Understanding and Optimising Vertical and Horizontal Force Production for Performance in Team Sport Athletes

Caleb William Dobbs

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Primary Supervisor: Assoc. Prof. Nicholas Gill

Secondary Supervisor: Prof. Michael McGuigan

Associate Supervisor: Dr. Daniel Smart

Sports Performance and Research Institute New Zealand

AUT University, Auckland, New Zealand

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ATTESTATION OF AUTHORSHIP

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

Caleb William Dobbs

DEDICATION

In dedication to Jedidiah Morey Dobbs, born 8th Jan 2015. I loved you even before I met you and will give all that I am to be a good father to you.

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Doctoral Candidate: Caleb Dobbs

Primary Supervisor: Dr. Nicholas Gill

Secondary Supervisor: Dr. Michael McGuigan

Associate Supervisor: Dr. Daniel Smart

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ABSTRACT

Power profiling allows greater prognostic and diagnostic information about the underlying mechanical determinants related to sports performance. To date, vertical jumps have been predominantly used in power profiling. Horizontal jumps have greater similarity with many functional movements but have received limited attention from researchers. Similarly, limited research exists concerning methods of improving acute and chronic jump performance in the horizontal plane of movement. Therefore, the aim of this thesis was to determine kinetic and kinematic variables in vertical and horizontal power profiling, compare them to measures of functional performance and to determine the effects of short term enhancement (STE) on jump performance.

The results of study one (n = 19) indicated that power profiling measures, including mean force (MF) and peak force (PF), were as reliable in horizontal jump types (ICC range: 0.79 - 0.97; CV range: 6.6% - 9.1%) as in their vertical counterparts (ICC range: 0.82 – 0.97; CV range: 2.1% - 9.2%). These measures may be used with confidence.

The results of study two (n = 17) suggested that many power profiling variables in horizontal counter movement jumps (CMJ), drop jumps (DJ) and squat jumps (SJ), including MF and PF, had greater relationships to sprint speeds (R^2= 0.13 to 0.58) than MF and PF in vertical jumps (R^2 = 0.01 to 0.50). This suggests that, when the prognostic value of such tests to functional

movements is of concern, horizontal jumps should be used alongside their vertical counterparts. Further, it is likely that horizontal dynamic training may have greater transfer to sprint performance than vertical dynamic training.

Study three explored the effects of STE on horizontal jump performance in developmental rugby players (n = 24). Four minutes post pre-intervention (4RM squats), STE caused meaningful small improvements in horizontal jump performance, including MF in CMJ (effect size (ES) = 0.51 ± 0.38) and DJ (ES = 0.45 ± 0.41). This demonstrates that STE is not specific to the plane of movement of the intervention and that subjects need not be highly trained to achieve STE.

This effective STE protocol was used to determine the training effect of contrast training in study four (n = 20). A matched pairs seven-week training intervention was implemented with a contrast (STE affected) and complex (control) training group. Differences in mean change of vertical and horizontal CMJ measures of force (ES Range = 0.40 - 0.46 ± 0.37 - 0.63), vertical CMJ peak velocity (ES = 0.84 ± 0.66) and mean velocity (ES = 0.62 ± 0.88) were meaningfully greater in the experimental training group. This demonstrates that an acute STE response in dynamic training movements can produce chronic improvements to a greater extent than identical training methods that do not elicit STE.

The results of these studies indicate that measures of horizontal power profiling are reliable and tend to have greater correlation to functional performance than their vertical counterparts. As such, they may be of greater prognostic and diagnostic value for team sport athletes. Furthermore, STE was found to improve both acute and chronic measures of horizontal jump performance. The use of horizontal jumps in dynamic testing and training should be considered by strength and conditioning practitioners concerned with developing lower limb dynamic ability for functional performance.

CHAPTER 1

INTRODUCTION

1.1 Background

Vertical jump tests such as the countermovement jump (CMJ), squat jump (SJ) and drop jump (DJ) are amongst the most widely performed assessments of lower limb dynamic ability in athletes [1]. The simplest variable to measure in these tests is jump height, but this provides limited information about the kinetic or kinematic aspects which contribute to power production in vivo [2]. In fact, differentiating between kinetic and kinematic measures obtained during jump testing, including peak power (PP), peak force (PF), mean force (MF), peak velocity and rate of force development (RFD), can provide detailed information about the muscular qualities of athletes. For example, force trace data taken from CMJ tests are able to provide diagnostic information on power production and RFD with a slow stretch shortening cycle (SSC) [3]. Additionally, the DJ is able to measure fast SSC ability (<250msec) [1; 4] and is a measure of power and force production involving only a concentric contraction [1]. Musculotendinous qualities such as these are important in different aspects of physical performance. Isolating muscular qualities such as these, gives greater prognostic and diagnostic information regarding athletes dynamic performance. This allows for more precise data on training effects and can help to optimise the development of training programs [1; 5]. The observation of kinetic and kinematic variables across a range of jumps in order to isolate and measure the physiological mechanisms contributing to power production is known as power profiling.

Despite the popularity of vertical jump tests, many sporting tasks require horizontal or a combination of horizontal and vertical force production [6-8]. Additionally, in many functional movements, such as sprinting, force in the horizontal plane of movement is of primary importance [9; 10]. Therefore, it would seem that kinetic and kinematic measures taken from vertical jumps provide an incomplete picture of athletic movement and may be of limited prognostic value to actual sporting performance [6; 7]. As such, the use of horizontal, or a combination of vertical and horizontal measures of power, would seem to have greater face validity to sporting performance.

There is, however, a relative lack of research into the reliability of tests involving horizontal jump movements in athlete populations. Although reliability of the vertical CMJ [7; 11-15], SJ [11; 13; 15; 16] and DJ [11; 17; 18] tests has been well established, the reliability of horizontal jump movements has received less attention from researchers, particularly with regard to high level athletes [1; 7; 17; 19]. The reliability of jump distance has been found in a range of horizontal jump types, including in the unilateral CMJ [7], unilateral horizontal CMJ, SJ, repetitive jump [1] and horizontal DJ [17]. It is important to note that measures of distance do not provide direct information regarding kinetic or kinematic factors contributing to jump performance [2]. Additionally, many of these previous studies have been carried out using recreationally trained athletes. A comprehensive study determining the reliability of kinetic and kinematic variables across a range of bilateral and unilateral horizontal jump types in high level athletes would be of value to researchers and strength and conditioning practitioners.

Some limited research exists concerning the relationship between horizontal jump ability and performance variables, showing that horizontal jump distance is equally effective or more effective than vertical jump measures at predicting functional sporting movements [1; 7; 20]. Research has also shown mean horizontal power in unilateral horizontal CMJ to have a significant correlation to sprint speed (r = 0.75) [21]. In addition, Cronin et al.[4] found significant correlations between both vertical and horizontal force measurements in unilateral horizontal DJ compared to sprint speed over short distances. To the author's knowledge, no comprehensive study has been previously undertaken to determine the relationship between sprint speed and kinetic and kinematic variables, including MF, PF and contact time in unilateral and bilateral CMJ, SJ and DJ.

Physical characteristics such as muscle architecture and muscle stiffness also affect the dynamic properties of a muscle. Muscle stiffness refers to the ability of a muscle to resist change in length when subjected to a force [22], and to the spring-like qualities of tendons [23]. This plays an important role in developing muscular force [24; 25] and is important in optimising dynamic movements, speed and stability during tasks such as running and jumping [23; 24; 26].

The relationship between muscle architecture and dynamic performance is of interest [27], as fascicle length and pennation angle are believed to be related to the maximal voluntary contraction force of a muscle and to the proportion of force transmitted from a muscular contraction to the tendon [28]. Fascicle length and muscle thickness have been found to be greater and pennation angle more acute in sprint athletes compared with endurance athletes [29], as well as in more physically capable individuals [30; 31]. It is clear that a relationship exists between fascicle pennation angle, fascicle length and muscle thickness, and functional performance [27; 29; 30; 32]. The relationship between these variables and kinetic and kinematic measures in horizontal jump movements has not yet been explored in high level athletes and would be of interest to strength and conditioning practitioners.

Improving our understanding of the relationship between vertical and horizontal power profiling measures and measures of functional performance is important. However, due to the strong relationship which exists between strength, power and dynamic athletic performance [33-35] it is also important to develop new and innovative methods to train and improve muscular strength and power. A method that may improve acute dynamic performance and has recently received a great deal of interest is post activation potentiation (PAP) or short term enhancement (STE) [36-40]. Previous research has shown STE to have positive acute effects on vertical jump performance [38; 41; 42] and sprint performance [37; 40]. Although the exact mechanism by which STE occurs is not yet known [43], the STE response appears to be related to the strength levels and training history of athletes [38]. In addition, appropriate stimulus and rest periods prior to undertaking an explosive movement are required to cause STE [44]. As such, not all STE studies have shown improvement in dynamic performance following near maximal contractions [45-47]. High variability in individual STE responses has also been observed [44; 48; 49] which may cause inconsistency in observing an ergogenic effect from STE. It is clear, however, that it is possible to achieve an acute enhancement in muscular performance characteristics as a result of previous contraction within a training session [37; 38; 40; 44]. There is currently very little research into the effect of STE in developmental athletes.

Similar to the case with athlete power profiling, very little research has been carried out concerning the effects of STE on horizontal jumps. In fact, when training for many functional movements, the use of horizontal or a combination of horizontal and vertical plane training movements has high face validity [2]. Horizontal jump distance has also been shown to have stronger correlations than vertical jump to sprint speed [1; 7]. Therefore, the effect of STE as a mechanism to produce acute and chronic improvements in horizontal dynamic ability is of interest to researchers and strength and conditioning practitioners.

Of the research that does exist investigating the effect of STE on horizontal jumps, not all results have found STE to have a positive effect on jump performance [41; 46]. For example, one study has shown STE to have no significant effect on jump performance (height or distance) in either vertical or horizontal jumps after pre-loading [46], and another found maximal isometric contraction to have a positive effect on vertical, but not horizontal, CMJ [41]. In contrast, a few studies have found a series of weighted vest loaded dynamic exercises to increase long jump distance in teenage subjects [50; 51]. Interestingly, in both studies, no improvement was found in vertical jump height [50; 51]. Additionally, Ruben et al. [52] found a back squat protocol utilising four sets of ascending load to cause STE in repeated horizontal hurdled jumps. However, considering the limited research into the effect of STE on horizontal jump performance, further research in this field is warranted.

The effect of STE as a mode of training to produce chronic improvements in dynamic ability is also of interest. Complex training may be an effective training modality by which to utilise STE to increase chronic dynamic performance. The term “complex training” refers to a series of strength sets being carried out, followed by a series of plyometric or dynamic training sets within the same training session [53]. It has been theorised that STE can be utilised through complex training to not only increase the performance of dynamic movements within a training session, but also to improve muscular ability to a greater extent than traditional training methods over a training cycle [54].

However, several studies have failed to show significantly greater training improvements in strength and power measures as a result of complex training over traditional training [55-58]. This may be because the effects of the mechanisms contributing to STE diminish over time and are likely to be offset by fatigue caused by additional training sets. Therefore, complex training is unlikely to produce a STE effect across a set of dynamic training movements. Some studies have found complex strength and plyometric training to improve dynamic variables over training without dynamic intent, such as weight training [59-61]. However, the principle of training specificity dictates that physiological adaptations will occur in accordance to the training stimuli [62]. As such, subjects who train with dynamic intent will improve in measures of power to a greater extent than those who do not [63], rendering these findings unremarkable.

Contrast training may prove to be a more effective mechanism than complex training for producing chronic strength and power improvements through STE. Contrast training involves sets of body weight or lightly loaded movements performed dynamically between sets of heavy strength movement [64]. This has the potential to elicit a STE effect in each dynamic training set and has been shown to improve sprint speed and squat jump height, as well as lower limb dynamic performance measures including the horizontal broad jump in young elite soccer players [64]. As such, contrast training seems to be a promising training approach in utilising STE to produce chronic improvements in dynamic movements and merits further research. However, training studies to date have failed to demonstrate acute STE during complex or contrast training. It would be of interest to determine whether or not utilising proven acute STE strategies in training would result in greater training effect than carrying out the same exercises utilising a protocol that does not induce STE.

1.2 Research Aims

This doctoral thesis was undertaken to enhance understanding of power profiling and the development of lower limb dynamic ability through STE, particularly in the horizontal plane of movement. The specific aims of the thesis were:

1. To investigate and compare the reliability of measures of horizontal and vertical power profiling.

2. To determine kinetic and kinematic variables in vertical and horizontal power profiling and compare them to measures of functional performance.

3. To determine the acute effect of STE on horizontal and vertical CMJ and DJ kinetics and kinematics.

4. To determine the chronic effect of STE as a training tool on horizontal and vertical CMJ and DJ kinetics and kinematics.

1.3 Significance of Thesis

Testing and understanding horizontal jump kinetics and kinematics allows for improved prognostic and diagnostic understanding of horizontal jump movements, and may be used to inform and improve future testing and training protocols. Prior to utilising such test variables, however, the reliability of horizontal power profiling measures must be determined. This research is significant in determining reliability of a range of kinetic and kinematic variables in horizontal jump movements, thereby allowing these measures to be used with confidence alongside their vertical counterparts in future power profiling. Additionally, determining the reliability of horizontal power profiling measures lays the ground work for the correlational study included in this thesis.

Research concerning the relationships between horizontal jump measures to functional performance (sprint speed) and physiological variables (muscle stiffness and muscle architecture) is also useful for informing future training direction for those interested in improving lower limb dynamic ability. By determining the relationship between vertical and horizontal jump power profiling variables to sprint speed, muscle stiffness and measures of muscle architecture, it can be determined whether it is vertical or horizontal jump movements that are more closely related to measures of functional performance. As such, those (horizontal) jump movements that are found to have high correlations to measures of functional performance are likely to have greater transfer in training to dynamic ability e.g. sprint speed. Additionally, by determining the relationship of these horizontal jump measures with sprint speed over varying distances, it can be determined which physiological mechanisms are most important in various phases of a sprint (e.g. acceleration, acceleration at high speed and maintenance of top speed) and which horizontal jump types may be most effectively used in training to improve these facets of sprint performance. As such, the greater prognostic value of such kinetic variables is a valuable tool for strength and conditioning practitioners.

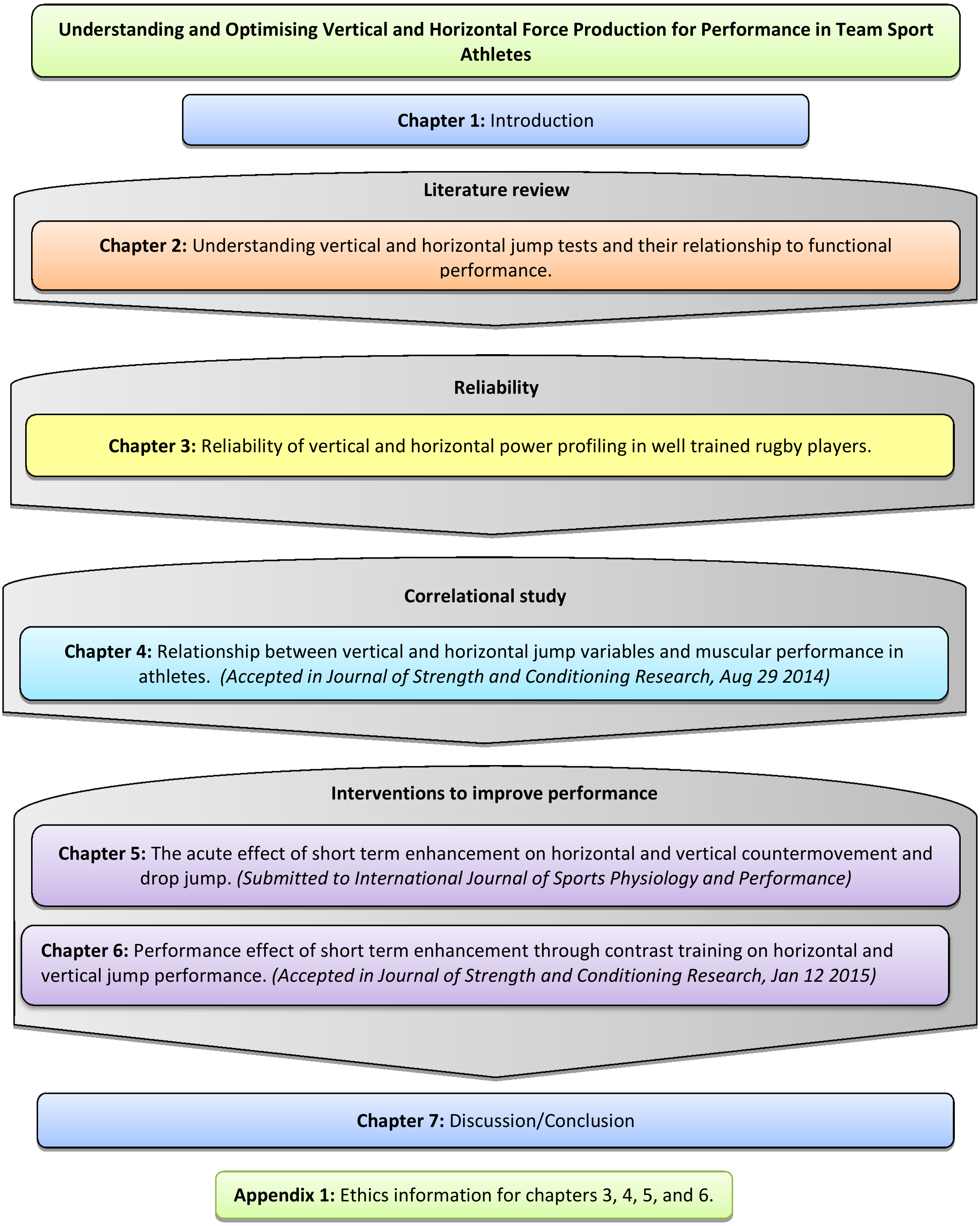
In order to further understand and develop new and innovative methods for improving muscular strength and power, further research into STE is also important. A large amount of research has been undertaken into the effect of STE in the vertical plane of movement. However, there is limited research into both the acute and chronic effects of STE in the horizontal plane of movement.

