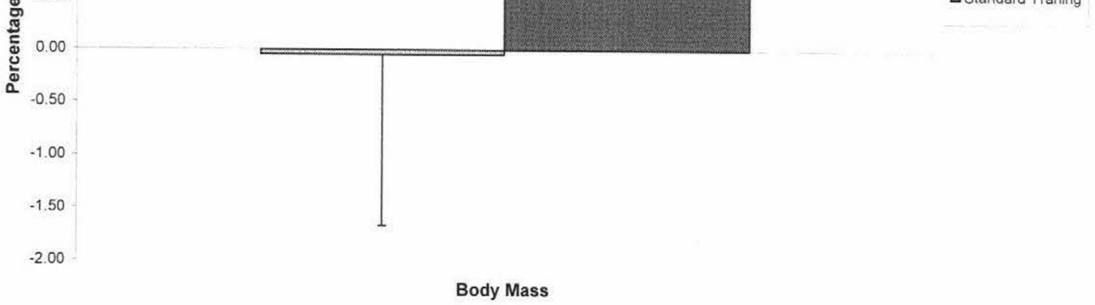

Figure 4. Mean change in body mass (as a percentage of body mass at the beginning of each phase) following standard and complex training.

3.2 5RM Squat

There were similar increases in 5RM squat for both training phases, 7.45 ±7.75% increase post standard and 9.56 ±5.11% increase post complex. The difference between means was non significant.

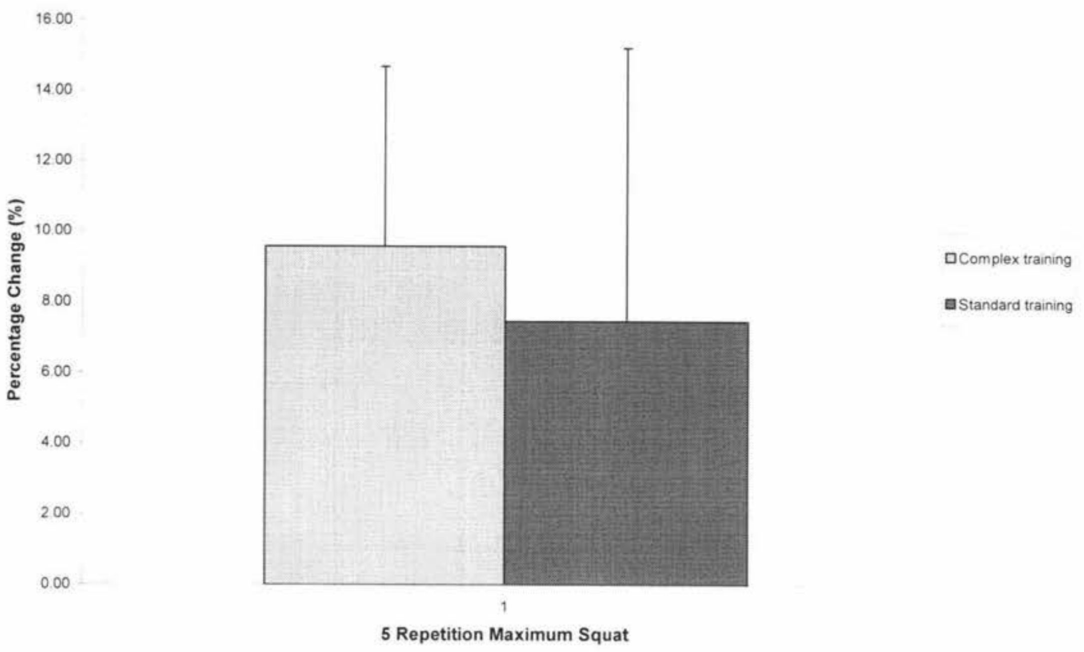

Figure 5. Mean change in 5 RM Squat performance following Standard and Complex training.

3.3 Static Force Production

As described previously the variables examined during static force production were maximum slope of the force curve, indicating the rate of force development, total area beneath the force curve indicating total impulse, and mean force produced. The resulting data pooled across subjects are summarised in table 2.

Table 2: Force parameters following standard and complex training

Parameter	Mean Change (%)		Paired Differences	
	Standard	Complex	mean	p
Maximum Slope	-29.51 ±35.99	12.29 ±33.59	41.80±49.29	0.03*
Total Work	26.01 ±24.24	27.86 ±30.68	1.85±49.95	0.91
Mean Force	-0.57 ±20.37	-0.03 ±18.96	0.54±35.35	0.97

3.3.1 Maximum Slope

There was a substantial difference between the post standard and post complex measures for maximum slope. Following standard training the value for maximum slope decreased on average by -29.51 ±35.99%. Following complex training maximum slope increased on average by 12.29 ±33.59%. There was a significant difference between means (p=.03).