Therefore, the aim of this thesis was to determine the reliability of vertical and horizontal power profiling measures and their correlation to functional performance. This is of significance because isolating different muscular qualities gives greater prognostic and diagnostic information about athletic performance, thus allowing for more precise data on training effects as well as helping to optimise training programs. Additionally, in order to improve understanding regarding the acute and chronic improvement of lower limb dynamic performance, the within session effect of STE in the horizontal plane of movements was determined. As well as this, the effect of strength and power complex training to cause chronic improvements in power was investigated.

1.4 Thesis Organisation

This thesis contains research concerning power profiling and STE in the horizontal plane of movement. There is a logical progression from descriptive, reliability and correlational research to investigations of the acute and chronic effects of STE, with each study building on the findings of the previous work (see Figure 1.1 – Thesis Organisation). This thesis is comprised of the following seven chapters: introduction (chapter one), literature review (chapter two), reliability study (chapter three), correlational study (chapter four), two original experimental investigations (chapters five and six), and discussion and conclusion (chapter seven). Several of the chapters included in the thesis have been submitted for publication to peer reviewed journals. Accordingly, each chapter is presented in the format required by the journal to which it has been submitted (Figure 1.1).

Figure 1.1: Thesis Organisation



CHAPTER 2

LITERATURE REVIEW: UNDERSTANDING VERTICAL AND HORIZONTAL JUMP TESTS AND THEIR RELATIONSHIP TO FUNCTIONAL PERFORMANCE

2.1.1 Introduction

It is widely recognised that the ability to develop high levels of muscular power is a critical component in many sporting activities [65]. Furthermore, the ability to accurately and reliably test power in vivo is important for determining both base level and changes in dynamic physical performance. However, this can be a challenging task due to the complex nature of power production in vivo which involves a number of factors such as concentric strength [66], the SSC [67], RFD [65; 66] and muscle stiffness [24; 25]. Each of these factors plays a unique and important role in developing muscular force and determining the capacity of a muscle to produce powerful movements.

Vertical jump tests are amongst the most widely performed movements used to assess lower limb dynamic ability [1]. In such tests, the measured variable has traditionally been jump height [68-71]. This is probably due to the ease of taking jump height measurements. Indeed, an advantage of using vertical jump tests is their simplicity [72]. However, jump height sheds limited information on the kinetic or kinematic variables which contribute to power production in vivo [2]. Differentiating between variables during jump testing provides greater detail concerning the musculotendinous qualities of athletes, and is of greater prognostic and diagnostic value [1; 5].

Kinetic and kinematic variables measured during vertical jumps, such as the CMJ, SJ and DJ, are believed to enable specific musculotendinous properties to be determined. For example, force trace data taken from CMJ tests are able to provide diagnostic information on power production and RFD with a slow SSC [3]. Additionally, the SJ measurement eliminates the influence of the SSC; it is a measure of power and force production involving only a concentric contraction [1]. The DJ, on the other hand, enables the assessment of fast SSC ability [1; 4]. Such musculotendinous qualities are important in different aspects of physical performance. For example, concentric contractile force in the SJ is thought to be important to early acceleration during a sprint performance [3; 73]. By isolating different musculotendinous qualities, greater prognostic and diagnostic information about athletes is obtained, which allows for more precise data on the training effects and can help to optimise the development of training programs [1; 5].

An important consideration in power profiling must be the force production needs of the athlete. For example, many sports require force to be produced in both the vertical and horizontal plane of movement [6-8]. It would, therefore, seem to have greater face validity if both vertical and horizontal jump tests were utilised in power profiling [2]. Currently In the body of literature, however, there is proportionately less research into horizontal than to vertical jump movements. Promisingly, the limited research concerning horizontal measures of power suggest that such measures are reliable and may be equally or more effective at predicting functional sporting movements [1; 7; 20]. However, an in-depth understanding of the physiological characteristics important in predicting functional movement during horizontal jump testing has not yet been obtained. As such, only a limited body of information exists concerning the kinetic and kinematic variables that contribute to the development of dynamic movement across a range of horizontal jump types.

Without understanding the determinants of dynamic performance, such as sprint speed, it is unlikely that training techniques and protocols will be utilised optimally [2]. This review critiques current literature regarding vertical and horizontal jump testing. Special interest is taken in literature regarding existing testing techniques which isolate and measure musculotendinous factors contributing to dynamic performance in both the vertical and horizontal planes of movement.

2.1.2 Factors contributing to power in vivo

In order to properly understand power development in vivo, it is important to understand the factors which contribute to this process. According to literature, force production within human skeletal muscle is complex and multifaceted, involving a number of factors including (but not limited to): concentric strength [66], the SSC [67], RFD [65; 66], muscle stiffness [24; 25] and muscle architecture [29]. Each of these factors plays a unique and important role in developing force and determining the capacity of a muscle to produce powerful movements.

Maximal concentric strength is known to be a prerequisite to the development of power [35]. As such, a strong relationship exists between maximal strength and dynamic performance [33; 74]. This relationship has been observed in numerous studies [33; 35; 74-76]. Despite this, the literature is not consistent in supporting a linear relationship between these two variables. For example, Baker, Nance and Moore [77] found similar strength scores in professional and semi-professional rugby league players, although professional players produced greater power scores. This does not preclude the relationship between strength and power. However, it does suggest that this relationship is complex and is influenced by factors other than concentric strength [35; 74], which could include RFD, SSC, muscle stiffness and muscle architecture.

According to literature, RFD can be defined as the development of maximal force in minimal time [78] or the rate of rise of contractile force at the beginning of muscular contraction [79], and is important for dynamic responses to postural imbalance as well as in athletic performance [80; 81]. A maximal voluntary contraction takes more than 300ms to reach PF [82]. However, many critical sporting movements, such as sprinting, long jump and high jump, allow less than 250ms to develop force [83; 84]. As such, rapid contractions in vivo may not allow enough time to reach maximal force [81]. The ability to produce force quickly allows greater force and velocity to be produced in such time-limited movements. Therefore, RFD is an important factor when great acceleration is required e.g. during the early phase of a sprint or sprint over short distances [85].

It has also been suggested that the muscle's ability to continue to produce high levels of force as velocity increases toward the end of a concentric contraction, i.e. late phase force development, is important in developing power [65]. Motor unit firing rates tend to be greatest (approximately 100-200 Hz) at the onset of voluntary maximal contraction [81]. However, these firing rates reduce as velocity increases, diminishing to 15-20 Hz at the point of maximal force generation [81]. That is, fewer actin-myosin cross-bridges are able to functionally contribute to force production as velocity increases [18]. The ability to continue to produce greater force as velocity increases throughout a concentric contraction would allow for greater cumulative force.

The SSC refers to the tension caused during eccentric stretch prior to a concentric contraction [18]. Research has found this to be an important component in dynamic movement and enhances maximal work output in the concentric contraction [86]. Furthermore, the ability to utilise stored musculotendinous energy is thought to reduce the amount of energy required during repeated dynamic movements [87]. Although extensive research has been undertaken into the role of SSC in vivo, the exact nature and performance of the mechanisms by which the SSC enhances concentric contractions is still under debate [18].

Related to the SSC is muscle stiffness. Muscle stiffness has been defined as “the force response to an imposed change in length of a tissue” (Kaminski et al. [25] p.45). There has recently been great interest in muscle stiffness, particularly in how this factor relates to strength and power production in different physical modalities [88]. Research has shown that muscle stiffness in the lower limb plays an important role in optimising human locomotion [24; 26]. It is hypothesised that muscle stiffness may contribute to running economy by storing and utilising elastic energy, reducing muscle activation and reducing energy expenditure, although the magnitude of this effect remains unclear [88]. Muscle stiffness is also related to the storage and utilisation of force in the SSC [89] and is thought to be an important factor in dynamic movements, sprint speed and stability [20; 25].

Despite this, not all studies have shown a relationship between muscular stiffness and dynamic performance [90]. It is known, however, that the force-producing ability of a single cross-bridge is determined by cross-distance or the elongation of elastic elements within the cross-bridge [91]. As a muscle is stretched and the cross-distance increases, potential force production by the cross-bridge is also increased [91]. Furthermore, elastic energy is thought to be produced in the connective tissue surrounding the muscle [18]. As such, it seems clear that the elastic properties of a muscle as related to muscle stiffness are important in the development of musculotendinous power.

Another factor pertaining to the dynamic properties of a muscle is muscle architecture. Muscle architecture has also been explored in relation to vertical force development and sprint speed [27]. More specifically, fascicle length and angle are believed to affect rate of contractile force and the number of muscle fibres attached to tendons [27; 44]. Fascicle length is thought to be proportional to the maximal voluntary contraction velocity of a muscle, while pennation angle is thought to dictate the proportion of force transmitted from a muscular contraction to the tendon [28]. In support of this, Abe et al. [29] found fascicle length to be greater in sprint-trained athletes than in distance runners, and Narici et al. [31] found fascicle length to be great in young men as compared to elderly men. Fascicle angles have also been shown to be greater in highly trained bodybuilders than in untrained subjects [92]. However, a dearth of research has been undertaken investigating the relationship between muscle stiffness, fascicle angle or fascicle length, and jump performance in the horizontal plane of movement in the athletic population. Further research in these areas would seem warranted.

2.1.3 Vertical jump tests of power

The vertical CMJ [7; 11-15], SJ [11; 13; 15; 16] and DJ [11; 17; 18] are amongst the most widely used measures of lower limb dynamic ability. Numerous studies have explored the relationship between vertical jump performance and measures of functional performance, particularly in sprinting [7; 20; 85; 93-95]. Vertical jumps are also commonly used as predictors of sprint speed [7; 34]. For example, Lieberman et al. [72] found a significant correlation between CMJ mean peak power and 20m sprint time (r = -0.88), and Loturco et al. [95] found significant correlations between 100m sprint speed and SJ (r = -0.82) and CMJ (r = -0.85) in elite male sprinters. However, because vertical jumps are traditionally used to measure only jump height, they provide limited information regarding the kinetic or kinematic variables which contribute to a dynamic performance and are of limited diagnostic and prognostic value [2]. The measurement of kinetic and kinematic variables through power profiling allows greater details concerning the musculotendinous characteristics force production in vivo to be observed.

Due to the complex nature of force development in vivo, it is important not only to measure gross performance, but also to determine the unique characteristics of how force is produced. Some vertical jump measures are thought to be able to isolate such musculotendinous qualities [1]. Additionally, different jump types rely on mechanisms in vivo which relate to physiological factors important throughout different phases of sprinting. The ability to isolate the components of musculotendinous power in testing is of importance in order to determine the effectiveness of training strategies [72]. Additionally, without understanding the determinants of powerful movements, such as sprint speed, it is improbable that training techniques and protocols will be utilised optimally [2].

Sprint performance consists of several phases including early acceleration, acceleration/transition and top speed/speed maintenance [70; 96-98]. Each phase is biomechanically distinct and relies on different physiological determinants [98]. The terms used to describe these phases in the literature are not uniform. However, the concept of three distinct phases in a sprint is. For the sake of this review, the terms early acceleration (0-10m) [96; 99; 100], acceleration (up to approx. 40m) [100; 101] and speed maintenance (40m or greater) [99] are used.

The CMJ is one of the most commonly used jumps amongst sports scientists and practitioners [102]. It can be used to provide diagnostic information concerning RFD with a slow SSC and power production [3], which is related to the acceleration phase of sprinting [103]. This concept is supported by Smirniotous et al. [70] who found CMJ height to be more strongly correlated to 10-30m sprint speed than sprint speed over 0-10m or 60-100m.

RFD can be calculated by averaging force development by time, i.e. the slope of the force time curve, in the first significant rise of force before plateau in a squat movement [104]. Similarly, average RFD can be measured in jump movements by dividing PF by the time taken to achieve

PF from the onset of a jump movement [78]. There are many methods for calculating RFD, e.g. initial RFD, reactivity coefficient, acceleration gradient. Such measures follow the same or similar methods of calculation, but typically occur at different parts of the force-time curve [80].

Similarly, late phase force development can also be measured from a CMJ. In this case, however, RFD is not measured from the onset of a jump movement but during the later phase of a jump movement, i.e force development >200ms from the onset of force development [82]. RFD is calculated by dividing PF by the time taken to achieve PF from 200ms or >200ms after the onset of a jump movement. It is important to note that not all research has shown a strong relationship between RFD and dynamic performance [85]; however, this is most likely to be due to methodological difficulties in accurately measuring RFD [78]. These findings could also be explained by the poor reliability that is often seen with these measures [14; 16; 78; 102; 105].

The SJ is a measure of force development using a concentric-only contraction [1]. It is thought to isolate physiological characteristics which are important to early acceleration during a sprint movement, e.g. concentric contractile force and RFD [3; 73]. This is supported by Young et al. [3], who found stronger relationships between concentric force in vertical SJ performance and sprint speed over short distances than longer distances [3]. Additionally, Comfort et al. [69] found SJ height to be strongly related to 5m sprint performance ($r = 0.76$), and Wilson et al. [106] found RFD in SJ to be a better predictor of short sprint performance than RDF in CMJ.

Further, when a muscle is stretched prior to a contraction, it typically exhibits 12-18% greater contractile force than without a pre-stretch [107]. The prognostic usefulness of isolating concentric strength by removing SSC is questionable, as the majority of functional movements contain a preceding counter movement. On the other hand, isolating concentric-only contraction in power movements may help to shed light on the extent of the SSC effect on dynamic performance by comparing performance in CMJ and SJ tests [108].

The DJ is proposed to be a measure of fast SSC ability [1; 4; 70]. This is typically defined as SSC performance <250 milliseconds [107], and can be measured as contact time or jump distance during both horizontal and vertical drop jumps [8]. The DJ relies heavily on the elastic property of muscles and tendons in the SSC, a characteristic shared with sprint performance at high speed [3; 109]. Thus, the DJ ought to have a stronger relationship to sprint speed over longer distances. Holm et al. [2] supported this in finding CT in unilateral horizontal drop jump distance to be more strongly correlated to 10-25m ($r = 0.39$) than 5m ($r = 0.17$) or 10m ($r = 0.24$) sprint speed. Therefore, the SSC through DJ movements is believed to be strongly related to acceleration at high speed and speed maintenance.

Despite the volume of research into power tests such as the vertical jump, no clear conclusion as to what method and which variables consistently predict powerful actions in real performances can be drawn [72]. This is probably due to the complexity of force production in vivo and the unique biomechanical demands of various powerful actions. However, developing greater understanding of the relationship between musculotendinous characteristics in relation to functional performance is of diagnostic and prognostic value.

2.1.4 Horizontal jump tests of power

Despite the popularity of vertical measures of power, the majority of movements within many sports require power to be produced in both the vertical and horizontal plane of movement [6-8]. As such, the use of vertical measures of power alone is of limited face validity. Therefore, regardless of the ability of vertical jump measures to predict functional performance, it would seem that a combination of vertical and horizontal jump tests would be a more specific and valid means of determining lower limb dynamic ability than the exclusive use of vertical measures.

Maulder and Cronin [1] attempted to answer the question of whether vertical or horizontal measures of power were a more accurate predictor of functional performance than vertical measures alone. This research found horizontal measures of power, i.e CMJ, SJ and cyclical jump distance, to be better predictors of 20m sprint performance (r = -0.73 to -0.86) than height in equivalent vertical jumps (r = -0.52 to -0.73). Although a contact mat (Swift Performance) was used to determine jump height for vertical measures of power in this study, no indication has been given as to the mechanism by which horizontal jump distance was measured.

Further comparisons of vertical and horizontal jump measures as predictors of functional sports performance have found greater correlations between single leg countermovement jump (r = -0.65) and 10m sprint times in male subjects than the same jump in the vertical plane (r = -0.61) [7].

Nesser et al. [20] also found five-step horizontal jump distance to be a better predictor of 40m sprint speed (r = -0.81) than vertical jump height (r = -0.46). However, this study measured horizontal jump distance rather than those measurements pertaining to horizontal force profiling.

An additional consideration highlighted in the research undertaken by Nesser et al. [20] is the comparative advantage of unilateral power tests, in this case the five step horizontal jump, and bilateral tests of power such as the vertical jump. Although bilateral jumps are popular as tests of lower limb power, the majority of human movements involve unilateral force production in a combination of horizontal and vertical plane [7; 8]. As such, it seems counterintuitive to utilise vertical bilateral measures of power when many functional movements, including sprinting, utilise unilateral power production in both the vertical and horizontal plane [8]. It has been suggested that unilateral tests of power would seem to better represent such movement patterns [1]. This is supported in the research by Nesser et al. [20], who found a greater correlation between five step horizontal jump distance than vertical jump height and 40m sprint speed.

While the validity of unilateral tests is greater than bilateral jumps with regard to many functional movements, it is also important for tests of power to be reliable. Although questions have been raised about the reliability of unilateral power tests, these tests have been shown to have similar reliability to many bilateral tests [8; 19; 110].

The aforementioned studies are effective in showing that horizontal jump measures may be better predictors of sprint speed than vertical measures. However, as only jump distance was measured, no in-depth understanding of the strength characteristics important in predicting functional movement during horizontal jump testing has been obtained. Measurements such as mean and peak horizontal and vertical force, which may be measured using tri-axial force plates, allow better analysis of the kinetics produced during jump tests [2] and are believed to be the most accurate measurement of strength qualities in jump power tests [102]. Similar research measuring ground reaction force to observe strength qualities in horizontal jump tests of power may produce results with better prognostic and diagnostic qualities and allow greater insight into horizontal strength qualities.

Research of a similar nature has been conducted investigating relationships between single leg DJ ground reaction force, jump distance and sprint speed [2]. One study found peak and average horizontal ground reaction force divided by contact time to have greater correlations to sprint speed over 5-10m and 10-25m than the equivalent vertical measures [2]. Conversely, vertical measures of power more accurately predicted sprint speeds over 0-5m and 0-10m, although none of these measures had a greater correlation than $r = 0.40$. The factor with greatest correlations to sprint time over a range of sprint distances, however, was a combined measure of jump distance normalised to subject's height ($r = 0.44 - 0.65$) [2].

These findings question the comparative usefulness of force plate data to simple measures of performance, i.e. jump distance and subject height as a prognostic tool. However, because measures of average and peak ground reaction force were divided by contact time rather than time to PF, a true RFD measure was not calculated [2]. Additionally, impulse, or average force over a given time period, has received little attention from researchers and may be an effective predictor of performance of functional movements [80]. It may be that an accurate measure of RFD would have predicted sprint speed, particularly over 5-10m and 10-25m, more accurately than jump distance normalised to subject's height. Further research is required to determine this.

To date, very little research exists concerning the relationship between kinetic and kinematic variables, as measured through power profiling, in horizontal jump movements. It is therefore unclear whether power profiling in the horizontal or vertical plane of movement has stronger correlation to measures of functional performance, particularly sprint speed. It is also unclear whether it is vertical or horizontal jump measures that better differentiate between different types of muscular functions [1]. Moreover, very little research currently exists exploring the relationship between strength characteristics in the horizontal and vertical plane of movement. Further research into such questions would be valuable in determining the prognostic and diagnostic value of power profiling in the horizontal plane of movement and the potential cross over between horizontal and vertical training modalities. This would be of interest to both scientists and practitioners.

Finally, the majority of research in these fields to date has been carried out using recreationally trained subjects or moderately trained athletes as subjects. Very few studies have used high-performance or elite athletes to investigate the predictors of sprint speed over short distances, particularly in the horizontal plane of movement [4]. This too is an area of research that warrants further investigation.

2.1.5 Conclusion

The nature of power development in vivo is multi-faceted and complex, involving a number of contributing factors. As such, a range of methods to measure and distinguish between the factors contributing to power production in vivo have been developed and discussed in the literature. However, the majority of this research has addressed vertical measures of power. There is, therefore, a need for further research into aspects of horizontal power testing. Specifically, further research is required into the relationship between the isolated factors contributing to dynamic performance in the horizontal and vertical planes of movement. Research into the comparative strength of the relationship between horizontal measures of power, and vertical measures of power to sprint speed, muscle stiffness and muscle architecture also seems warranted.

2.2 SHORT TERM ENHANCEMENT

Prelude: It is important to explore methods to train and improve muscular strength and power. Although traditional training methods should not be discarded, novel approaches that may improve muscular performance to a greater extent than traditional training are continually being sought. One such method of interest is PAP or STE. STE may improve acute dynamic performance as well as chronic dynamic performance when utilised in training. This is currently an active area of research.

Considering the growing body of literature in this field, this literature review focuses on the aspects of STE most relevant to the topic of this thesis i.e. understanding and optimising vertical and horizontal force production for performance in team sport athletes. For broader reviews on the topic, the reader is referred to Tillin and Bishop [44]; Hodgson et al. [54] and Wilson et al. [49].

2.2.1 Introduction

New and innovative methods to improve muscular performance are continually being sought. One such method that has recently received a great deal of interest is PAP or STE [36-38; 40; 43]. This refers to an acute enhancement in muscular performance characteristics as a result of changes in contractile history, resulting in improved performance and/or training stimulus [36; 44]. This is typically achieved through the completion of a heavy conditioning stimulus prior to a dynamic movement [111; 112]. However, the exact mechanism by which acute enhancements in muscular performance occurs is unknown [43]. A number of physiological mechanisms are purported to contribute to STE.

Primary amongst these is the theory that maximal or near maximal contractions causes twitch potentiation through phosphorylation of myosin regulatory light chains [54; 113; 114]. This is thought to increase actin-myosin interactions sensitivity to Ca^{2+} released from the sarcoplasmic reticulum and allow greater ATP availability resulting in increased actin-myosin cross-bridging [54; 113]. Phosphorylation of regulatory light chains is also believed to enhance contractile ability by orienting myosin heads in such a way that cross bridge interaction is optimised [112].

Another theory is that neurological factors contribute to STE. Post activation depression [115; 116] and post tetanic potentiation [54; 117] of the H-reflex have been observed following a muscular contraction. It is theorised that this improves synchronisation of motor units and decreases pre-synaptic inhibition resulting in greater muscle fibre recruitment [112; 113].

Factors including changes in muscle-tendon stiffness [118], core temperature [119] and the hormonal response to training [120] have also been proposed as contributing to STE. To date, these and other emerging theories have limited empirical support. Therefore, although it is clear that STE can be achieved as a result of a conditioning stimuli, STE would appear to be complex and is affected by a range of neurological and muscular mechanisms which are not yet fully understood [113].

2.2.2 *Acute effects of STE*

That STE has the ability to improve acute performance is not disputed [49]. A number of studies show the effectiveness of STE in increasing acute dynamic ability and power [37; 38; 40; 121-126]. However, it is important to acknowledge that these findings are not consistent across the literature, as some of the studies utilised experimental protocols which failed to produce improvement in performance measures post condition contractions [46; 127-131]. Additionally, of those studies demonstrating STE, many report enhancement under some, but not all, tested conditions. For example Chatzopoulos et al. [37] found improvements in sprint speed over 30m five minutes after heavy (90% 1RM) squats, but not three minutes after these squats. Additionally, STE has been found to improve sprint time over 40m after heavy squats (3 x 90% 1RM), but no improvement was observed after a light CMJ (3 x 30% 1RM) [40]. In light of this, it is clear that acute muscular ability can be improved through STE. However, this relies on a number of procedural factors, including the type and intensity of stimulus and rest period prior to undertaking an explosive movement [44].

Fatigue plays an opposing role in vivo to the mechanisms proposed to enhance performance through STE. Although a conditioning stimulus potentiates subsequent muscular contractions, reduced muscular performance occurs concurrently due to fatigue [132; 133]. As such, any enhancement in physical performance is a balance between the positive potentiation and negative fatigue effects resulting from the contractile history of a muscle [38]. This balance is dynamic and changes over time. STE occurs if the effects of fatigue reduce at a greater rate than potentiation effects, resulting in improved muscular performance [44].

In a meta-analysis, Wilson et al. [77] found rest periods of seven to ten minutes post conditioning contraction to increase (effect size (ES) = 0.70) to a greater extent than rest periods of three to seven minutes (ES = 0.54) or greater than ten minutes (ES = 0.02). Although this finding is supported in other studies [49; 134], STE is complex and effected by the physiological attributes of the subject. The time course of fatigue and potentiation is a highly individual factor, and STE may not always occur to its greatest extent seven to ten minutes after a conditioning contraction or contractions for every individual. For example, Boullosa et al. [135] found the nature of the conditioning stimulus to effect the recovery period causing the greatest STE response. Within the same subject population, vertical jump peak power was found to be greatest after nine minutes of recovery post a set of 5RM half squats, but greatest after only one minute of recovery following a cluster set of half squats [135]. Additionally, Jo et al. [136] found 1RM back squat strength to be significantly correlated (r = -0.77) to rest duration for optimal STE. It seems that, under the same conditioning stimulus, stronger athletes require less recovery time to develop STE. As with many aspects of STE, it is acknowledged that the combination of volume and intensity of conditioning stimuli and the amount of rest required to elicit the greatest STE response is an active field of research [112].

STE is also affected by the physical attributes of any given individual [113]. Arguably the most important physiological factor effecting STE is the proportion of slow and fast twitch fibres [137]. As STE is thought to improve muscular performance through phosphorylation of regulatory light chains, and fast twitch muscle fibres have a greater proportion of light chain kinases than slow twitch fibres, a greater potentiation effect is thought to be obtained in fast twitch muscle [138]. This premise has been supported by the results of clinical animal trials showing phosphorylation of regulatory light chains to cause increased muscular force production [139; 140] and that this effect is more pronounced in fast twitch muscle fibres [141]. Therefore, it is believed that STE has a greater effect on highly trained or naturally dynamic athletes with more type two muscle fibres than on the general population [112; 137]. This is supported in the current body of literature, with a number of studies showing greater STE in subjects with more type two muscle fibres [137; 142; 143]. However some studies have shown no significant relationship between muscle fibre type and STE [144]. This may be explained by the fact that fast twitch muscle fibres not only produce greater potentiation, but also experience greater fatigue in response to a conditioning contraction [44].

Strength has also been found to affect STE. A greater STE response has been observed in elite versus recreationally trained athletes [49; 145] and recreational athletes versus untrained individuals [77.] For example, Gourgoulis et al. [123] found greater improvement in vertical jumping height (4.0%) in stronger subjects (1RM squat) than in subjects with lower maximal strength (0.42%) after five sets of squats at increasing loads. Additionally, a significant relationship between strength and peak power and CMJ height eight minutes post a set of 3RM squat has been reported (r = 0.49) [38]. It has been suggested that strength effects STE because of its linear relationship to type two muscle fibre [44]. That is to say, stronger subjects have greater amounts of type two muscle fibres (and cross sectional area) and this is what causes greater STE. Additionally, higher training levels may increase the effect of STE by moderating the subject's fatigue response [145].

The intensity of a conditioning contraction also affects STE. In the meta-analysis by Wilson et al. [49], conditioning contractions of moderate intensity (60-84% 1RM) are reported to have a greater effect on STE (ES = 1.06) than heavy (85-100% 1RM) conditioning contractions (ES = 0.31). It has been suggested that this is because moderate intensity conditioning contractions cause potentiation while minimising fatigue, resulting in greater STE than high intensity contractions, which cause potentiation with a greater fatigue response [49]. However, in this analysis, only 15 subjects were represented in studies with moderate intensity conditioning contractions [49]. A greater subject pool would seem warranted before this evidence could be considered conclusive.

Additionally, Wilson's findings are contradicted by those of Rahimi [125], whose research showed greater improvement in 40m sprint speed following two sets of four repetitions of heavy squats at 85% 1RM (-2.98%) compared to moderate squats at 70% 1RM (-2.77%) and low intensity squats at 60% 1RM (-1.9%). Further, Lowery et al. [126] found four reps of moderate intensity (70% 1RM) and three reps of high intensity (93% 1RM) back squats to produce similar improvements in jump height after four minutes of recovery (ES = 0.15 and 0.13 respectively). Moreover, after eight minutes of recovery, STE was still significant following high intensity (ES = 0.15) but not moderate intensity (0.90) back squats. As such, although low intensity conditioning contractions seem to be ineffectual [37; 125; 126], whether or not moderate or high intensity conditioning contractions are more effective at eliciting STE is not yet clear. It may be that this is dependent on additional factors such as the volume of training, recovery period, subjects' training status and the predominance of fast twitch muscle fibre within subjects.

A number of other factors including age and gender are thought to effect STE [44]. However, it is the opinion of the author that these factors are likely to be relevant only insofar as they relate to the aforementioned affecters of STE, i.e. training level, proportion of fast twitch muscle fibre and strength. Therefore, they are not discussed further in this review.

2.2.3 Chronic Effects of Short Term Enhancement

Although it is clear that STE can result in acute improvements in dynamic performance, the long term effects of utilising STE in training is less well defined [54]. STE may be achieved through complex training (a series of strength training sets followed by a series of biomechanically comparable dynamic exercises within the same training session) [53; 146] or contrast training (strength training sets alternated with sets of dynamic exercise) [64; 147]. It has been suggested that such acute improvements in dynamic performance during training may result in chronic performance gains [132].

In the existing literature, it has been demonstrated that complex strength and plyometric training can improve dynamic variables over traditional strength training [59-61; 148; 149]. For example, Kotzamanidis et al. [61] found that complex strength and power training had a greater positive effect on sprint speed and jump performance than weight training alone. Similarly, Adams et al. [148] found that jump height improved to a greater extent from complex squat and jump squat training (+10.6cm) compared to squat training alone (+3.3cm) in recreationally trained subjects. However, the principle of training specificity dictates that subjects who train dynamically will improve in those measures to a greater extent than subjects who do not train dynamically. These findings, then, are somewhat predictable and do not clearly demonstrate a training advantage from STE; rather, they confirm the principle of specificity.

Furthermore, a number of studies have failed to find significantly greater training improvements in strength and power measures as a result of complex training over traditional training [55-58; 150; 151]. This may be a result of utilising training protocols that fail to cause acute STE responses. For example, Duthie et al. [152] showed that, in female athletes, complex training caused diminished performance in the first set of dynamic training compared to traditional and contrast training, due to fatigue from repeated sets of heavy condition contractions[152]. This contradicts the findings of Wilson et al. [49], who found multiple conditioning sets to have a greater ES (0.66) than a single condition set (0.24). This was particularly true for highly trained subjects i.e. athletes. Additionally, however, complex training is unlikely to cause STE across several sets of dynamic training, as the effects of the mechanisms contributing to STE diminish over time; they are likely to be offset by fatigue from subsequent dynamic training sets. As such, complex training may not be the most effective vehicle by which to test the training effects of STE.

Contrast training, in which dynamic sets are alternated with sets of heavy strength movement [64], would seem to have greater potential to elicit a STE effect in each dynamic training set. It has been found that both one and two contrast training sessions a week can improve sprint speed and squat jump height over a six week training period in young elite soccer players [64]. As well as this, researchers have found strength-power contrast training to be more effective than speed-power contrast training protocols at improving lower limb dynamic performance measures, including the horizontal broad jump [153]. These studies show contrast training to be an effective strategy in improving dynamic performance. However, they fail to show that contrast training causes greater training adaptation than the same training stimuli implemented in a traditional or complex training program.

A handful of studies have addressed the comparative training effects of complex and contrast training. Mihalik et al. [57] found vertical jump height to improve as a result of both complex and contrast training in college-aged volley ball players over a 4 week period. However, no significant difference in change was found between the complex and contrast training groups. Burger [154] also found no significant difference between complex and contrast training in a range of upper and lower body strength and power measures in division 1A football players. It is important to note, however, that, although the aim of both complex and contrast training is to maximise power in dynamic movements through potentiation, [147] these studies do not prove acute STE within training sessions. A training protocol proven to induce STE within the population being studied is required; thereby these studies fail to adequately address the question of the training effect of STE.

Although both complex and contrast training have been shown to be effective in developing muscular dynamic ability, current training studies have failed to adequately demonstrate that STE is being achieved during complex or contrast training. What has yet to be explored is whether utilising a proven STE strategy, through complex and/or contrast strength and power training, will result in greater training effect over time than the same training exercises undertaken without STE. This would also be of great interest to strength and conditioning practitioners.

2.2.4 Effects of Short Term Enhancement on Jump Performance

A number of studies have investigated the effect of STE on vertical jump performance [41; 122; 123; 135; 155-157]. For example, vertical jumping has been found to improve after five sets of squat at increasing load (4.0%) [123] and at the mid-point (5.8%) and end (5.9%) of a snatch pull training protocol [156]. Additionally, maximum isometric voluntary contraction in the squat has been found to improve sprint and vertical jump ability [122]. Young et al. [158] also found a significant improvement in loaded CMJ height after 5RM squat (2.8%), but not after loaded CMJ.

The majority of these studies focus on jump height to measure jump performance. However several studies have also looked at the effect of STE on kinetic and kinematic variables, such as peak power, RFD and PF during the vertical CMJ [131; 135; 147; 155; 157]. Most of this research has been successful in demonstrating STE, although Pearson et al. [131] failed to demonstrate an improvement in peak power or RFD after isometric contractions of varying lengths. This is likely to be due to methodological variation between studies.

Measuring variables such as these can be useful in isolating the mechanisms in vivo that contribute to dynamic performance. Within the existing research, however, there is a lack of information concerning the effect of STE on DJ performance, a measure of fast SSC ability, [1; 4] and SJ, a measure of concentric force development [108]. Further research into the effects of STE in vertical DJ and SJ would be of interest.

There has been very little research carried out to date into the effect of STE on horizontal jump performance. Additionally, very few attempts have been made to isolate and compare the effects of STE in the vertical and horizontal planes of movement, although Scott and Docherty [46] have investigated the effect of STE on vertical and horizontal countermovement jumps. In this study, no significant change in jump performance was found in either plane of movement after pre-loading. It has been suggested that the lack of positive effect of STE in this study was due to the experimental protocol. Given the lack of findings in either plane of movement, this study is of limited usefulness. In another study, Kovavić et al. [41] found an STE after a maximal isometric contraction to have a positive effect on vertical CMJ, but not horizontal CMJ performance.

In contrast, Ruben et al. [52] found a back squat protocol utilising four sets of ascending load to cause STE in repeated horizontal hurdle jumps. Further, as sprint speed has been shown to be positively affected by STE [37; 40; 122], and sprint speed utilises power in both the vertical and horizontal plane of movement, it may be assumed that STE improves force in both planes of movement. Indeed, very recently, Evetovich et al. [124] found statistically significant improvements post parallel squat in both vertical (Pre = 61.9 ± 12.3 cm; Post = 63.6 ± 11.6 cm) and horizontal (Pre = 93.7 ± 11.0 cm; Post = 95.9 ± 11.5 cm) jumps.