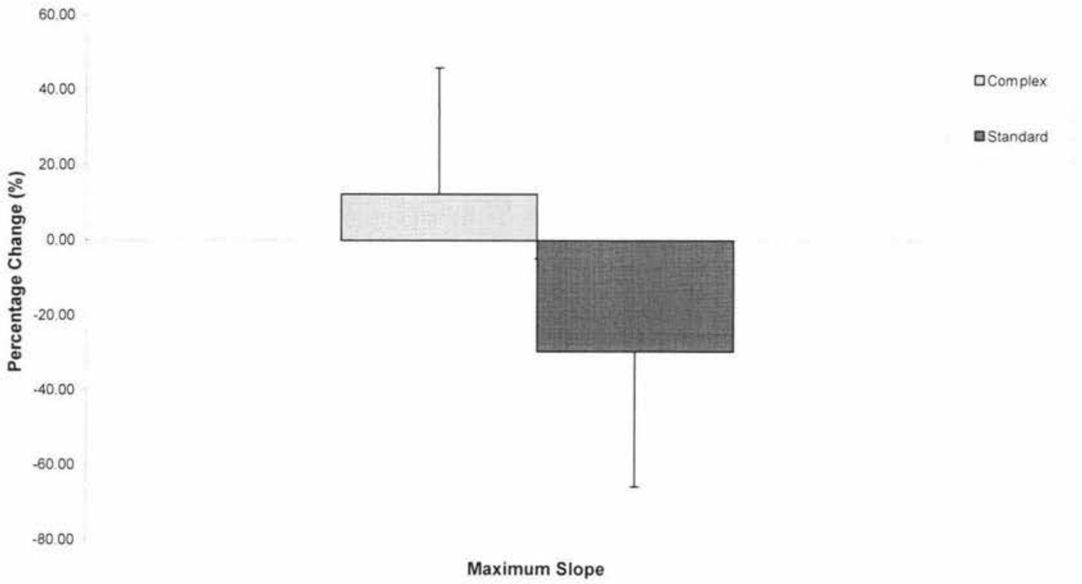

Figure 6. Mean change in maximum slope of the static force during static force production following complex and standard training.

3.3.2 Total Impulse

The increase in total impulse following both standard and complex training was similar, 26.01 ±24.24% and 27.86 ±30.68% respectively. There was no significant difference between means.

3.3.3 Mean Force

Mean force production was similar following both training phases, there was a slight decrease in mean force from both standard training, (-0.57 ±20.37%), and complex training, (-0.03 ±18.96%). There was no significant difference between means.

3.4 Power

As described previously the variables examined during power production were maximum power, maximum and minimum slope of the power curve, the time interval between the occurrences of maximum and minimum slope was taken as the curve width, time to peak force, and total work done. Furthermore the force and velocity components of power were examined separately to determine maximum force, maximum slope of the force curve, mean force, maximum velocity, and maximum slope of the velocity curve.

Table 3: Power parameters following standard and complex training

Parameter	Mean Change (%)		Paired Differences	
	Standard	Complex	mean	p
Maximum Power	3.82 ±7.88	15.13 ±7.49	11.30±11.20	0.02*
Maximum Slope	5.78 ±8.14	-7.48 ±29.80	-13.26±31.96	0.25
Minimum Slope	8.56 ±22.07	10.70 ±22.11	2.14±35.51	0.86
Time to Peak Force	-1.32 ±12.49	2.85 ±14.67	4.16±24.41	0.62
Curve Width	11.13 ±17.33	28.29 ±18.16	17.16±22.11	0.05*
Total Work	20.11 ±12.63	33.45 ±10.18	13.34±19.25	0.07

3.4.1 Maximum Power

Following standard training maximum power production increased by 3.82 ±7.89%, while following complex training maximum power increased by 15.13 ±7.49%. The difference between means was significant (p=.02).

3.4.2 Curve Width

There was a substantial difference between the mean curve widths observed. Following standard training curve width increased by an average of 11.13 ±17.33%. Following complex training curve width increased by an average of 28.30 ±18.16%. The difference between means was significant (p=.05).

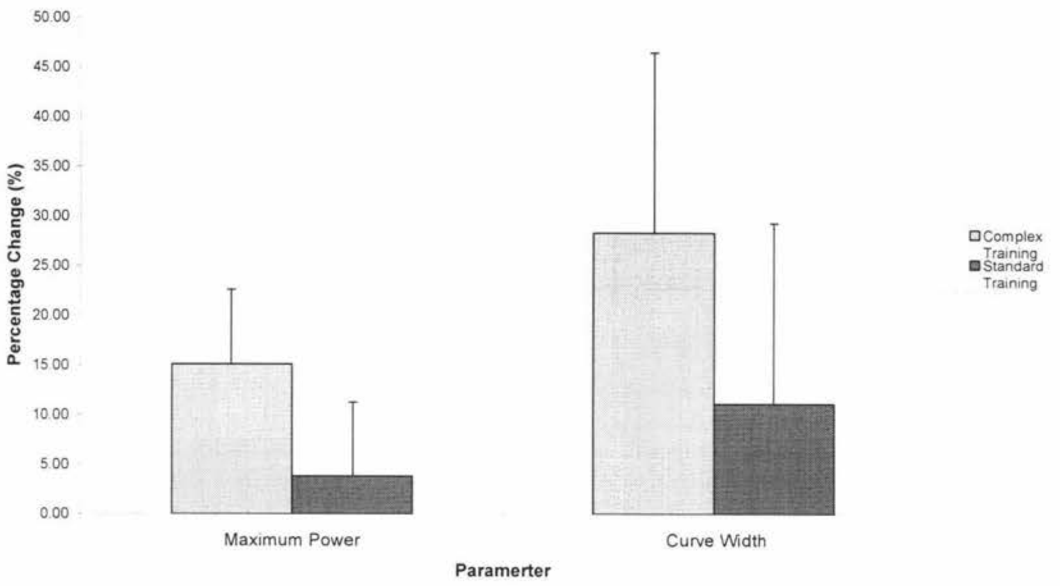

Figure 7. Mean change in Maximum Power and Curve Width following Standard and Complex training.