Of the research that exists to date into the effects of STE on horizontal jump performance, none has attempted to isolate the physiological mechanisms contributing to dynamic performance by measuring kinetic and kinematic variables. Furthermore, considering the limited and contradictory nature of findings regarding the effects of STE on horizontal jump performance and power production in the horizontal plane of movement, more research would seem warranted.

2.2.5 Conclusion

Research into STE has been effective in showing acute improvements in power. However, it is also clear that STE is complex and highly individualised, being affected by the physiological characteristics of subjects including fibre type and training level. Additionally the subject's fatigue response plays a critical role in determining if and when STE will occur post a conditioning contraction. Because of this, many studies fail to demonstrate STE. To date, attempts to identify the training effect of STE through complex and contrast training have been flawed, as they have not utilised training protocols proven to induce STE in populations of interest.

Only a limited amount of research exists concerning the effect of STE on kinetic and kinematic variables during DJ and SJ performance. Moreover, research attempting to determine the effect of STE on kinetic and kinematic variable with horizontal jump movements has not yet been undertaken. Such research may be valuable for gaining a fuller understanding of the effects of STE in vertical jumps and movements in the horizontal plane.

CHAPTER 3

RELIABILITY OF VERTICAL AND HORIZONTAL POWER PROFILING IN WELL TRAINED RUGBY PLAYERS

Prelude: Before utilising kinetic and kinematic variables from vertical and horizontal jumps in future research or in the field, such measures must first be shown to be reliable. This is particularly important as limited research exists concerning the reliability of these measures in horizontal jumps. Therefore the purpose of this chapter was to determine the reliability of the kinetic and kinematic variable from both vertical and horizontal jumps relevant to power profiling.

3.1 Abstract

Purpose: To determine the reliability of vertical and horizontal power profiling measures in well trained rugby players. *Methods:* A test re-test study design was implemented to determine the intraclass correlation coefficient (ICC) and coefficient of variation (CV) of kinetic and kinematic variable in bilateral and unilateral vertical and horizontal CMJ, SJ and DJ. *Results:* PF and MF were reliable in all vertical (ICC range: 0.82 – 0.97; CV range: 2.1% - 9.2%) and horizontal jumps (ICC range: 0.79 - .97; CV range: 6.6% - 9.1%). In contrast, PP was reliable in all vertical jumps (ICC range: 0.70 – 0.88; CV range: 6.2% - 9.9%) but generally unreliable in horizontal jumps (ICC range: 0.77 - 0.94; CV range: 9.9% - 19.6%). RFD and early RFD were unreliable in both vertical (ICC range: 0.74 - 0.96; CV range: 10.5% - 26.3%) and horizontal jumps (ICC

range: 0.73 - 0.95; CV range: 8.9% - 16.2%). *Conclusion:* Vertical kinetic and kinematic measures were shown to be reliable with the exception of RFD and early RFD. Horizontal measures of force were also shown to be reliable in the CMJ, SJ and DJ and can be used in future power profiling tests. Both PP and RFD were largely unreliable in horizontal jumps therefore caution must be used with such measures.

3.2 Introduction

Power profiling tests have shown that athletes' dynamic ability is affected by movement type and external load, which in turn can impact kinetic and kinematic measures [159]. The ability to assess how athletes produce force and to isolate factors contributing to power production allows for a more detailed understanding of an athlete's strengths or deficiencies. The ability to differentiate between kinetic and kinematic measures such as PP, PF, MF, peak velocity and RFD gives greater prognostic and diagnostic information for more precise observation of training effects and development of optimal training programs [1].

Kinetic and kinematic measures obtained during different types of jumps may be used to isolate muscular qualities. For example, the CMJ is able to provide diagnostic information regarding power production and RFD with a slow SSC [3]. Additionally, the SJ, by removing the SSC component is a measure of power and force production involving only a concentric contraction [1]. Additionally, the drop jump (DJ) is an effective measure of fast SSC ability [1; 4].

The CMJ, SJ and DJ are amongst the most widely used exercises to assess lower limb dynamic ability [1]. The vertical CMJ [7; 11-15], SJ [11; 13; 15; 16] and DJ [11; 17; 18] have previously been reported to be reliable in a number of different populations. However, kinetic and kinematic variables measured during such vertical jump movements may have limited prognostic value as many sports require force to be produced in both the vertical and horizontal plane of movement [6-8]. The inclusion of horizontal, or a combination of vertical and horizontal measures of power, may have greater face validity for sports [2]. Furthermore, CMJ, SJ and cyclical jump distance has been found to better predict 20m sprint performance than jump height in equivalent vertical jump [1] and single leg CMJ distance has been found to have a greater correlation to 10m sprint times than single leg CMJ height [7]. Nesser et al. [20] also found five step horizontal jump distance to be a better predictor of 40m sprint speed than vertical jump height.

It has been suggested that unilateral assessments are more closely related to functional movement than bilateral assessment and may provide better training information [1; 7]. Indeed, unilateral horizontal CMJ distance has been found to have a greater correlation to 10m sprint time compared to the vertical CMJ height [7]. Additionally, unilateral horizontal CMJ, SJ and cyclical jump for distance have been shown to have a greater correlation to 20m sprint speed than equivalent vertical measures[1].

The reliability of a range of horizontal jump types has been previously reported when measuring jump distance including unilateral CMJ [7], unilateral horizontal CMJ, SJ, repetitive jump [1] and horizontal DJ [17]. However, such measures of distance do not isolate the kinetic or kinematic variables contributing to the jump performance [2]. Furthermore, there is limited research investigating kinetic and kinematic variables in the horizontal plane of movement. Stalbom et al.[19] reported horizontal PF, MF, peak impulse, mean impulse and contact time to be reliable in the unilateral horizontal DJ (ICC 0.90 - 0.96, coefficient of variation (CV) (4.7% - 5.9%). However, it appears that the reliability of such kinetic and kinematic measures has not been reported for unilateral or bilateral CMJ or SJ or bilateral DJ.

To date, a comprehensive horizontal power profiling test battery with the ability to determine and reliably differentiate between kinetic and kinematic variables has not been developed. Therefore the aim of this study was to determine the reliability of horizontal and vertical power profiling measures in well trained rugby players.

3.3 Methods

3.3.1 Subjects

Nineteen well trained male rugby union players (mean ± SD; age 20.2 ± 2.1 years; 1RM box squat 180.2 ± 18.4 kg; mass 104.4 ± 12.9 kg; height 183.7 ± 7.6 cm) competing in New Zealand's Senior Club competition were recruited for this study. The study was approved by Auckland University of Technology Ethics Committee. Written informed consent was obtained from the subjects prior to participation. Subjects had a minimum training age of two years (mean 4.3 ± 1.1 years) in a structured strength and conditioning program and were familiar with plyometric and explosive jump training.

3.3.2 Design

To determine the reliability of kinetic and kinematic variables in power profiling, three sessions were performed. These included one familiarisation and two testing sessions in which data was recorded. Each session consisted of a standardised warm up and prescribed dynamic lower limb stretches followed by a comprehensive power profiling test. The familiarisation session was administered in the same way as the testing sessions although no data was recorded from this session.

Testing sessions consisted of a set of three jumps of both unilateral and bilateral vertical CMJ, SJ and DJ as well as three sets of unilateral and bilateral horizontal CMJ, SJ and DJ. The jump order, i.e. unilateral or bilateral, jump type and jump direction (vertical or horizontal), was randomised. Unilateral jumps were performed using the subjects' dominant leg.

3.3.3 Methodology

Subjects reported to each testing session at the same time of day to minimise variation in performance due to diurnal variation [160]. Test sessions were completed 48 hours apart within a normal training week and no loaded exercise was completed in the 24 hours before testing. Testing took place during the in-season. The familiarisation session was performed on a Monday with testing session taking place on Wednesday and Friday, with equal time allowed between club skills training sessions (Tuesday and Thursday) and jump testing. A standardised warm up of ten minutes of cycling (at 150W) on a Cycle Ergometer followed by five minutes of prescribed lower limb dynamic stretches was completed. Dynamic stretches of the groin, quadriceps, calves, hip flexors, gluteals and hamstrings were performed for 30s each side. Data was collected using the Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) at a sampling rate of 500Hz. Variables that were derived from force plate data and recorded for subsequent analysis included vertical force, power, velocity and impulse and horizontal force and power. These variables were obtained using a custom designed software program ForceBoardSW - 1.3.19 (Objective Design Limited, Auckland, New Zealand).

Each jump type was tested in a set of three jumps. There was 30s rest between each jump within the set of two to three minutes rest between each set of jumps. Both vertical and horizontal CMJ consisted of a self-selected countermovement depth immediately followed by a jump of maximal intensity [7]. Instructions were given to jump for maximal height or distance in the vertical and horizontal CMJ respectively. All jumps were performed with no arm swing. During the familiarisation session jumps of all types were observed by the tester to ensure correct jump technique.

A three second static hold at a 90° knee angle was required for both horizontal and vertical SJ followed by a jump of maximal intensity in either the vertical or horizontal plane of movement [161]. No additional eccentric dip was allowed after the static hold. Any eccentric dip immediately preceding concentric movement resulted in that test being disqualified and repeated after a 30s rest.

The bilateral DJ was performed from a 40cm height and the unilateral DJ was performed from a 20cm height [109]. Subjects were instructed to minimise contact time on the force plate while maximising jump height or distance. Jump order was randomised using the random function in Microsoft Office Excel (Microsoft Corporation, Washington, United Sates of America).

Both PP and PF were calculated by recording the largest vertical power or force for vertical jumps and largest horizontal power or force for horizontal jumps. MF was calculated as the mean of all force data recorded from the start of a jump movement until PF. Vertical force was used to mark the start of both vertical and horizontal jumps. The start of the CMJ was determined as the lowest point in vertical force during the eccentric phase of movement [162]. The start of the SJ was determined as an increase of 10N above the body weight of the subject at the beginning of the concentric phase. The force-time trace was analysed to ensure that there was no small amplitude countermovement prior to the concentric phase of the jump [105]. The start of the DJ was determined as force exceeding 10N at initial foot contact.

RFD was calculated by dividing PF by the time taken to achieve PF from the onset of the jump movements [78]. Early RFD development was calculated from force at 100ms after the onset of the movements [82]. In the DJ contact time was determined as the time between vertical force exceeding 10N at initial foot contact with the force dropping below 10N. PF divided by contact time (PF/CT) and MF divided by contact time (MF/CT) were also calculated.

Peak velocity and impulse were calculated by recording the largest vertical velocity or impulse in vertical jumps. Mean velocity and impulse were calculated as the mean of all velocity or impulse measures recorded from the start of a jump movement until peak velocity or impulse.

Time to peak velocity was calculated by subtraction of the time at the start of a jump by the time at peak velocity. Peak and mean force measures were used across all jump types.

3.3.4 Statistical Analysis

Of the three jumps of each type completed in each test session, the two jumps with greatest PF were used for further analysis. The average of the two jumps was then calculated for each variable. The within subject test - re-test reliability between the two trials of each measure was calculated using an intraclass correlation coefficient (ICC) [163]. Data was log transformed for analysis to account for non-uniformity in the error. Standard error and CV as a percentage, was calculated to give a measure of the dispersion of data collected and the stability of measurements between trials [8; 163]. A CV of <10% was considered to be the highest acceptable variation for reliability [11; 162].

3.4 Results

Vertical PF and MF was shown to have higher reliability than their horizontal equivalents with a CV range of 5.4% - 6.4% for vertical CMJ and 6.6% - 7.6% in horizontal CMJ (Table 3.1). Similarly CV for PF and MF in the SJ ranged from 2.1% - 5.5% in vertical jumps and from 7.6% - 8.8% in horizontal jumps (Table 3.2). The ICC's for vertical and horizontal jumps ranged from 0.79-0.97 (Table 3.3).

Table 3.1 Reliability of vertical and horizontal *counter movement jump* kinetic and kinematic variables

		Vertical				Horizontal			
		ICC	Mean	Typical Error	CV%	ICC	Mean	Typical Error	CV%
Bilateral	Peak Power (W)	0.74	6539	725.7	9.8	0.88	1148	94.17	11.5
	Peak Force (N)	0.90	2584	141.7	5.4	0.82	1002	71.68	7.5
	Mean Force(N)	0.92	1590	93.88	6.0	0.91	492.9	35.31	7.6
	RFD (Ns)	0.96	6921	1000	14.4	0.80	1591	184.0	14.7
	Early RFD (Ns)	0.93	6935	1053	13.3	0.88	2072	258.9	14.3
Unilateral	Peak Power (W)	0.84	3810	213.5	6.2	0.77	690.4	97.67	14.4
	Peak Force (N)	0.87	2038	123.0	6.4	0.84	738.6	49.7	6.8
	Mean Force(N)	0.89	1436	81.00	6.1	0.95	396.1	23.2	6.6
	RFD (Ns)	0.74	3544	743.1	26.2	0.87	1292	160.9	12.8
	Early RFD (Ns)	0.86	4888	982.9	26.3	0.94	1110	131.3	14.3

Abbreviations: RFD, rate of force development; Early RFD, early rate of force development.

Table 3.2 Reliability of vertical and horizontal *squat jump* kinetic and kinematic variables

		Vertical				Horizontal			
		ICC	Mean	Typical Error	CV%	ICC	Mean	Typical Error	CV%
Bilateral	Peak Power (W)	0.88	5929	463.4	8.8	0.94	970.5	98.66	12.1
	Peak Force (N)	0.92	2326	80.75	3.6	0.94	955.4	73.87	8.8
	Mean Force(N)	0.97	1687	38.19	2.1	0.97	516.8	35.82	8.7
	RFD (Ns)	0.82	3811	513.3	13.5	0.76	1932	245.8	13.5
	Early RFD (Ns)	0.82	3869	567.2	14.8	0.94	1458	195.9	13.2
Unilateral	Peak Power (W)	0.76	3480	225.3	6.5	0.80	615.9	88.35	16.4
	Peak Force (N)	0.88	1855	111.5	5.5	0.95	691.4	48.72	8.4
	Mean Force(N)	0.90	1402	64.45	4.4	0.97	400.0	27.69	7.6
	RFD (Ns)	0.83	1825	170.1	10.5	0.73	1081	93.09	8.9
	Early RFD (Ns)	0.80	1647	217.2	15.1	0.83	755.6	93.19	14.9

Abbreviations: RFD, rate of force development; Early RFD, early rate of force development.

In all vertical jump types PP was shown to have ICC's of 0.70 – 0.88 and CV's of 6.2% - 9.9%. Conversely, horizontal jump PP measures had ICC values of 0.77 - 0.94 and CV values of 9.9% - 19.6%.

For RFD, only in the unilateral horizontal SJ was the ICC>0.70 and CV<10% (ICC: 0.73. CV: 8.9%). RFD and early RFD for all other vertical jumps had low reliability (ICC range: 0.74 - 0.96; CV range: 10.5% - 26.3%) and horizontal jumps (ICC range: 0.73 - 0.95; CV range: 8.9% - 16.2%).

Both vertical and horizontal DJ, contact time had reliability values of ICC>0.70 and ICC<10% (Table 3.3). For PF and MF calculated relative to contact time, the ICC range was 0.85 - 0.94 and CV range 9.7% - 13.4%. For all velocity and impulse measures in the vertical jumps the ICC range was 0.71 - 0.94 and CV range: 3.1% - 9.9% (Table 3.4).

Table 3.3 Reliability of vertical and horizontal *drop jump* kinetic and kinematic variables

		Vertical				Horizontal			
		ICC	Mean	Typical Error	CV%	ICC	Mean	Typical Error	CV%
Bilateral	Peak Power (W)	0.73	14454	1570	9.9	0.90	1110	112.3	9.9
	Peak Force (N)	0.87	4562	363.2	8.7	0.79	1146	78.2	7.2
	Mean Force (N)	0.82	2527	219.0	9.2	0.92	528.5	51.9	8.9
	RFD (Ns)	0.92	46828	5080	12.9	0.90	6673	902.5	13.4
	Early RFD (Ns)	0.77	56689	7200	14.1	0.94	7665	706.9	12.5
	Contact Time (s)	0.93	0.282	0.017	6.1	0.88	0.309	0.08	6.2
	Peak Force / CT (N)	0.90	17140	2306	12.3	0.85	3833	441.6	11.3
	Mean Force / CT (N)	0.93	9419	1012	11.5	0.92	1711	226.6	12.7
Unilateral	Peak Power (W)	0.70	7263	754.6	9.3	0.88	510.4	82.99	19.6
	Peak Force (N)	0.90	2989	242.1	8.4	0.89	685.7	47.40	7.6
	Mean Force (N)	0.92	1757	100.8	6.6	0.91	359.4	31.12	9.1
	RFD (Ns)	0.91	26012	3359	14.7	0.89	3845	510.2	16.2
	Early RFD (Ns)	0.77	34174	3985	13.9	0.95	4617	685.2	11.4
	Contact Time (s)	0.81	0.342	0.024	6.7	0.73	0.380	0.033	8.8
	Peak Force / CT (N)	0.94	7743	827.5	9.7	0.86	1864	196.8	12.5
	Mean Force / CT (N)	0.92	5334	529.3	9.8	0.88	949.9	107.2	13.4

Abbreviations: RFD, rate of force development; Early RFD, early rate of force development; CT, contact time.