3.4.3 Maximum Slope and Minimum Slope of the power curve

Maximum slope increased following standard training by an average of 5.77 ±8.14%, but decreased following complex training by an average of -7.48 ±29.80%. Minimum slope increased following both standard and complex training conditions by 8.56 ±22.07% and 10.70 ±22.11% respectively. There were no significant differences between the mean values of maximum or minimum slope.

3.4.4 Total Work Done

Total work done was calculated by integration of the power-time curve and there was a substantial difference between the mean integral for each condition. Following standard training the integral increased by 20.11 ±12.64%, following complex training the integral increased by 33.45 ±10.18%, the difference between means approached significance (p=.07).

3.4.5 Force and Velocity components of power

The data from analysis of the force and velocity components of the power curve are presented in table 4.

Table 4: Force and Velocity parameters following standard and complex training.

Parameter	Mean Change (%)		Paired Differences	
	Standard	Complex	mean	p
Mean Force	7.83 ± 6.96	12.75 ± 15.33	4.92±15.63	0.37
Maximum Force	7.54 ± 6.03	10.64 ± 6.89	3.10±9.39	0.35
Maximum Slope (Force)	16.14 ± 19.68	3.03 ± 28.11	13.11±33.44	0.2
Maximum Velocity	3.00 ± 3.79	20.63 ± 14.21	17.62±15.47	0.01*
Maximum Slope (Velocity)	11.16 ± 15.81	8.05 ± 6.55	3.11±19.72	0.65

Only one significant difference between respective means following standard and complex training was evident; maximum velocity. Following standard training maximum velocity improved by 3.00 ± 3.79%, following complex training maximum velocity improved by 20.63 ±14.21%, the difference between means was significant (p=.01).

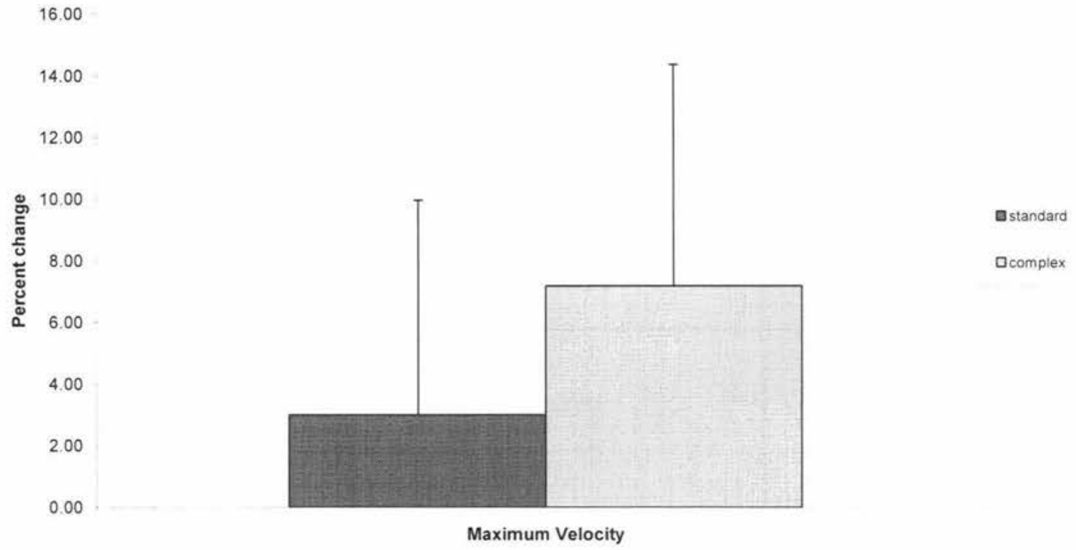

Figure 8. Mean change in maximum velocity as a component of power following Standard and Complex training.

3.4.6 Frequency Analysis

As previously described a Fast Fourier transform was applied to the power data. This allowed the examination of the power component amplitudes across a spectrum of frequencies. Initial frequency data were produced at intervals of 0.12 Hz. Subsequently, data were grouped in 0.5 Hz bins, that is, all values between 0 and .49Hz were averaged and labelled as the 0.5 Hz bin, values between 0.5 and 0.99 were averaged and labelled as the 1Hz bin, and so on up to a 2.5Hz. Data beyond this frequency were excluded because movement frequencies above 3Hz under voluntary control are unlikely in this situation. Grouping the data in this way allowed for meaningful interpretation of the frequency data.

There was no difference observed between the low frequency (0-1Hz) components of either treatment power curve. There was a substantial upward shift in the higher (1.5-2.5Hz) frequency components of the power curve following complex training.