Table 3.4 Additional vertical countermovement, drop and squat jump kinematic and kinetic variables

		Counter Movement Jump				Drop Jump				Squat Jump			
		ICC	Mean	Typical Error	CV%	ICC	Mean	Typical Error	CV%	ICC	Mean	Typical Error	CV%
Bilateral	Peak Velocity (m/s)	0.79	2.968	0.172	5.8	0.74	4.579	0.284	6.6	0.72	2.697	0.161	6.3
	Mean Velocity (m/s)	0.93	0.768	0.067	8.6	0.73	2.106	0.156	8.2	0.92	1.063	0.047	4.5
	TT Peak Velocity (s)	0.93	0.411	0.035	8.6	0.84	0.244	0.025	9.6	0.75	0.391	0.026	6.8
	Peak Impulse (Ns)	0.76	310.0	23.27	7.2	0.71	426.1	36.41	8.4	0.80	275.8	11.91	4.3
	Mean Impulse (Ns)	0.91	82.48	7.23	9.0	0.76	206.0	16.35	8.5	0.87	107.9	5.73	5.1
Unilateral	Peak Velocity (m/s)	0.85	2.22	0.08	3.7	0.84	3.21	0.18	5.7	0.92	2.166	0.153	6.0
	Mean Velocity (m/s)	0.91	0.567	0.035	6.6	0.80	1.40	0.11	8.3	0.92	0.862	0.071	7.9
	TT Peak Velocity (s)	0.80	0.465	0.045	9.9	0.82	0.288	0.022	7.6	0.77	0.493	0.031	6.8
	Peak Impulse (Ns)	0.93	226.3	7.34	3.1	0.76	324.1	20.02	7.7	0.94	223.4	13.86	6.0
	Mean Impulse (Ns)	0.93	57.79	4.49	7.7	0.81	142.4	11.97	8.6	0.93	88.94	6.75	7.7

Abbreviations: TT, time to i.e. time to peak velocity.

3.5 Discussion

The purpose of this study was to determine the reliability of horizontal and vertical power profiling measures in well trained rugby players. The results showed that although many horizontal power profiling measures were reliable, the kinetic and kinematic variable measured during vertical CMJ, SJ and DJ tended to have a greater number of reliable measures than their horizontal counterparts. This does not discount the potential usefulness of reliable horizontal kinetic and kinematic measures (e.g. PF, MF in unilateral and bilateral CMJ, SJ and DJ), particularly considering horizontal jump performance has potentially greater face validity to many functional movements and that some horizontal jump types have been shown to have stronger correlation to sprint speed than vertical jump performance [1]. It does however indicate that careful consideration is required as to the type of test and variables selected when investigating performance capabilities of athletes.

As vertical CMJ, SJ and DJ are amongst the most widely used exercises used to assess lower limb power [1] it seems likely that the majority of athletes are more familiar with vertical jumps. It is possible that greater reliability in vertical jump measures may be a product of greater familiarity with these movements. When subjects are not familiar with a test, systematic error may be caused as subsequent test improve due to a learning effect. This results in reduced reliability. However, no clear trend of improvement in performance from test to test was observed in horizontal jump data. As such, an assumption that the smaller number of reliable measures in horizontal jump movements is caused by a lack of familiarity with horizontal jump movement in the subject population does not seem to be well founded. This may in fact reflect sample error.

The present research indicates that RFD in well trained rugby players is not reliable in either the vertical or horizontal jumps. RFD is thought to be important as many critical sporting movements take less than 250ms, which does not allow enough time to reach maximal force [83; 84]. As such, the ability to produce force quickly, or the RFD, allows greater force and velocity to be produced in such time limited movements. Measures of RFD have been shown to be reliable in power cleans [164] but very few studies have found RFD measures to be reliable in jump movements[16]. Indeed, the majority of studies indicate that measures of RFD are unreliable in vertical jump movements. This includes peak RFD in CMJ [102], maximum RFD in loaded and unloaded CMJ [105], peak and mean RFD in both the concentric and eccentric phase of CMJ in both men and women [14], peak RFD in loaded and unloaded SJ [16] and peak and mean RFD in CMJ and SJ [78]. In previous studies the CV has been found to be as high as 35.6% and 39.9% in physically active men and women performing CMJ [14]. However, until now, no research had determined the reliability of RFD in horizontal jumps. These too were found to be unreliable. Although there are a variety of methods for calculating RFD it seems that, too date, none seem to demonstrate acceptable reliability in jumping. The current research demonstrates that RFD was also unreliable in horizontal jump movements.

The PF/CT and MF/CT were calculated as previous research has shown PF/CT in horizontal unilateral drop jumps to have significant correlation to sprint speed over 25m than PF alone [2]. Although PF, MF and contact time were shown to be reliable in both horizontal and vertical unilateral and bilateral DJ, PF/CT and MF/CT were found to be generally unreliable in other jump types. This is likely due to the compounded error from combining two variables. However, considering that the PF/CT and MF/CT measures were of similar reliability to some other jump types (ICC 0.85 - 0.93, CV% 11.3 - 12.5), it is possible, with greater subject numbers, PF/CT and MF/CT may be found to be reliable. Further research into these measures would seem to be warranted.

Velocity and impulse measures in vertical jumps power profiling measures were shown to be reliable in developmental rugby players. Such measures were unable to be calculated in the horizontal plane of movement and were not investigated in this study. However, some significant correlation have been found between vertical impulse in horizontal DJ and sprint speed [2] and peak vertical velocity in vertical CMJ and five meter sprint speed [93]. As such, further research into the reliability of velocity and impulse measures in the horizontal plane of movement should also be investigated.

3.6 Practical Application

The use of power profiling to improve and guide performance programs in athletes is becoming more widespread. Arbitrary cut-off points for reliability are often presented in the literature but it is important for practitioners to use measures that are as reliable as possible. As high reliability was shown for PF and MF in the horizontal jumps tested, i.e. CMJ, SJ, DJ, these horizontal measures can be used with confidence by coaches and athletes in power profiling. Conversely, the lack of reliability of RFD and early RFD observed using this methodology and cohort of athletes in both vertical and horizontal jumps and PP in horizontal jumps show that these kinetic variables should not be utilised unless reliable testing and calculation protocols can be developed. The findings of this research indicate that the variables measured and used to guide the direction of an athlete's training program require careful consideration.

3.7 Conclusion

This study showed that, PF and MF are reliable kinetic measures in both unilateral and bilateral horizontal CMJ, SJ and DJ. These measures can be used alongside their vertical counterparts in future power profiling with confidence. RFD and early RFD were found to be unreliable in both vertical and horizontal unilateral and bilateral jumps. Additionally, PP was found to be unreliable in horizontal but reliable in vertical bilateral and unilateral jumps. Measures of velocity and impulse were found to be reliable in vertical unilateral and bilateral jumps.

CHAPTER 4

RELATIONSHIP BETWEEN VERTICAL AND HORIZONTAL JUMP VARIABLES AND MUSCULAR PERFORMANCE IN ATHLETES

Prelude: Having determined that many kinetic and kinematic variables in vertical and horizontal power profiling were reliable, the relationship between such variables and aspects of functional performance could be explored with confidence. Determining these correlations is of prognostic and diagnostic value, allowing sports scientist's and practitioner's greater detail in testing and the knowledge regarding the likely transferability of jump training to sprint performance.

4.1 Abstract

This study investigated the relationship between vertical and horizontal measures in bilateral and unilateral CMJ, DJ and SJ and sprinting speed and muscle architecture of both the vastus lateralis and gastrocnemius. Subjects (n = 17) completed a 30m sprint test, muscle stiffness test; ultrasound measures and a jump testing session. Measures of horizontal peak and mean force, in both bilateral and unilateral jumps, tended to have greater relationships to sprint speeds (R^2 = 0.13 to 0.58) than peak and mean force in the vertical plane (R^2 = 0.01 to 0.50). Vertical velocity variables also showed some large and very large correlations to sprint speed (R^2 = 0.06 to 0.64). Unilateral measures of velocity tended to have larger correlations to sprint performance than their bilateral counterparts across all jump types and peak and mean velocity in SJ showed large and very large correlations to sprint speed (bilateral R^2 = 0.23 to 0.64; unilateral 0.39 to 0.57). Few large correlations were found between muscle stiffness measures, muscle architecture and kinetic and kinematic variables in either vertical or horizontal jumps. The present findings

suggest that sport scientists and strength and conditioning practitioners concerned with the prognostic value of kinetic variables to functional movements such as sprint speed should also use horizontal jumps in addition to vertical jumps in testing and training.

4.2 Introduction

The vertical CMJ, SJ and DJ are amongst the most widely performed movements to assess lower limb power [1]. Despite the popularity of vertical jumps as a test of lower limb power, many sports require force to be produced in both the vertical and horizontal plane of movement [6-8]. As such, it has been suggested that the prognostic value of kinetic and kinematic measures taken from vertical jump movements to actual sporting performance is of limited value [6; 7]. The use of horizontal, or a combination of vertical and horizontal measures of power, may have greater face validity to sporting performance.

A limited amount of research has been undertaken on the relationship between horizontal jump distance and sprint speed [4; 20]. Research indicates that measures of horizontal jump distance are reliable and may be equally or more effective at predicting functional sporting movements than vertical jump measures [1; 7; 20]. However, measures such as jump distance do not isolate what kinetic or kinematic aspects contribute to jump performance [2]. Cronin and Hansen [4] found significant correlations between both vertical and horizontal force measurements in unilateral horizontal DJ compared to sprint speed over short distances. However, to the author's knowledge no comprehensive study has been undertaken to determine the relationship between kinetic variables such as MF and PF in other horizontal jump types e.g. CMJ, SJ and bilateral DJ.

Additionally, sprint performance relies on different physiological factors throughout different phases of a sprint i.e. acceleration at different speeds and maintenance of top speed [109]. For example, early acceleration is thought to be heavily dependent on concentric contractile force and RFD [73]. Similarly, jumps of different types rely on different physiological characteristics e.g. SJ relying on concentric contractile force and RFD [4]. As such, different jump types may be utilised to predict performance characteristic during sprinting. Furthermore, different types of plyometric and jump movements may be included in training programs in order to improve specific physiological characteristics contributing to sprint performance [165].

Muscle stiffness plays a unique and important role in developing muscular force and determining the capacity of a muscle to produce powerful movements [24; 25]. Muscle stiffness is the muscles ability to resist change in length when subjected to a force [22]. This plays an important role in optimising dynamic movements, speed and stability during tasks such as running and jumping [24; 26]. Additionally, tendons are thought to act as a spring in vivo and tendon stiffness is also thought to be important in optimising dynamic performance [23]. Significant correlations between tendon stiffness and jump performance have been found [23; 26]. However, the relationship between muscle and joint stiffness and kinetic and kinematic variables in vertical and horizontal jumping movements has received limited research.

Of further interest is muscle architecture and its relation to sprint speed [27]. Fascicle length is thought to be proportional to the maximal voluntary contraction velocity of a muscle and pennation angle is thought to dictate the proportion of force transmitted from a muscular contraction to the tendon [28]. Fascicle length has been found to be greater in sprint trained athletes when compared to distance runners [32], and in young men when compared to elderly men [31]. Furthermore, Kumagai et al. [30] found 100m sprinters with personal best times of 10.00 to 10.90s to have greater muscle thickness and lesser fascicle pennation angle in several lower limb testing sights than those with personal best times of 11.00 to 11.70s. As such, it is clear that a relationship exists between fascicle pennation angle, fascicle length and muscle thickness and functional performance. However the relationship between these measures and kinetic and kinematic measures in vertical and horizontal jumps has not yet been explored.

Determining the relationship between not only jump height and distance but the kinetic and kinematic variables that contribute to power production in these jumps would give greater prognostic and diagnostic value for strength and conditioning practitioners. No previous research has determined the relationship of kinetic and kinematic variables in the vertical and horizontal CMJ, DJ and SJ and functional performance. Therefore the aim of this study was to determine the relationship between kinetic and kinematic measures in both bilateral and unilateral CMJ, DJ and SJ in the horizontal and vertical plane of movement and sprints speeds over 5m, 10m, 20m and 30m, lower limb muscle stiffness and fascicle angle, and fascicle length of both the vastus lateralis and gastrocnemius.

4.3 Methods

4.3.1 Experimental Approach to the Problem

The relationship between kinetic and kinematic measures in various jump types and functional performance measures was determined over three testing sessions. The first session included a 30m sprint test, an assessment of lower limb stiffness and familiarisation of all jump types. Sprint speed and muscle stiffness was measured in a randomised order after the standardised warm up. The second session required the subject to undergo ultrasound imagery to allow the determination of muscle pennation angle and fascicle length at specific points on the vastus lateralis and gastrocnemius of the dominant leg. The third testing session consisted of performing three horizontal and three vertical CMJ, SJ and DJ in a randomised order. Subjects completed the first and third testing session at the same time of day seven days apart, while the second test session was completed in the morning at a date convenient to the subjects within the seven day period between the first and third tests.

4.3.2 Subjects

Seventeen highly trained male rugby union players (age = 20.1 ± 2.3 years; mass = 102.3 ± 13.5kg; 1RM back squat = 182.5 ± 20.1kg; sprint speed 5m = 1.04 ± 0.07s; 10m = 1.80 ± 0.12s; 20m = 3.12 ± 0.21s; 30m = 4.40 ± 0.34s; muscle stiffness = 24.78 ± 9.70 $kN.m^{-1}$) competing in Senior Club competition were recruited for this study. The study was approved by the Auckland University of Technology Ethics Committee. Written informed consent was obtained from the subjects prior to study participation. All athletes were over the age of 18 (age = 18 to 28 years). Subjects had a minimum training age of two years in a structured strength and conditioning program and were familiar with plyometric and explosive jump training and sprinting.

4.3.3 Procedures

This investigation was conducted during an "unloading" period during the off-season where no structured weight lifting was prescribed. Subjects participated in normal club rugby skills training during the testing period. Subjects were instructed not to participate in strenuous exercise in the 24 hour period leading into training sessions. Within subjects, testing was completed at the same time of day in test sessions one and three and in the morning for test session two.

The first testing session consisted of a standardised warm up, followed by a 30m sprint speed test and a muscle stiffness assessment. The standardised warm up consisted of ten minutes of cycling (at 150W) on a Cycle Ergometer followed by five minutes of prescribed lower limb dynamic stretches. Stretches consisted of high knee lateral rotation, standing side to side groin stretch, calf pumps, front to back and side to side leg swings and pronated alternating lower back kick overs performed for 30s. Two sprint tests were measured with timing lights (Swift Performance Technology, Australia) over 30m with the time to cover 5m, 10m, 20m and 30m recorded. Subjects were required to start with their preferred foot on a standardised mark 50cm behind the first timing light so that the subject would not cross the first timing light at their start point but would cross it in their first stride. Subjects were instructed to sprint at full speed without slowing until they had passed the last timing light at 30m. A three minute rest period occurred between sprints.

Muscle stiffness testing consisted of ten consecutive maximal effort bilateral hops completed on a Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) using the maximal repeated hop protocol outlined by Dalleau et al. [24]. This testing method has been shown to be highly related (r = 0.98; P<0.001) to reference measures of muscle stiffness [24]. Subjects were instructed to jump for maximal height while keeping their legs as straight as possible and their hands on their hips. Jump height and CT were recorded for each jump from force plate data. Two muscle stiffness tests were performed with three minutes rest between tests. At least fifteen minutes rest was required between sprint and muscle stiffness tests.

The second testing session consisted of ultrasound imagery using B-Mode Ultrasound (SSD-500, Aloka, Japan) to determine muscle thickness, and fascicle pennation angle of both the vastus lateralis and gastrocnemius. Ultrasound testing was completed by a professional ultrasound practitioner familiar with the use of B-Mode Ultrasound. Ultrasound testing took place in the morning under resting conditions. No attempt was made to standardise hydration levels during ultrasound testing.

Muscle thickness was measured as the distance between the adipose tissue-muscle interface and the muscle-bone interface in vivo and was determined using ultrasonic images [32]. The precision of this method has been previously established [92]. Fascicle pennation angle was measured by the angle between the deep aponeurosis of the muscle and interspace among the fascicle of the muscle, this method for determining pennation angle has been utilised in previous research [32]. The vastus lateralis measure was taken midway between the lateral condyle of the femur and the greater trochanter with the subject lying supine while the gastrocnemius measure was taken at 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia with the subject lying prone [32]. Each measure was determined by taking the average of three trials. These measures have been previously shown to be highly reliable [166; 167].

The third testing session consisted of 12 sets of jumps with two minutes rest between each set. Each set consisted of three repetitions with 30s rest between repetitions. The jumps (CMJ, SJ, DJ) were performed as unilateral vertical, bilateral vertical, unilateral horizontal and bilateral horizontal and completed in random order. Unilateral jumps were performed using the subjects' dominant leg. Data for jump tests was collected using a Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) at a sampling rate of 500Hz. Vertical force, velocity and impulse and horizontal force were recorded and stored for subsequent analysis using a custom designed software program (Objective Design Limited, Auckland, New Zealand).

Both vertical and horizontal CMJ consisted of a self-selected countermovement depth immediately followed by a jump of maximal intensity [7]. Instructions were given to jump for maximal height or distance in vertical and horizontal CMJ respectively. Assessment of SJ consisted of a three second static hold at an approximate 90° knee angle followed by a jump of maximal intensity in either the vertical or horizontal plane of movement [161]. No eccentric dip was allowed after the static hold. Any eccentric dip immediately preceding concentric movement resulted in that test being disqualified and repeated after a 30s rest. Assessments of DJ were performed with a drop depth of 20cm in unilateral DJ and 40cm in bilateral DJ [109]. This was immediately followed by a jump of maximal intensity. Subjects were instructed to minimise CT on the force plate while maximising jump height or distance.

In an attempt to standardise testing conditions, minimal feedback was given to subjects during all testing sessions, however, feedback was given to correct technical errors in testing e.g. concentric dip in SJ. Reliability of jump tests for all kinetic and kinematic jump measures and performance tests utilised in this research was determined prior to testing [168].