However, no significant differences were observed between the mean amplitudes of any of the frequency components between standard and complex training.

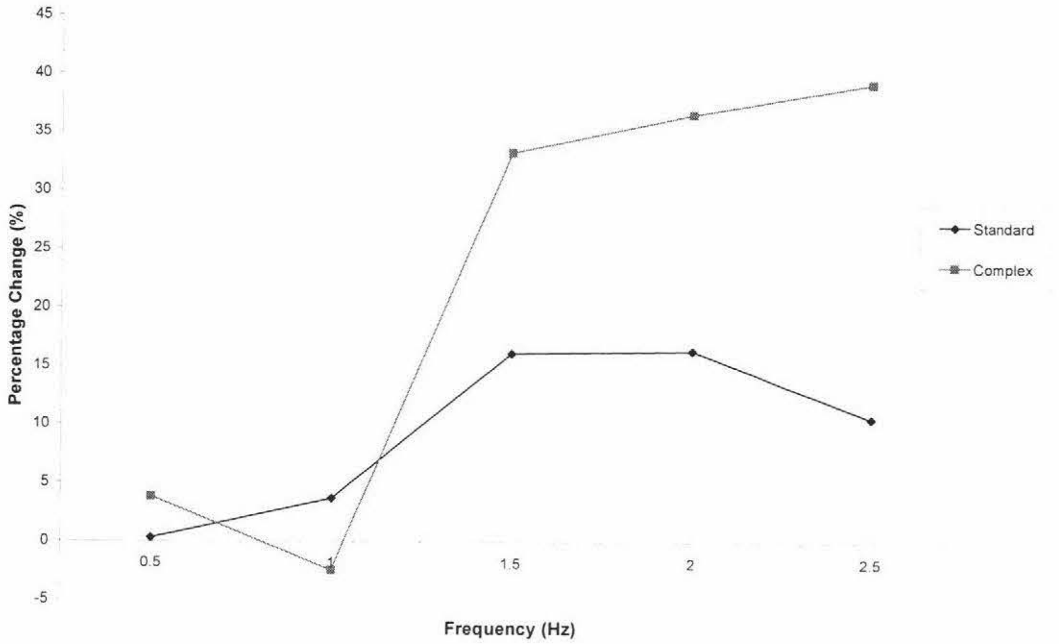

Figure 9. Mean change in amplitude of frequency components following Standard and Complex training.

4 Discussion

The purpose of this research was to examine the effect of a complex training regime on power and force production specific to skills practiced in Rugby Union. The components of power are strength and speed, but these cannot be expressed maximally at the same instant because of the Force-Velocity relationship of skeletal muscle. Therefore, there is a trade-off between these two components in the production of maximal power. Strength and speed are trainable qualities and hence power production can be enhanced via muscular conditioning programmes. The specificity of such enhancement, that is the direct translation to a sporting setting, is often limited.

The results presented in Chapter 3 indicate a significant improvement in a rugby specific performance parameter (horizontal power) following a complex training regime versus a standard training regime. There are three primary parameters in which significant differences were observed between training conditions: Maximum Power, Width of the Power Curve, and Maximum Velocity.

The first two of these parameters, Maximum Power and Width of the Power Curve, indicate that power production specific to the body orientation in rugby union was significantly improved following complex training. These results show participants were able to produce greater power and able to apply higher levels of power for longer periods of time.

In order to explain how power production could be altered it would seem reasonable to suggest that greater force was being applied at an unaltered velocity. This would seem logical because it is the magnitude of muscular force producing the movement that determines the final velocity of movement. In the absence of any data indicating otherwise one might conclude that the complex training regime has created an upward shift in the traditional force-velocity relationship explaining the increase in power producing ability. However, further examination of the results suggests that this was not the case. The level of force production was unaltered in two instances. Firstly, no significant difference was observed between groups in 5RM Squat, and secondly, no significant difference was observed in peak or mean static force applied to the Grunt 3000. Consequently, it appears that force parameters are not responsible for the observed difference in horizontal power production.

The locus of this change can be found through the examination of each of the force and velocity components of the power task. The result of this examination reveals no significant change in force; this agrees with the lack of change observed in 5RM squat and static Grunt 3000 performance. However the same examination reveals a significant increase in the velocity of the movement (indicated by Maximum Velocity). In concert these results suggest the change in velocity is the parameter responsible for the increase in horizontal power production.

It is possible to confirm this conclusion by examining the data from two alternative perspectives: a frequency analysis and force-velocity plot. From a power-spectrum analysis of the force data it was evident, although not statistically significant, that differences in amplitude were observed in some of the frequency components of the power curve between complex and standard training. There was a distinct upward shift of the frequency curve (Figure 9) following complex training. The range at which the shift is present (between 1.5Hz and 2.5Hz) indicated a general increase in the amplitude of high frequency power components. This increase would suggest force is being applied at higher velocities.

When force and velocity are plotted against one another (x = force, y = velocity) it is evident that there is an upwards shift in the force-velocity curve with little lateral shift. Lateral shift would indicate a greater force is being developed at an unchanged peak velocity, whereas an upward shift indicates relatively unchanged peak force produced at higher peak velocity.