4.3.4 Statistical Analysis

The mean and standard deviation (SD) of all measured variables were calculated. Mean and peak force measures were divided by subjects' weight to give a measure of relative force, absolute force was used in the correlation analysis. Pearson product-moment correlation coefficient were used to determine the strength of the relationships between vertical and horizontal kinetic and kinematic variables (MF, PF, contact time, mean velocity, peak velocity, time to peak velocity, mean impulse and peak impulse) and measures of sprint speed, muscle stiffness and muscle architecture. The magnitudes of the correlation coefficients were interpreted as: <0.10 = trivial, 0.10-0.29 = small, 0.30-0.49 = moderate, 0.50-0.69 = large, >0.70-0.89 = very large, >0.90 = nearly perfect [169]. Coefficient of determination (R^2) was also calculated.

4.4 Results

The summary of the results for muscle stiffness and measures of muscle architecture are shown in Table 4.1 and for jump tests in Table 4.2. Measures of horizontal peak and mean force, in both bilateral and unilateral jumps, had greater relationships to sprint speeds (R^2 = 0.13 to 0.576) than peak and mean force in the vertical plane (R^2 = 0.01 to 0.50), with the exception of MF in the bilateral SJ (horizontal $R^2 = 0.37$ to 0.47, vertical $R^2 = 0.41$ to 0.50). In bilateral jumps (Table 4.3), mean and peak force measures in horizontal CMJ and DJ had larger correlations to sprint speed over 10m, 20m and 30m then vertical CMJ and DJ. However, in bilateral SJ, mean and peak force in both vertical and horizontal jumps show similar, generally large, correlations to sprint speeds. In unilateral jumps (Table 4.4), mean and peak forces in horizontal jumps were found to have larger correlations to sprint speed over all distances than vertical jumps of the same type.

Table 4.1 Group means for muscle stiffness and architecture measures in club level rugby union players (n=17)

Muscle stiffness (kN x m^{-1})		26.4 ± 6.97
Fascicle Angle (°)	LG	12.3 ± 2.45
	VL	15.3 ± 1.85
Muscle Thickness (cm)	LG	1.43 ± 0.17
	VL	1.70 ± 0.36

LG = Lateral Gastrocnemius; VL = Vastus Lateralis

Table 4.2 Group means for vertical and horizontal jump kinetic and kinematic measures in club level rugby union players (n=17)

		Vertical		Horizontal	
		Bilateral	Unilateral	Bilateral	Unilateral
CMJ	Peak Force (N)	2579 ± 430.1	2036 ± 341.0	997.3 ± 170.4	697.9 ± 126.0
	Mean Force (N)	1551 ± 259.8	1386 ± 201.1	463.9 ± 100.3	395.5 ± 81.03
	Peak Velocity (m/s)	2.716 ± 0.684	2.123 ± 0.341		
	Mean Velocity (m/s)	0.677 ± 0.155	0.534 ± 0.164		
	TT Peak Velocity (s)	0.414 ± 0.109	0.504 ± 0.150		
	Peak Impulse (Ns)	290.8 ± 33.72	225.5 ± 29.82		
	Mean Impulse (Ns)	68.30 ± 15.01	53.29 ± 13.20		
DJ	Peak Force (N)	4915 ± 1073	3178 ± 512.2	1163 ± 235.7	714.6 ± 167.2
	Mean Force (N)	2749 ± 399.6	1864 ± 242.1	528.9 ± 131.5	368.7 ± 103.5
	CT (s)	0.258 ± 0.032	0.323 ± 0.041	0.304 ± 0.047	0.358 ± 0.034
	Peak Velocity (m/s)	2.802 ± 0.931	2.413 ± 0.599		
	Mean Velocity (m/s)	1.092 ± 0.398	0.892 ± 0.299		
	TT Peak Velocity (s)	0.199 ± 0.040	0.262 ± 0.039		
	Peak Impulse (Ns)	341.6 ± 99.34	255.9 ± 73.70		
	Mean Impulse (Ns)	134.5 ± 52.34	94.78 ± 35.44		
SJ	Peak Force (N)	2252 ± 351.4	1875 ± 340.9	757.5 ± 169.3	569 ± 117.1
	Mean Force (N)	1633 ± 195.7	1443 ± 221.4	379.5 ± 72.46	293 ± 50.21
	Peak Velocity (m/s)	2.562 ± 0.253	1.919 ± 0.227		
	Mean Velocity (m/s)	1.062 ± 0.101	0.749 ± .0106		
	TT Peak Velocity (s)	0.365 ± 0.051	0.452 ± 0.083		
	Peak Impulse (Ns)	258.6 ± 29.93	195.0 ± 26.48		
	Mean Impulse (Ns)	109.6 ± 15.94	76.19 ± 10.83		

TT Peak = time to peak; CMJ = countermovement jump; DJ = drop jump; SJ = Squat Jump

Table 4.3 Correlation between *bilateral* horizontal and vertical jump kinetics and kinematics and sprint speed over 5m, 10m, 20m and 30m and muscle stiffness and architecture in club level rugby union players (n=17)

		Horizontal							Vertical						
		CMJ		Drop Jump			Squat Jump		CMJ		Drop Jump			Squat Jump	
		Mean Force	Peak Force	Mean Force	Peak Force	CT	Mean Force	Peak Force	Mean Force	Peak Force	Mean Force	Peak Force	CT	Mean Force	Peak Force
Sprint Distance	5m	-0.470	-0.371	-0.632*	-0.363	0.169	-0.609*	-0.391	-0.309	-0.334	-0.297	-0.183	0.327	-0.662*	-0.396
	10m	-0.563*	-0.494	-0.658*	-0.410	0.123	-0.666*	-0.515*	-0.373	-0.391	-0.389	-0.268	0.305	-0.710**	-0.544*
	20m	-0.583*	-0.541*	-0.752**	-0.543*	0.235	-0.682*	-0.538*	-0.303	-0.335	-0.467	-0.345	0.241	-0.686*	-0.512*
	30m	-0.625*	-0.621*	-0.759**	-0.521*	0.154	-0.621*	-0.563*	-0.395	-0.437	-0.407	-0.280	0.213	-0.642*	-0.534*
Muscle stiffness		-0.440	-0.225	-0.305	-0.314	-0.003	-0.504*	-0.531*	-0.440	-0.610*	-0.129	0.032	-0.003	-0.022	0.068
Fascicle Angle	LG	0.147	0.173	-0.141	-0.312	0.288	0.001	-0.041	0.056	-0.036	0.182	0.190	0.288	0.381	0.537
	VL	-0.067	-0.001	-0.194	0.061	-0.104	0.034	-0.041	-0.198	-0.378	-0.063	0.085	-0.104	-0.269	-0.155
Muscle Thickness	LG	-0.108	-0.402	-0.470	-0.656*	0.137	-0.504*	-0.360	-0.199	-0.198	-0.265	-0.141	0.137	-0.073	-0.200
	VL	0.132	0.263	0.302	0.135	-0.179	0.223	-0.054	0.385	0.219	0.109	0.142	-0.179	0.146	0.144

*Large; ** Very Large

TT Peak = time to peak; CMJ = countermovement jump; CT = contact time; LG = Lateral Gastrocnemius; VL = Vastus Lateralis

Table 4.4 Correlation between *unilateral* horizontal and vertical jump kinetics and kinematics and sprint speed over 5m, 10m, 20m and 30m and muscle stiffness and architecture in club level rugby union players (n=17)

		Horizontal							**Vertical**						
		CMJ		Drop Jump			Squat Jump		CMJ		Drop Jump			Squat Jump	
		Mean Force	Peak Force	Mean Force	Peak Force	CT	Mean Force	Peak Force	Mean Force	Peak Force	Mean Force	Peak Force	CT	Mean Force	Peak Force
Sprint Distance	5m	-0.556*	-0.391	-0.492	-0.556*	0.315	-0.629*	-0.414	-0.492	-0.125	-0.350	-0.143	0.376	-0.354	-0.297
	10m	-0.660*	-0.514*	-0.619*	-0.629*	0.274	-0.691*	-0.512*	-0.523*	-0.170	-0.406	-0.211	0.329	-0.340	-0.322
	20m	-0.638*	-0.527*	-0.706**	-0.749**	0.304	-0.725**	-0.592*	-0.485*	-0.092	-0.485	-0.270	0.337	-0.325	-0.303
	30m	-0.629*	-0.551*	-0.699*	-0.726**	0.184	-0.730**	-0.589*	-0.545*	-0.158	-0.474	-0.235	0.269	-0.311	-0.321
Muscle stiffness		-0.506*	-0.278	-0.234	-0.240	-0.074	-0.512*	-0.534*	-0.639*	-0.298	-0.163	-0.026	0.074	-0.036	-0.151
Fascicle Angle	LG	0.106	0.034	-0.072	-0.151	0.017	0.211	-0.065	-0.091	-0.107	0.059	0.155	0.017	0.076	0.029
	VL	-0.221	-0.007	-0.069	0.019	0.142	-0.171	0.004	-0.300	-0.256	-0.149	-0.070	0.142	-0.271	-0.349
Muscle Thickness	LG	-0.119	-0.353	-0.565*	-0.561*	-0.037	-0.378	-0.417	-0.226	-0.004	-0.082	-0.007	-0.037	-0.185	-0.242
	VL	0.258	0.326	0.392	0.286	0.096	0.228	0.102	0.220	0.205	-0.119	-0.063	0.096	0.117	0.121

*Large; ** Very Large

TT Peak = time to peak; CMJ = countermovement jump; CT = contact time; LG = Lateral Gastrocnemius; VL = Vastus Lateralis

Few of the jumps showed large correlations between force measures and 5m sprint speed. In vertical jumps, only MF in the bilateral SJ showed a large correlation to 5m sprint time. Although horizontal jumps showed more large correlations to 5m sprint time than vertical jumps, fewer large correlations were found to sprint time over 5m than over 10m, 20m or 30m. No large correlations were found between CT and sprint time. However CT generally had greater correlation to 5m sprint speed than sprint speed over longer distances.

Vertical velocity variables showed some of the strongest correlations to sprint speed out of all tested variables (Tables 4.5 and 4.6). Unilateral measures of velocity tended to have larger correlations to sprint performance than their bilateral counterparts across all jump types. Additionally, peak and mean velocity in SJ showed larger correlations to sprint time (bilateral R^2 = 0.228 to 0.635; unilateral R^2 = 0.393 to 0.574) than CMJ or DJ. Correlations between time to peak velocity and sprint time were also largest in unilateral and bilateral SJ as compared to CMJ and DJ.

No measured variables showed large positive correlations to muscle stiffness. However mean and peak forces in both bilateral and unilateral horizontal SJ were shown to have large negative correlations to muscle stiffness. MF in the horizontal unilateral CMJ and vertical unilateral CMJ were also found to have large negative correlations to muscle stiffness (horizontal R^2 = 0.256, vertical R^2 = 0.408). In the unilateral CMJ a large correlation between peak velocity and muscle stiffness was also found (R^2 = 0.410).

Table 4.5 Correlation between *bilateral* vertical jump velocity, impulse and sprint speed over 5m, 10m, 20m and 30m and muscle stiffness in club level rugby union players (n=17)

		Countermovement Jump					**Drop Jump**					**Squat Jump**				
		Velocity			Impulse		Velocity			Impulse		Velocity			Impulse	
		Mean	Peak	TT Peak	Mean	Peak	Mean	Peak	TT Peak	Mean	Peak	Mean	Peak	TT Peak	Mean	Peak
Sprint Distance	5m	-0.250	-0.419	0.232	0.241	0.429	-0.185	-0.174	0.345	0.474	0.445	-0.548*	-0.797**	0.566*	0.361	0.361
	10m	-0.332	-0.472	0.263	0.146	0.301	-0.137	-0.137	0.332	0.458	0.413	-0.537*	-0.796**	0.645*	0.339	0.329
	20m	-0.327	-0.437	0.212	0.146	0.336	-0.173	-0.165	0.376	0.437	0.383	-0.477	-0.686*	0.600*	0.414	0.434
	30m	-0.364	-0.380	0.379	0.070	0.230	-0.202	-0.219	0.205	0.369	0.293	-0.482	-0.744**	0.496	0.355	0.312
Muscle stiffness		-0.254	-0.206	0.064	0.112	0.324	-0.267	-0.239	-0.226	0.145	0.144	-0.332	-0.039	-0.103	0.354	0.357
Fascicle Angle	LG	-0.032	0.320	-0.012	-0.031	0.246	-0.315	-0.261	0.054	-0.129	-0.123	0.117	0.297	-0.528*	0.272	0.243
	VL	0.125	-0.097	0.198	0.368	0.380	0.281	0.159	0.020	0.183	0.133	-0.294	-0.540*	0.207	0.047	0.041
Muscle Thickness	LG	0.004	-0.278	0.042	0.242	0.342	0.034	-0.033	0.096	0.202	0.139	0.164	-0.049	-0.020	0.509	0.476
	VL	0.417	0.546*	-0.433	0.348	0.064	-0.294	-0.251	-0.282	-0.231	-0.213	-0.193	0.243	-0.179	-0.235	-0.008

*Large ** Very Large

TT Peak = time to peak; LG = Lateral Gastrocnemius; VL = Vastus Lateralis

Table 4.6 Correlation between *unilateral* vertical jump velocity and impulse measures and sprint speed over 5m, 10m, 20m and 30m and muscle stiffness in club level rugby union players (n=17)

		Countermovement Jump					Drop Jump					Squat Jump				
		Velocity			Impulse		Velocity			Impulse		Velocity			Impulse	
		Mean	Peak	TT Peak	Mean	Peak	Mean	Mean	TT Peak	Mean	Peak	Mean	Peak	TT Peak	Mean	Peak
Sprint Distance	5m	-0.589*	-0.686*	0.286	-0.448	0.196	-0.252	-0.234	0.057	0.008	0.130	-0.676*	-0.627*	0.519*	0.096	0.281
	10m	-0.538*	-0.696*	0.372	-0.438	0.072	-0.324	-0.321	0.001	-0.095	0.012	-0.753**	-0.728**	0.496	-0.018	0.155
	20m	-0.477	-0.609*	0.388	-0.380	0.137	-0.446	-0.431	0.062	-0.186	-0.063	-0.765**	-0.718**	0.466	-0.016	0.172
	30m	-0.387	-0.610*	0.546*	-0.352	0.096	-0.518*	-0.519*	-0.066	-0.302	-0.195	-0.761**	-0.758**	0.426	-0.080	0.065
Muscle stiffness		-0.476	-0.640*	0.332	-0.421	-0.139	-0.045	-0.042	0.276	0.221	0.313	-0.258	-0.424	-0.134	0.300	0.220
Fascicle Angle	LG	0.035	0.202	-0.060	0.064	0.297	-0.442	-0.382	0.141	-0.419	-0.353	0.311	0.159	-0.382	0.373	0.200
	VL	-0.544*	-0.434	0.271	-0.600*	-0.017	0.097	0.093	0.133	0.238	0.284	-0.125	-0.249	0.018	0.272	0.177
Muscle Thickness	LG	-0.239	-0.188	0.290	-0.178	0.326	-0.446	-0.396	0.038	-0.355	-0.240	-0.282	-0.270	-0.228	0.163	0.211
	VL	0.286	0.209	-0.226	0.261	-0.146	0.085	0.026	0.195	0.198	0.153	0.160	0.170	-0.067	0.086	0.077

*Large ** Very Large

TT Peak = time to peak; LG = Lateral Gastrocnemius; VL = Vastus Lateralis

Similarly, few measures variables showed strong correlations to measures of muscle architecture. Fascicle angle in both the lateral gastrocnemius and vastus lateralis showed no large correlations to force measures for any jump type. However, in the bilateral SJ, fascicle angle of the vastus lateralis showed a large correlation ($R^2 = 0.292$) to peak velocity and fascicle angle of the lateral gastrocnemius showed a large correlation ($R^2 = 0.279$) to time to peak velocity. Fascicle angle of the vastus lateralis also showed large correlations to mean velocity ($R^2 = 0.296$) and Mean impulse ($R^2 = 0.360$) in the unilateral CMJ. Muscle thickness of the lateral gastrocnemius had large correlations to PF in the bilateral DJ ($R^2 = 0.430$) and SJ ($R^2 = 0.254$) vastus lateralis had a large correlation ($R^2 = 0.298$) to peak velocity in the bilateral CMJ.

4.5 Discussion

The purpose of this study was to determine the relationship between kinetic and kinematic measures in bilateral and unilateral CMJ, DJ and SJ in the horizontal and vertical plane of movement and measures of functional performance. The results indicated that horizontal mean and peak force have a better relationship to sprint performance than vertical mean and peak force. Historically, measures of muscular explosive ability have predominantly been undertaken in the vertical plane of movement. In light of the current research it would seem that horizontal mean and peak force are useful prognostic measures for many functional movements, such as sprint speed, and should be included alongside their vertical counterparts. This could provide strength and conditioning practitioners with useful information about the physical qualities of their athletes, which is not fully captured by relying on vertical measures alone. These findings are consistent with previous research which has shown horizontal jump for distance to have stronger correlations to sprint speed than vertical jump height [1; 7].

Additionally, many kinetic and kinematic variables measured in horizontal jumps had stronger correlations to sprint performance than the same measures taken in vertical jumps. These findings suggest that using horizontal dynamic training movements may have a greater transfer to sprint performance than vertical dynamic training. However, it is important to note that there is a proportion in a given variable that is predictable from a secondary variable. That is to say, there is a shared variance between kinetic and kinematic variables measured in horizontal and vertical jumps. Given the already broad scope of this study, shared variance has not been included in the results and will not be widely discussed. Notwithstanding this, it would seem reasonable to favor those jump types shown to have stronger correlations to sprint performance e.g. unilateral DJ and SJ. Further training studies are required to prove this hypothesis.

The majority of human movements, including sporting movements, involve some degree of unilateral force production [7; 8]. As such, it has been suggested that unilateral assessments are more closely related to functional movement than bilateral assessment and therefore may provide better training information [1; 7]. The current research largely supports this claim, as the kinetic and kinematic measures from unilateral jumps generally had a stronger relationship to sprint speed in both the vertical and horizontal CMJ and DJ. However, this was not the case for the SJ which showed similar correlations between unilateral and bilateral force measures and sprint speed in horizontal jumps and greater correlations in vertical jumps.