Figure 10. A typical Force vs. Velocity phase plot

This distinct shift following complex training supports the argument that increased velocity has produced the increase in power, which confirms the suggestion that it is the ability to produce force at higher velocities that has increased rugby specific power production. This notion is supported by previous research. In an analysis of the applied force and velocity relationship during three different bench press techniques (concentric only, stretch-shorten cycle, and ballistic bench press), Cronin et al. (2003) found that force production was unaltered across conditions, but during the stretch-shorten and ballistic technique significantly greater velocity was achieved leading to greater power production. The authors suggest that movements such as these may improve functional (sporting) performance, but the movement velocities used did not approach those seen in actual performance (such as a martial arts punch or a netball chest pass), which limits the direct application of their findings.

It is unlikely that muscular adaptation can account for the observed change, especially considering the short time frame over which the intervention was applied. If muscular adaptation is not responsible, neural adaptation must be considered. Previous research (Patten et al., 1995) has shown neuro-motor adaptation to strength training in as little as one day when training was isolated to the fifth finger of the dominant limb. Following one day training the authors observed a 9-13% increase in force generation and a significant increase in MU discharge rate. This supports the argument that the mechanisms responsible for the adaptation are neural because muscular adaptation is not possible within such a short time frame. Therefore, it is considered that neural mechanisms accounted for the difference in power production following complex training in this study. That is to say that recruitment of a greater number of high threshold MUs, a greater firing rate or a greater synchronization of MUs, are possible explanations, either in isolation or in unison, for the measured outcome. However at this point in time the exact mechanism is uncertain. This assumption is supported by Behm & Sale (1993) who report that:

> *"at the highest speeds of movement, it is thought that adaptations are neural, that is, movements with the greatest speed and effort are developed as a learned response."*

Therefore, the suggestion is that a neuro-motor adaptation was induced by complex training possibly because of the potentiation effect created by the use of PAP within the regime. By exploiting the potential to recruit high threshold MUs following a non-specific maximally heavy lift greater numbers of high threshold MUs may be recruited into the sport specific task. This suggests that rather than improving the athletes' strength (assuming they have sufficient absolute strength levels required for the task) we should create a training situation to facilitate neuro-motor adaptations that induce greater realisation of force producing potential in position specific and velocity specific situations. This also indicates that we are not bound by the time course required to create muscular adaptation and can, therefore, create significant improvement in sport specific power production in a much shorter time, possibly days rather than weeks or months.

It is clear then that there has been a significant improvement in horizontal power production following a complex training regime versus a standard training regime. However, this may be perceived as a self-fulfilling prophecy as the exercise used to test performance was also used during complex training as the sports specific exercise (dynamic mode of the Grunt 3000). Previous research suggests that results such as these are likely when the mode of exercise and mode of testing are closely related. However, the data presented strongly suggest that complex training not only enhanced the trained exercise but also created transfer of the training effect to a novel performance test, in this case the static mode of the Grunt 3000 which was not trained. Although similar to the dynamic mode, the static mode differs in both contraction type and velocity and can, therefore, be regarded as novel.

A significant difference was observed between the training conditions with respect to maximum slope of the static force curve. There was a mean -29.51% decrement in maximum slope following standard training, but a mean 12.29% improvement following complex training. Maximum slope is an indication of the rate at which force is developed, and is a vital performance component in some aspects of rugby union, and various other sports. Young et al. (1995) report that the single best correlate of maximum sprinting speed is force relative to body weight applied at 100ms from the commencement of a loaded jumping action, implying that rapid rate of force development is one determinant of performance success.

While changes in maximum slope were significantly different from each other, they were not significantly different from zero. Therefore, the results presented here suggest that complex training may improve the rate of force development during the static condition while standard training does not change, and may reduce, the rate of force development in the static condition. Therefore, in a static horizontal force producing condition, standard training may reduce the initial impulse an athlete can produce, whereas complex training could substantially improve the initial impulse an athlete can produce.

These results are supported by Hetzler et al. (1997) who observed a decrement in functional performance measures following a 12 week non-specific strength and power regime relative to a non strength and power control group. The authors report that while the regime created significant improvement in the trained activities (leg press and bench press) there was no transfer of the training effect to functional activities (mean and peak anaerobic power and 40yd dash). This conflicts with previous research showing increased rate of force development of the quadriceps femoris muscle group following a 14 week strength training regime (Aagaard et al., 2002). The reason for the conflict may lie, as previously suggested, in the mode of exercise used to test performance. In Hetzler et al. (1997) the performance measures were different from the resistance exercises used in training whereas Aagaard et al. (2002) used the same exercise for testing and training.

Similarly, Cronin et al. (2003) suggest that the lack of transfer observed following a jump squat training regime was because the exercise used in training (a supine jump squat) was too far removed from the exercises use to test performance (multi-directional agility, lunge ability, and single leg jump). This lends further support to the notion that the movements used in strength training may be represented in the CNS as discrete skills with little relevance to more dynamic sport specific tasks.