Mean and peak velocity in the vertical CMJ and SJ were shown in this study to have strong correlations to sprint performance. However, horizontal velocity was unable to be determined in this research. This research shows that kinetic variables in horizontal jumps seem to have stronger relationships to sprinting speed than in vertical jumps. As such, it would appear that horizontal velocity may be a promising predictor of sprint performance. Further research should be undertaken into the relationship between horizontal velocity and functional performance measures and utilise longitudinal designs to investigate this question more fully.

Additionally, it has been previously suggested that different jump types rely on mechanisms in vivo which relate to physiological factors important throughout different phases of a sprint and that both the DJ and sprint performance at high speed depend heavily on the elastic property of muscles and tendons in the SSC [3; 109]. Thus, DJ ought to have a stronger relationship to sprint speed over longer distances. The current research clearly supports such findings with peak and mean force and velocity having progressively stronger correlations to sprint speed over greater distances. This also supports the concept that training the stretch shorten cycle through DJ movements may improve acceleration at high speed and speed maintenance.

The SJ is thought to isolate the physiological characteristics which are important to early acceleration during a sprint movement i.e. concentric contractile force and the RFD [3; 73]. Previous research supports this by demonstrating stronger relationships between concentric force in vertical SJ performance and sprint speed over short distances than longer distances [3]. This is somewhat supported by the findings of this study which has found force and velocity measures in the SJ tended to have greater correlations to sprint performance over shorter distances.

However, this is not the case in the horizontal SJ which shows both stronger correlations than its vertical counterparts and correlations which were generally as strong or stronger over longer distances i.e. 20-30m. This suggests that horizontal SJ may be an effective tool in developing both early acceleration but also physiological characteristics relevant to sprint speed over longer distances. Further research is required in this field.

Muscle stiffness was shown to largely have trivial or small negative correlations to both unilateral and bilateral jump kinetic and kinematic measures. Although this is counterintuitive, particularly when comparing muscle stiffness to DJ variables, this is not the only research to produce such findings. Walshe and Wilson [90] found stiff subjects performed less well than their compliant counterparts in vertical CMJ and DJ height tests. However, additional research has shown positive relationships between vastus lateralis aponeurosis tendon stiffness and dynamic performance including SJ and CMJ height [26] and series elastic component stiffness and concentric motion in the bench press [170]. Additionally, men have been shown to have greater muscle leg stiffness than women during volleyball block jump landing [171] and male children during CMJ [172]. Although it seems clear that a relationship exists between running economy [88], the relationship between muscle stiffness and jump performance seems unclear.

Tendon stiffness is also thought to be important in important in optimising dynamic performance [23] and has been shown to have significant correlations to jump performance [23; 26]. However tendon stiffness was not measured in the current study. Understanding how this variable affects the kinetics and kinematics of jump performance would be of interest.

Previous research has found measures of muscle architecture to have significant correlations to sprint performance [29-31]. In the present study there were no very large correlations between kinetic and kinematic variables in horizontal and vertical jumps. However, several large positive correlations were found between muscle thickness and fascicle angle of the vastus lateralis and velocity and impulse measures in CMJ and SJ. The lack of very large correlations may be a result of differences in subject populations between this study and previous research i.e. sprint trained athletes [29; 30] as compared to rugby players in the current study. Furthermore, Blazevich et al. [27] showed that although subjects who participate in strength training to the exclusion of sprint training show improvements in measures of muscle architecture, they show no improvement in sprint speed. Position specific training variation is common in high performance rugby players. As such, it is possible that a highly trained forward may have improved measures of muscle architecture through strength training without improving dynamic ability, while a back may have both improved dynamic ability and measures of muscle architecture through dynamic jump and sprint training. Regardless, this research shows some vertical and horizontal jump kinetics and kinematics have meaningful relationships to muscle architecture in this group of subjects. Further research into the relationship between measures of muscle architecture, jump kinetics and kinematics and functional performance measures in more diverse population groups would be of interest.

4.6 Practical Applications

The present findings suggest that strength and conditioning practitioners concerned with the prognostic value of kinetic variables to functional movements such as sprint speed should also use horizontal jumps alongside vertical jumps in testing and training. Peak and mean force in the unilateral DJ, MF in the bilateral DJ and MF in both the vertical and horizontal bilateral SJ showed the strongest relationship to sprint speed. Furthermore, peak and mean force in horizontal CMJ had greater correlations to sprint speed than in the vertical CMJ. As these horizontal jump movements have large correlations to sprint speed, it is also likely that using horizontal dynamic training movements, particularly those jump types shown to have stronger correlations to sprint performance, may have a greater transfer to sprint performance than vertical dynamic training. Furthermore, mean and peak velocity in bilateral and unilateral SJ were found to have a strong relationship to sprint speeds, jumps of this modality focusing on velocity of movement should be favored as a training tool for sprint speed.

Additionally, this study supports previous research which has suggested that DJ movements have stronger relationships to sprint speed over longer distances. This is true in both the vertical and horizontal DJ. As such, practitioners can use this jump type to improve acceleration at high speed and speed maintenance. However, horizontal SJ did not have greater correlations to sprint speed over shorter distances. It seems therefore that this may not be used by practitioners to target concentric force production specifically although considering the strength of the correlations to all sprint distances this jump modality would still appear to be effective as a training tool to improve sprint performance.

CHAPTER 5

THE ACUTE EFFECT OF SHORT TERM ENHANCEMENT COUNTERMOVEMENT AND DROP JUMP PERFORMANCE

Prelude: Having determined the importance of horizontal jump kinetic and kinematic variables to aspects of functional performance, it is clear that developing dynamic ability in the horizontal plane of movement is import for athletic performance. Because of this, novel approaches to improve muscular performance are of interest to practitioners. One such method is PAP or STE. Research into the acute effects of STE on vertical jump height and sprint performance has been undertaken, but there is a dearth of research into the effects on horizontal jump performance and the kinematic and kinetic variables therein. Due to the complex and highly individualised nature of STE, it is important to determine the acute effect of a STE protocol in a given population group before attempting to determine chronic or training effect of STE.

5.1 Abstract

The aim of this study was to determine the acute effect or STE on horizontal and vertical CMJ and DJ kinetic and kinematic measures. Subjects were developmental rugby players (n = 24; age = 17.0 ± 0.7 years; 4RM back squat =133.5 ± 16.7 kg). The first testing session consisted of four repetition maximum (4RM) back squat testing and jump familiarisation. After a one week rest period a second testing session determined non STE affected and STE affected jump performance. This was determined by comparing pre intervention horizontal and vertical jump performance to jump performance two, four, six and eight minutes post intervention. Horizontal and vertical jump performance improved as a result of STE. Improvements were greatest four minutes post squat intervention with all measures except peak velocity in vertical CMJ

improving. Meaningful small improvements were found four minutes post squat in CMJ vertical MF (ES = 0.40 ± 0.32) and horizontal MF (ES = 0.51 ± 0.38), time to peak velocity in vertical CMJ (ES = -0.49 ± 0.33), MF in horizontal DJ (ES = 0.45 ± 0.41) and vertical DJ contact time (ES = -0.31 ± 0.25). It is possible to produce an ergogenic effect in both vertical and horizontal jumps from a single set of heavy back squat in high school athletes. This shows that subjects need not be highly trained to achieve STE and suggests that the effect of STE is not specific to the plane of movement of the intervention.

5.2 Introduction

It is an ongoing challenge for practitioners and sports scientists to improve methods for developing muscular strength and power. One such method which has recently received a great deal of interest is PAP or STE [36-38; 40-43; 45]. STE refers to an acute enhancement in muscular performance characteristics as a result of their within session contractile history [40; 44], which results in improved muscular performance and acute power [37; 38; 40]. The exact mechanism by which this occurs is unknown [43] but is thought to be caused by phosphorylation of myosin regulating light chains [54; 113] as well as improved synchronisation of motor units and decreased pre-synaptic inhibition [113] as a result of the prior maximal or near maximal contractions.

Previous research has found STE to have positive acute effects on vertical jump performance [38; 41; 42] and sprint performance [37; 40; 173]. However, some STE studies showed no improvement in power measures following near maximal contractions [45-47; 158]. It appears that STE can improve acute muscular performance although this relies on an appropriate stimulus and rest periods prior to undertaking an explosive movement [44]. Additionally, it is theorised that STE can be utilised through complex training to not only increase the performance of dynamic movements within a training session but that, over a training cycle, this may result in greater chronic improvement in muscular ability than traditional training methods [54].

There is currently limited research into the effects of STE on jumps in the horizontal plane of movement. Understanding the effect of STE in the horizontal plane of movement is important as many functional movements utilise horizontal or a combination of horizontal and vertical force. As such, when training for many functional movements including sprinting, the use of horizontal or a combination of horizontal and vertical plane training movements has high face validity [174-176]. Indeed, several studies have found measures of horizontal jump performance to have stronger correlations than their vertical jump counterparts to sprint speeds of various distances [1; 7]. Therefore, the effect of STE as a mechanism to produce both acute and potentially chronic improvements in horizontal dynamic ability is of interest.

Of the research that has investigated the effect of STE on horizontal jumps; some have shown that it does not have a positive effect on jump performance [41; 46]. For example, Scott and Docherty [46] investigated the effect of STE on both horizontal and vertical CMJ and found no significant change in jump performance (height or distance) in either vertical or horizontal jumps after pre-loading. The lack of positive effect of STE in this study has been suggested to be due to the experimental protocol and is consequently of limited usefulness. Additionally, Kovacević et al. [41] found an STE after a maximal isometric contraction to have a positive effect on vertical but not horizontal CMJ performance.

In contrast, Ruben et al. [52] found a back squat protocol utilising four sets of ascending intensity to cause STE in repeated horizontal hurdled jumps. Additionally, it has been shown that STE can improve sprint speed [37; 40; 177], and sprint speed utilises power in both the horizontal and vertical plane of movement [175]. As such, it seems that, given appropriate stimulus, STE can improve performance in both horizontal and vertical planes of movement. However, considering the limited research into the effect of STE on horizontal jump performance, particularly in developmental athletes, further research in this field is warranted. This study aims to determine the effect of a single set of heavy squat as a STE stimulus on horizontal and vertical CMJ and DJ kinetics and kinematics.

5.3 Methods

5.3.1 Subjects

Twenty four male high school rugby union players (age = 17.0 ± 0.7 years; mass = 87.1 ± 8.0 kg; height: 1.81 ± 0.06 m, 4RM back squat =133.5 ± 16.7 kg) competing in the New Zealand Secondary School Super Eight competition were recruited for this study. The study was approved by the Auckland University of Technology Ethics Committee. Written informed consent was obtained from the subjects and subject's legal guardian prior to study participation. Subjects had a minimum training age of one year in a structured strength and conditioning program and were familiar with plyometric and explosive jump training.

5.3.2 Procedures

The effect of STE on bilateral horizontal and vertical CMJ and DJ kinetic and kinematic measures was determined over two testing sessions (Table 5.1). The first testing session included a four RM squat test and jump familiarisation of both horizontal and vertical CMJ and DJ. The second session consisted of three horizontal and three vertical CMJ and DJ in a randomised order to determine base line jump performance. This was followed by a 4RM squat with a single jump measured at two, four, six and eight minutes post squat. This was repeated for all jump types. Subjects completed the testing sessions seven days apart during a non-training period.

Table 5.1 Research timeline and design

Test Session 1		Test Session 2
Warm Up	7 Days	Warm Up
4RM Back Squat Test		Non STE Effected Horizontal and Vertical CMJ and DJ Tests*
Horizontal and Vertical CMJ and DJ Familiarisation		STE Effected Horizontal and Vertical CMJ and DJ Tests*

* = randomised order

This research was conducted in-season during a non-training period with no field or gym training prescribed over the testing period. Subjects were instructed not to participate in strenuous exercise in the 24 hour period leading into training sessions. Testing sessions took place at the same time of day to avoid the effect of diurnal variation on performance [160].

Both test sessions consisted of a standardised warm up, comprising ten minutes of cycling (at 150W) on a Cycle Ergometer followed by five minutes of prescribed lower limb dynamic stretches. Stretches were performed for 30s each and consisted of high knee lateral rotation, standing side to side groin stretch, press up position heel pumps, front to back and side to side leg swings, pronated alternating lower back kick and kneeling lower back flexion and extension.

The first testing session consisted of a 4RM back squat test and familiarisation of all jump types. Due to the age of the subjects a 4RM back squat test was deemed to be safer than a 1RM test. Back Squat 4RM testing consisted of a submaximal eight and six repetition lift before a four repetition lift at predicted maximal load. If the subject completed the 4RM lift the load was increased and an additional four repetition lift was attempted. This process continued until the subject failed to complete a four repetition lift. The heaviest load before failure was considered to be the 4RM load. A minimum squat depth of 90 degrees was required. A lift was considered a failure if the subject did not achieve the required depth or was unable to complete the lift. A rest period of five minutes was required between lifts. Previous studies have also implemented similar 4RM protocols in college age athletes to predict 1RM back squat loads with reduced risk of injury [177].

The second testing session consisted of baseline or non-STE bilateral horizontal and vertical CMJ and DJ jump performance following a 4RM squat. Baseline jump testing consisted of three repetitions of each jump with 30s rest between repetitions. Two minutes rest was required between each jump type. The STE of 4RM squat on jump performance was determined by completing four repetition of back squat at 4RM load followed by a single jump at two, four, six and eight minutes after the squat. Following the jump at eight mins post squat, a five minute rest was required before repeating the squat and jump protocol for the next jump type. This was completed for each jump type in a randomised order. The procedure for testing is further outlined in table 5.2.

Table 5.2 Short term enhancement and non-short term enhancement jump test experimental procedures

Non STE effected jump testing protocol					
Jump	30s rest	Jump	30s rest	Jump	2 mins rest
STE effected jump testing protocol					
4 RM Squat	2 mins post Jump	4 mins post Jump	6 mins post Jump	8 mins post Jump	5 mins rest

*STE = short term enhancement

Data for jump tests was collected using a Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) at a sampling rate of 500Hz. Vertical force, velocity, impulse and horizontal force were recorded and stored for subsequent analysis using a custom designed software program (Objective Design Limited, Auckland, New Zealand).

Both horizontal and vertical CMJ consisted of a self-selected countermovement depth immediately followed by a jump of maximal intensity [7]. Subjects were instructed to jump for maximal distance or height in horizontal and vertical CMJ respectively. DJ were performed from a depth of 40cm [109] immediately followed by a jump of maximal intensity. Subjects were instructed to minimise contact time on the force plate while maximising jump height or distance. Subjects were required to place their hands on their hips during all jump tests. Reliability of jump tests for all kinetic and kinematic jump measures and performance tests utilised in this research was determined prior to testing [168]. Reliability of the tests ranged utilised in this study from ICC: 0.79 to 0.93 and CV%: 5.4 to 9.2% (Chapter three).

5.3.3 Statistical Analysis

To examine differences in performance between pre and post squat jump performance, ES statistics were calculated as the mean difference divided by the pooled between-subject SD. Outcomes were reported in Cohen units. Significance was classified using the following criteria: < 0.2 = trivial, $0.2 - 0.6$ = small, $0.6 - 1.2$ = moderate, and > 1.2 = large [178]. The smallest worthwhile change in performance from test to test established as a “small” ES ($0.2 \times$ between-participant SD) according to methods outlined previously [178].

5.4 Results

Both horizontal and vertical jump performance improved as a result of STE (Tables 5.3 and 5.4). The ES of change tended to be greatest four minutes post intervention as compared to jump tests performed two, six and eight minutes post intervention. All measures improved four minutes post intervention in both vertical and horizontal jumps with the exception of peak velocity in vertical CMJ (ES = -0.27 ± 0.19).

In the horizontal jump measures, meaningful small improvements were found four minutes post squat in CMJ horizontal MF (ES = 0.51 ± 0.38) and DJ horizontal MF (ES = 0.45 ± 0.41) (Tables 5.3 and 5.4). In vertical jump measures meaningful small improvements were found four minutes post squat in CMJ vertical MF (ES = 0.40 ± 0.32), time to peak velocity (ES = $-0.49 \pm$

0.33) and vertical DJ contact time (ES = -0.31 ± 0.25). The majority of meaningful improvements occurred four minutes post STE, however, meaningful improvement were also found eight minutes post squat in vertical DJ contact time (ES = -0.33 ± 0.26) and in vertical CMJ MF (ES = 0.32 ± 0.23). Time to peak velocity in the vertical CMJ showed meaningful improvements both six and eight minutes post squat (ES = -0.37 ± 0.31 and -0.39 ± 0.25 respectively).

There did not seem to be a difference in improvement post STE intervention between horizontal and vertical jump performance. Both horizontal and vertical jump performance improved meaningfully in most measures. In the vertical CMJ mean velocity and time to peak velocity improved after all tested rest periods i.e. two, four, six and eight minutes post squat. In contrast peak velocity decreased after all tested rest periods.