Considering past research (Cronin, J. et al., 2003; Hetzler et al., 1997) one would not expect significant improvement in the novel task. However, it appears that the complex training regime has in some way created a persistent change in the control mechanisms regulating the performance of both the strength and power conditions. Analysis of the force and velocity components of the power curve and the force data from the static condition indicated that there was no significant change in the force producing capacity following either training condition in either mode but there was a significant increase in Maximum Velocity (of the power curve) and Maximum Slope (of the static force curve) following complex training. The significant improvement in velocity in conjunction with the significant improvement in maximum slope of the force curve supports the notion that true transfer is present because these variables (velocity and rate of force development) are linked by the impulse-momentum relationship (Aagaard et al., 2002).

5 Conclusion

This investigation has shown complex training to improve the performance of a sports specific activity namely the production of both horizontal force and power specific to the sport of rugby union. In this case improved performance is manifested through an enhanced ability to produce force at higher velocities during the power task and an enhanced rate of force development during the static force task. These results show evidence of transfer of the training effect to a novel task (performance of the static mode of the Grunt 3000) because of the link between velocity and rate of force development expressed by the impulse-momentum relationship.

This information suggests that, in athletes who already possess sufficient strength, non-specific resistance training alone will not provide significant benefit in a sports-specific setting. Rather, athletes with sufficient strength should train to enhance the velocity at which they are able to produce sports-specific power. The results of this investigation show that complex training is a suitable training method for producing such adaptation.

Athletes who do not possess sufficient absolute strength would still require the development of strength using traditional methods. The use of complex training could in this situation, optimise the transfer of non-specific strength gains during an off-season programme to use in sports-specific power production. The use of this information may allow the optimal utilisation of an athlete's force producing capabilities in an applied setting.

These results and conclusions, while specific to rugby union, are not limited to rugby union and provide a basis for application of complex training in other sporting codes.

To clarify the effects of complex training future research should focus on such aspects as optimal interaction of the stimuli, optimal recovery times between stimuli, the number of combinations of tasks required to optimise transfer, and appropriate uses of combination training in the periodised training scheme. The benefits of such research will be directly relevant to athletes when considering the multiple demands imposed by professional sport. Extended seasons, lack of rest periods, and pressure to perform at all stages of the season demand the utmost dedication in terms of time and energy. Because peaking is required at numerous times during the season the most beneficial and efficient training methods must be employed.

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7 Appendices

7.1 Appendix 1

The effect of complex training on horizontal power production in rugby players.

INFORMATION SHEET

Introduction

Complex training combines various training stimuli in one training session ranging from non-specific exercises in the gym to sport-specific tasks. This research aims to investigate complex training methods for rugby players to determine optimal combinations of training stimuli, and to develop training methods that enhance specificity of training and transfer of the training effect to rugby performance.

The project will be conducted by David Graham (a postgraduate student) supervised by Dr. Alan Walmsley of the Institute of Food Nutrition and Human Health.

Participant involvement

40 Participants are being sought to take part in the project.

Participants need to be

Healthy males over the age of 16

Have been playing competitive school boy rugby for at least one season

Have trained with weights for at during the past 12 months

Participants who agree to take part will be asked to complete a standard Physical Activity Readiness Questionnaire to ensure participants have no pre-existing condition(s) that preclude participation in the project. When accepted into the project, participants will undertake strength and horizontal power assessments using the squat exercise and Grunt 3000 rugby ergometer respectively. Your height, weight, and other body measurements will be taken to determine your body composition.

Each participant will undertake two periods of training:

A standard strength training progreamme; and

A Complex training programme.

Exercises used will be those commonly used in strength and power training such as the squat and leg-press, and a simulated scrumaging/rucking task. You will probably experience some muscular fatigue associated with heavy resistance training during the training sessions. It is also likely that you will experience delayed onset muscle soreness 1-2 days after exercise sessions. It is expected these effects would be no greater than you would experience during your normal training regime. There are no risks to your health other than those associated with normal pre-season rugby training.

It is expected that you will need to be available for

3 testing sessions (15min ea)

8 training session (25min ea)

8 training sessions (35min ea)

A total of 10hrs over a 9 week period

Project Procedures

The data produced during the project will be part of a Masters Thesis and may be published in a scientific journal. No personal information will be published in any form and no participant will be able to be individually identified. All data sheets will be assigned a code known only to the researchers to ensure anonymity.

Data will be stored electronically, and will be accessed only by the researchers. You will not be identifiable in any data file. All data access will be password protected and data will be archived on removable media (Zip disks) which will be stored in a locked cabinet.

At the end of the project you will be provided with a summary of your individual results and a seminar will be held to discuss the collated results and possible implications for the participants.

Participant's Rights

You have the right to:

decline to participate;

decline to answer any particular question;

withdraw from the study at any time;

ask any questions about the study at any time during participation;

provide information on the understanding that your name will not be used unless you give permission to the researcher;

be given access to a summary of the project findings when it is concluded.

Project Contacts

If you have any further questions regarding this project and your potential involvement please contact either David Graham or Dr. Alan Walmsley.

David Graham	Dr. Alan Walmsley
Ph. 350 5600 ext 2535	Ph 350 5600 ext
D.F.Graham@massey.ac.nz	*a.walmsley@massey.ac.nz*

This project has been reviewed and approved by the Massey University Human Ethics Committee, PN Protocol 02/132. If you have any concerns about the conduct of this research, please contact Professor Sylvia V Rumball, Chair, Massey University Campus Human Ethics Committee: Palmerston North, telephone 06 350 5249, email S.V.Rumball@massey.ac.nz.

PRE-ACTIVITY READINESS QUESTIONAIRRE

The effect of complex training on horizontal power production in rugby players.

Code:…………………………………….**Date:**……………………………….

Date of Birth:…………………………………………………………………………….

Address:…………………………………………………………………………………..

Phone: (day)……………………………(evening)……………………………………

1) Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

YES/NO

2) Do you feel pain in your chest when you do physical activity?

YES/NO

3) In the past month, have you had chest pain when you were not doing any physical activity?

YES/NO

4) Do you lose your balance because of dizziness or do you ever lose consciousness?

YES/NO

5) Do you have a bone or joint problem that could be made worse by a change in your physical activity?

YES/NO

6) Is your doctor currently prescribing medication (for example, water pills) for your blood pressure or heart condition?

YES/NO

7) Do you know of any other reason why you should not do physical activity?

YES/NO

8) How long have you been playing competitive Rugby?

…………………………………………………………………………………………..

9) How long have you been training with weights?

…………………………………………………………………………………………..

To the best of my knowledge the above details and information is both true and correct.

Signed:…………………………………………..**Date:**………………………………..

7.2 Appendix 2

Key to Abbreviations

c	Denotes results following complex training
s	Denotes results following standard training
Weight	Body Mass
Squat	5 Repetition Maximum Squat
0.5-2.5Hz	Frequency "bins" for FFT
Dyn Max Sl	Maximum slope of the power curve
Dyn Min Sl	Minmum slope of the power curve
Max Pow	Maximum power
Work	Total impulse
Width	Width of the power curve
T peak	Time to peak power
Stat Max Sl	Maximum slope of the force curve
Stat Work	Total work done in the static condition
Stat Mean F	Mean force in the static condition

Raw Data: Percentage change following Complex Training

	cWeight	cSquat	c0.5Hz	c1Hz	c1.5Hz	c2Hz	c2.5Hz	c3Hz	cDyn Max SI	cDyn Min SI	cMax Pow	cWork	cWidth	cT peak	cStat Max SI	cStat Work	cStat Mean F
DW	3.13	7.41	15.47	30.82	52.85	39.08	70.73	78.06	2.60	29.83	14.12	28.92	36.56	2.54	76.24	1.56	-15.40
GW	-0.81	15.91	36.90	16.66	43.95	40.45	-3.71	-27.99	-47.09	-26.19	28.52	37.98	26.68	-21.71	-51.13	76.07	15.77
WM	0.13	4.17	-27.09	-45.97	-21.88	10.87	-15.62	-42.52	3.84	8.61	22.30	46.83	16.56	1.38	-18.85	4.95	-36.08
RB	-0.62	13.04	-3.48	9.83	48.47	10.68	-27.35	-25.34	-68.05	-19.98	3.55	14.13	40.02	4.49	378.11	67.65	3.29
SF	-2.88	4.35	16.00	-16.31	8.98	68.27	27.48	-18.84	13.90	11.26	19.48	41.03	8.85	-2.19	104.08	14.60	-7.88
NS	0.71	9.09	8.48	4.62	-9.62	-7.30	59.02	32.58	8.31	2.74	12.28	37.61	68.80	17.54	-40.48	14.30	1.86
JL	-0.25	8.93	-40.13	-32.42	38.65	99.10	29.49	22.48	-8.60	32.88	13.63	41.46	22.17	30.87	-68.54	-4.26	-5.78
ML	-0.68	5.00	13.56	3.95	94.76	-1.10	86.76	205.65	17.03	23.83	7.85	25.69	18.48	-2.61	14.68	17.82	19.47
JM	0.84	18.18	14.61	6.86	42.88	68.29	125.25	-30.37	10.70	33.28	14.40	27.40	16.53	-4.70	20.66	58.07	24.46
Mean	**-0.05**	**9.56**	**3.81**	**-2.44**	**33.23**	**36.48**	**39.12**	**21.52**	**-7.48**	**10.70**	**15.13**	**33.45**	**28.30**	**2.84**	**46.08**	**27.86**	**-0.03**
SD	**1.61**	**5.11**	**23.85**	**24.46**	**35.53**	**36.43**	**50.70**	**79.29**	**29.80**	**22.11**	**7.49**	**10.18**	**18.16**	**14.67**	**137.13**	**30.68**	**18.96**

Raw Data: Percentage change following Standard Training

	sWeight	sSquat	s0.5Hz	s1Hz	s1.5Hz	s2Hz	s2.5Hz	s3Hz	sDyn Max SI	sDyn Min SI	sMax Pow	sWork	sWidth	sT peak	sStat Max SI	sStat Work	sStat Mean F
DW	1.41	6.90	6.71	-19.27	101.03	41.06	2.16	60.67	21.11	11.30	4.54	35.12	18.25	-11.15	-3.77	20.11	9.50
GW	-0.41	1.96	1.83	7.49	18.91	1.92	23.44	109.37	0.95	16.89	-0.02	22.81	43.26	9.73	-20.00	7.50	1.95
WM	0.00	4.00	-25.58	-21.40	-7.44	-17.26	-10.80	-19.37	-0.65	-15.78	-0.09	-1.08	-21.08	2.58	21.51	23.79	20.75
RB	0.41	0.00	-3.55	3.72	1.52	20.83	103.05	124.55	11.59	2.68	-10.99	10.92	22.24	13.71	-77.33	-11.38	-8.77
SF	1.62	4.17	1.20	31.69	-1.56	-21.10	-23.59	20.33	-4.85	24.87	2.99	7.44	13.66	0.55	-27.75	18.51	6.20
NS	3.44	22.22	15.13	50.82	73.79	87.84	13.90	-8.23	-1.71	40.77	11.23	27.43	8.80	-12.06	-33.54	65.04	2.09
JL	0.62	16.67	-7.76	-14.90	-11.01	12.20	-8.73	131.03	6.68	-17.29	1.84	14.92	9.92	-18.20	-5.69	43.09	-0.16
ML	2.52	11.11	9.12	12.18	-8.03	9.32	26.22	25.89	9.85	31.45	16.88	31.25	2.97	15.08	-25.39	55.27	13.31
JM	2.60	0.00	5.47	-17.20	-22.16	12.30	-30.57	213.80	9.03	-17.85	8.01	32.19	2.18	-12.08	-93.67	12.16	-50.02
Mean	**1.36**	**7.45**	**0.28**	**3.68**	**16.12**	**16.35**	**10.56**	**73.12**	**5.77**	**8.56**	**3.82**	**20.11**	**11.13**	**-1.31**	**-29.51**	**26.01**	**-0.57**
SD	**1.31**	**7.75**	**11.82**	**25.07**	**42.44**	**32.72**	**39.90**	**77.01**	**8.14**	**22.07**	**7.89**	**12.64**	**17.33**	**12.49**	**35.99**	**24.24**	**20.37**

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	CWEIGHT - SWEIGHT	-1.4044	1.87888	.62629	-2.8487	.0398	-2.242	8	.055
Pair 2	CSQUAT - SSQUAT	2.1167	10.75170	3.58390	-6.1478	10.3812	.591	8	.571
Pair 3	C0.5HZ - S0.5HZ	3.5278	18.06673	6.02224	-10.3595	17.4151	.586	8	.574
Pair 4	C1HZ - S1HZ	-6.1211	32.18872	10.72957	-30.8636	18.6213	-.570	8	.584
Pair 5	C1.5HZ - S1.5HZ	17.1100	58.15581	19.38527	-27.5925	61.8125	.883	8	.403
Pair 6	C2HZ - S2HZ	20.1367	57.62716	19.20905	-24.1595	64.4328	1.048	8	.325
Pair 7	C2.5HZ - S2.5HZ	28.5522	78.40519	26.13506	-31.7153	88.8198	1.092	8	.306
Pair 8	C3HZ - S3HZ	-51.5922	125.06638	41.68879	-147.7268	44.5423	-1.238	8	.251
Pair 9	cDyn Max SI - sDyn Max SI	-13.2622	31.95691	10.65230	-37.8265	11.3020	-1.245	8	.248
Pair 10	cDyn Min SI - sDyn Min SI	2.1356	35.50956	11.83652	-25.1595	29.4306	.180	8	.861
Pair 11	cMax Pow - sMax Pow	11.3044	11.19887	3.73296	2.6962	19.9127	3.028	8	.016
Pair 12	CWORK - SWORK	13.3389	19.24532	6.41511	-1.4544	28.1321	2.079	8	.071
Pair 13	CWIDTH - SWIDTH	17.1611	22.11390	7.37130	.1629	34.1594	2.328	8	.048
Pair 14	cT peak - sT peak	4.1611	24.40655	8.13552	-14.5994	22.9216	.511	8	.623
Pair 15	CMEANF - SMEANF	4.9156	15.62894	5.20965	-7.0979	16.9290	.944	8	.373
Pair 16	CMAXF - SMAXF	3.0978	9.39312	3.13104	-4.1224	10.3180	.989	8	.351
Pair 17	CMAXSLF - SMAXSLF	-13.1111	33.44486	11.14829	-38.8191	12.5969	-1.176	8	.273
Pair 18	CINTF - SINTF	-7.3311	38.83358	12.94453	-37.1812	22.5190	-.566	8	.587
Pair 19	CMAXV - SMAXV	17.6211	15.47141	5.15714	5.7287	29.5135	3.417	8	.009
Pair 20	CMAXSLV - SMAXSLV	-3.1144	19.71753	6.57251	-18.2707	12.0418	-.474	8	.648
Pair 21	cStat Max SI - sStat Max SI	41.8011	49.28694	16.42898	3.9158	79.6864	2.544	8	.034
Pair 22	cStat Work - sStat Work	1.8522	49.94728	16.64909	-36.5407	40.2451	.111	8	.914
Pair 23	cStat Mean F - sStat Mean F	.5400	35.35281	11.78427	-26.6346	27.7146	.046	8	.965