Table 5.3 Countermovement jump kinetic and kinematic variables pre and post a 4 repetition maximum squat

		Pre 4RM	2 minutes post		4 minutes post		6 minutes post		8 minutes post	
		Mean ± SD	% Change	ES	% Change	ES	% Change	ES	% Change	ES
Horizontal	Mean Force (N)	344 ± 54	-2.1 ± 4.5	-0.13 ± 0.27	8.9 ± 6.6	0.51 ± 0.38†	5.1 ± 8.7	0.30 ± 0.50	5.8 ± 8.1	0.34 ± 0.47
	Peak Force (N)	693 ± 80	-1.4 ± 3.5	-0.12 ± 0.28	2.7 ± 6.4	0.22 ± 0.50	2.3 ± 6.1	0.19 ± 0.48	2.0 ± 7.7	0.16 ± 0.6
Vertical	Mean Force (N)	1366 ± 190	3.4 ± 4.8	0.24 ± 0.35	5.6 ± 4.4	0.40 ± 0.32†	3.0 ± 4.4	0.22 ± 0.32	4.5 ± 3.2	0.32 ± 0.23†
	Peak Force (N)	2226 ± 420	1.4 ± 8.4	0.08 ± 0.44	5.0 ± 4.2	0.27 ± 0.22	3.8 ± 5.4	0.21 ± 0.29	3.4 ± 3.9	0.18 ± 0.21
	Peak Velocity (m/s)	2.69 ± 0.16	-1.57 ± 1.5	-0.24 ± 0.23	-1.8 ± 1.2	-0.27 ± 0.19	-2.23 ± 1.3	-0.35 ± 0.20	-1.9 ± 1.1	-0.29 ± 0.16
	Mean Velocity (m/s)	0.59 ± 0.11	2.21 ± 11.1	0.12 ± 0.60	4.4 ± 6.2	0.25 ± 0.35	2.22 ± 7.1	0.12 ± 0.39	1.7 ± 9.5	0.10 ± 0.52
	TT Peak Velocity (s)	2.69 ± 0.05	-5.28 ± 8.5	-0.24 ± 0.35	-10.7 ± 7.9	-0.49 ± 0.33†	8.15 ± 7.2	-0.37 ± 0.31†	8.4 ± 5.9	-0.39 ± 0.25†

ES = effect size; CT = contact time; RM = repetition maximum; † = statistically significant

Table 5.4 Drop jump kinetic and kinematic variables pre and post a 4 repetition maximum squat

		Pre 4RM	2 minutes post		4 minutes post		6 minutes post		8 minutes post	
		Mean ± SD	**% Change**	**ES**	**% Change**	**ES**	**% Change**	**ES**	**% Change**	**ES**
Horizontal	Mean Force (N)	486 ± 62.3	-0.2 ± 1.0	-0.01 ± 0.08	6.0 ± 5.5	0.45 ± 0.41†	-2.9 ± 5.2	-0.22 ± 0.39	-3.9 ± 4.5	-0.31 ± 0.34
	Peak Force (N)	925 ± 137	-0.4 ± 2.0	-0.02 ± 0.13	3.8 ± 5.9	0.24 ± 0.37	0.8 ± 2.5	-0.05 ± 0.15	-3.9 ± 3.5	-0.25 ± 0.22
	Contact Time (s)	0.33 ± 0.05	1.8 ± 9.2	0.11 ± 0.54	-3.8 ± 3.9	-0.23 ± 0.23	-3.6 ± 4.9	-0.22 ± 0.29	-1.1 ± 3.2	-0.07 ± 0.19
Vertical	Mean Force (N)	2438 ± 346	-4.5 ± 1.9	-0.32 ± 0.13	1.7 ± 5.6	0.12 ± 0.38	-0.4 ± 1.4	-0.03 ± 0.1	0.8 ± 3.42	0.06 ± 0.21
	Peak Force (N)	4033 ± 921	-6.9 ± 4.0	-0.47 ± 0.17	3.6 ± 7.8	0.15 ± 0.32	1.1 ± 14.7	0.05 ± 0.59	3.6 ± 6.3	0.15 ± 0.26
	Contact Time (s)	0.28 ± 0.06	3.7 ± 7.4	0.17 ± 0.34	-6.3 ± 5.4	-0.31 ± 0.25†	-2.1 ± 5.6	-0.10 ± 0.26	-6.6 ± 5.6	-0.33 ± 0.26†

5.5 Discussion

The purpose of this study was to determine the effect of STE from a back squat intervention on kinetic and kinematic measures in horizontal and vertical CMJ and DJ. The results showed that both horizontal and vertical jump kinetic and kinematic variables can be improved as a result of STE. Although many other studies have shown STE to have a positive effect on vertical jump performance [38; 41; 42], the existing literature is less convincing with regards to horizontal jump performance [41; 46]. However as Scott and Docherty [46] found no improvement in either vertical or horizontal jump performance this study may reflect the use of an ineffective STE protocol rather than the inability of STE to improve horizontal jump performance. In contrast, Ruben et al. [52] found a back squat protocol utilising four sets of ascending loads to produce STE in repeated horizontal hurdled jumps. This is in line with the findings of the current study; uniquely however, this current research found STE was obtained in both the vertical and horizontal plane of movement after a single heavy back squat stimulus.

It was also interesting to note that improved performance in the horizontal plane of movement was obtained following a vertical STE stimulus. This is supported by previous research which found an ascending back squat, i.e. loading in the vertical plane, to improve repeated hurdled horizontal jump performance [52]. This suggests that the physiological mechanisms contributing to STE are not specific, or at least not exclusively specific, to the plane of movement the STE stimulus exercise is performed in. This is of interest as vertical STE interventions such as the squat is familiar to most athletes and can easily be implemented in most training environments without equipment required for heavy horizontal pre STE interventions.

The STE model utilised in this study found the ES of change in kinetic and kinematic measures of jump performance to be greatest four minutes post squat intervention. Previous research has suggested that longer recovery periods may be required to produce STE. For example, Kilduff et al. [38] found significant improvement in jump height, peak RFD and power output eight minutes after heavy squat training in professional rugby players. Small improvements were found in jump height and power output four minutes post resistance training although these were not meaningfully large. Chiu et al. [145] also found a rest period of 18.5 minutes produced greater STE than a rest period of five minutes. Additionally, research has found no meaningful improvement in CMJ kinetic and kinematic variables measured post a 5RM squat intervention [179]. It has been suggested that the lack of improvement in this study was a result of insufficient rest period post the squat intervention [38]. This seems unlikely however as Comyns et al. [179] found CMJ performance, while still bellow base level performance, to be better two and four minutes post intervention as compared to six minutes post intervention. Additional research has also shown ergogenic effects after a rest period of four minutes following an STE interventions [158]. As such a lack of consensus exists regarding the ideal rest period to produce STE.

STE is complex and effected by the subjects physiological attributes including the proportion of slow and fast twitch fibres [137] and strength [38]. STE is also effected by the type and intensity of pre STE intervention [44]. As such, it seems likely that the lack of consensus regarding the ideal rest periods to obtain a STE effect is at least partially due to variation in subjects training status and the nature of the pre STE intervention. Therefore, although the finding of this research, that STE was greatest four minutes post a STE stimulus, is not consistent with some research in this field, this is likely due to methodological differences.

Previous research has also found the STE response is greater in highly trained athletes [38; 44; 49; 52; 123; 145]. For example, Ruben et al. [52] found that subjects with back squat equal to or greater than 2.0 times body weight exhibit a greater STE effect. Additionally, Gourgoulis et al.[123] found greater STE effects in individuals with 1RM back squats greater than 160kg. This study did not determine the within group difference between stronger and weaker subjects. However, this study found a significant STE effect in a relatively untrained subject, young athletes (age = 17.0 ± 0.7, 4RM back squat = 133.5 ± 16.7 kg). This finding is of particular interest as it is in contrast to the majority of research which shows STE to be greater in well trained athletes. In light of these findings however, it is possible that STE may be achieved in young, developmental, athletes if the pre STE intervention and rest period is appropriate.

5.6 Conclusion

The major findings of this research were that an acute STE effect can be obtained in both vertical and horizontal jump kinetic and kinematic variables as a result of a single back squat intervention in relatively untrained subjects. Additionally, it was found that the STE response was greatest four minutes post intervention in both vertical and horizontal jump kinetic and kinematic measures. These results demonstrate that it is possible to produce an ergogenic effect from a single set of heavy back squat. Furthermore, this study demonstrates that STE can be achieved in both the vertical and horizontal plane of movement as a result of a vertically loaded intervention, suggesting that the STE effect is not specific to the plane of movement that the intervention takes place in. Finally, this study showed that subjects do not need to be highly trained and rest periods do not need to be excessive in youth to achieve a STE response.

5.7 Practical Application

The findings of this study indicate that preloading in the vertical plane of movement improved horizontal dynamic performance. As the STE response is not limited, or not exclusively limited, to the plane of movement in which the pre loading intervention occurs, strength and conditioning practitioners may consider utilising vertical preloading exercise, such as the back squat, to cause STE in the horizontal plane e.g. horizontal jumps or sprinting.

Furthermore, as STE was demonstrated to occur in developmental athletes, practitioners may consider implementing STE protocols in younger and less highly trained athletes than may have been otherwise considered. Because of the complex nature of STE, it is important to note that any STE protocol should be carefully considered regardless of the training status of the target athletes.

This research also indicates that a rest period of four minutes can be effective in eliciting STE. Once again however, the rest period at which STE will occur, or occur to the greatest extent, is dependent on the physical characteristics of an individual and the nature and intensity of the pre STE intervention. It is clear however that practitioners need not prescribe long rest periods in an attempt to achieve STE, particularly if the pre intervention consists of a single set of strength training.

CHAPTER 6

PERFORMANCE EFFECT OF SHORT TERM ENHANCEMENT THROUGH CONTRAST TRAINING ON HORIZONTAL AND VERTICAL JUMP PERFORMANCE

Prelude: Because of the complex and highly individualised nature of STE, it is important to determine the acute effect of a STE protocol in a given population group before attempting to determine a chronic or training effect of STE. Having achieved this in the previous study (Chapter five) the training effect of STE through contrast training in team sport athletes could be explored.

6.1 Abstract

The purpose of this study was to investigate the chronic effect of a contrast training program designed to elicit an acute STE effect during training. A matched pairs training study design was implemented with contrast (STE affected) and complex (control) training groups completing a seven week training intervention. Twenty subjects participated. The contrast training group completed training based on a preloading protocol that had previously been shown to induce an acute STE effect within the subject population. The control group completed the same volume and type of training in a complex training format. Changes in squat 4RM strength and kinetic and kinematic performance in vertical and horizontal CMJ and DJ were measured via a force plate. Differences between the experimental and control group in change of mean strength (ES = 0.03 ± 0.33), vertical DJ (ES = contact time -0.22 ± 0.52; PF 0.20 ± 0.30; MF 0.30 ± 0.74) and horizontal DJ (ES = contact time -0.47 ± 0.73; PF 0.03 ± 0.36; MF 0.13 ± 0.56) were not meaningful. However, differences in mean change of vertical and horizontal CMJ measures of

force (ES range 0.40 - 0.46 ± 0.37 - 0.63), vertical CMJ peak velocity (ES = 0.84 ±0.66) and mean velocity (0.62 ± 0.88) were meaningful. These findings demonstrate that eliciting an acute STE response in dynamic training movements through contrast training can produce a chronic improvement in dynamic movements as a training effect.

6.2 Introduction

The importance of developing strength and power attributes in athlete populations is widely recognised. As such, methods of more effectively developing these traits in athletes are continually being sought. PAP or STE is one such method that has received attention from researchers [36-38; 40; 43; 59; 60]. STE can be defined as an acute improvement in muscular performance as a result of changes in contractile history [40; 44]. This can be utilised in training through the use of strength-power complexes to induce a more dynamic training movement, additionally, a primer set or work out immediately prior to competition may also improve competitive performance.

Although the exact mechanism by which STE occurs is unknown [43], it is suggested that STE is the result of both neurological and muscular mechanisms [113]. It is thought that near maximal contractions cause an increase in phosphorylation of myosin light chains [52] leading to increased actin-myosin interaction sensitivity to Ca^{2+} released from the sarcoplasmic reticulum and greater ATP availability resulting in increased actin-myosin cross-bridging [54; 113]. It is also thought that improved synchronisation of motor units and decreased pre-synaptic inhibition may contribute to STE [113]. Additional to the STE effect, a fatigue response is also caused as the result of immediate contractile history. The relationship between fatigue and the mechanisms contributing to STE is such that, immediately post a contractile stimulus, dynamic performance is not improved. However, as fatigue subsides at a greater rate than the effect of the mechanisms contributing to STE, after a sufficient rest period, an improvement in dynamic performance may occur [44]. The relationship between the mechanisms contributing to STE and fatigue is complicated and is affected by volume, intensity and type of contractile stimulus and subject characteristics including strength, fiber type and power to strength ratio, as well as the type of activity performed after the contractile stimulus [44].

Despite the lack of certainty regarding the mechanism causing STE and the complexity of the relationship between fatigue and STE, there is ample research which has demonstrated the effectiveness of STE to improve acute dynamic performance [37; 38; 40; 52; 177; 180]. It has also been shown that weighted stimulus in the vertical plane of motion, such as squatting, can improve not only vertical jump but also horizontal CMJ and DJ kinetic and kinematic measures [181]. It may be reasonably assumed that this acute effect can be used in training to elicit increased within session dynamic performance. It would be of interest to the sports science community to determine if STE can be used to not only improve the acute effect of dynamic training and performance, but to improve chronic dynamic performance through the use of complex pairs as a training tool. To date, however, an absence of studies exists regarding the chronic effect of STE through strength-power complexes when used as a training technique [54].

A number of studies have failed to show significantly greater training improvements in strength and power measures as a result of “complex training” over traditional training [55-58]. The term “complex training” in these studies refer to a series of strength sets being completed followed by a series of plyometric or dynamic training sets within the same training session [53]. However, Kotzamanidis et al. [61] found that complex strength and dynamic training had a greater positive effect on sprint speed and jump performance than weight training alone; this finding is somewhat predictable. Other studies have also demonstrated that complex strength and plyometric training can improve dynamic variables over not specifically dynamic training [59; 60]. The principle of training specificity would suggest that subjects who train with dynamic intent will improve in measures of power to a greater extent than subjects who do not train with dynamical intent.

However, complex training is unlikely to cause a STE effect across the dynamic training sets as the effects of the mechanisms contributing to STE diminishes over time and are likely to be offset by fatigue of additional dynamic training sets. As such, complex training must be considered distinct from the use of contrast training as a training tool which involves performing sets of body weight or lightly loaded movements performed dynamically between sets of heavy strength movement [64], which has the potential to elicit a STE effect in each dynamic training set.

It has been found that both one and two sessions of contrast training per week can improve sprint speed and squat jump height over a six week training period in young elite soccer players [153]. Additionally, research has found strength-power contrast training to be more effective than speed-power contrast training protocols at improving lower limb dynamic performance measures including the horizontal broad jump [64]. However, although these studies show contrast training to be an effective training strategy, they fail to show that contrast training causes greater training adaptation than the same training stimuli implemented in a traditional or complex training program.

What has yet to be established is whether utilising STE through contrast strength and plyometric training will result in a greater training effect over time than the same training protocol undertaken in a complex training format. The aim of this study was to determine the chronic training effect of STE as a training tool. This was done by comparing changes in performance variables in a contrast training group and a control group completing the same type and volume of training implemented in a complex training format. Comparative changes in strength as well as vertical and horizontal CMJ and DJ kinetic and kinematic variables were measured. A STE protocol developed by Dobbs et al. [181] was used in testing.

6.3 Methods

6.3.1 Experimental Approach to the Problem

The chronic training effect of STE on vertical and horizontal CMJ and DJ performance was determined using a matched pairs training study design based on subjects' squat strength. A seven week training intervention was completed to compare the mean changes in vertical and horizontal CMJ and DJ performance between a training group using STE as a training tool through the use of contrast training and a non STE training control group undergoing complex training. Each training group completed identical training protocols with the exception of the timing and order of jump and squat training sets.

Subjects completed two pre intervention and two post intervention testing sessions seven days apart during a non-training period (see table 6.1). Prior to the training intervention, a 4RM squat and jump familiarisation testing session and a testing session measuring baseline vertical and horizontal CMJ and DJ jump kinetic and kinematic measures were performed. After the training intervention a 4RM squat was retested followed by a test session in which vertical and horizontal CMJ and DJ jump performance were retested. The training intervention was implemented in season, during the subject's final training phase. Both pre and post intervention testing was implemented during non-training weeks.

Table 6.1 Research timeline and design

Pre Training Intervention				Post Training Intervention		
Testing Session 1		Testing Session 2		Post Test 1		Post Test 2
Warm Up	7 Days	Warm Up	7 Week Training Interventions	Warm Up	7 Days	Warm Up
4RM Back Squat Test		Horizontal and Vertical CMJ and DJ Tests*		4RM Back Squat Test		Horizontal and Vertical CMJ and DJ Tests*
Horizontal and Vertical CMJ and DJ familiarisation*						

CMJ = counter movement jump; DJ = drop jump; * = randomised order.

6.3.2 Subjects

Twenty male high school rugby union players (age = 17.0 ± 0.7 years; mass 87.4 ± 8.2 kg; height: 1.82 ± 0.06 m, 4RM back squat = 135.3 ± 17.3 kg) competing in the New Zealand Secondary School Super Eight competition were recruited for this study. The study was approved by the Auckland University of Technology Ethics Committee. Written informed consent was obtained from the subjects and subjects' legal guardian prior to study participation.

Subjects had a minimum training age of one year in a structured strength and conditioning program and were familiar with jump movements and plyometric training.

6.3.3 Procedures

Before each testing session a standardised warm up was undertaken, consisting of ten minutes of cycling (at 150W) on a cycle ergometer. This was followed by five minutes of prescribed lower limb dynamic stretches. Stretches were performed for 30s each and consisted of high knee lateral rotation, standing side to side groin stretch, calf pumps, front to back and side to side leg swings and pronated alternating lower back kick and kneeling lower back flexion and extension.

Both pre and post training RM testing followed the same protocol and consisted of a submaximal 8RM and 6RM lift before a 4RM lift at predicted maximal load. A rest period of five minutes was required between lifts. If successfully completed, the load was increased and an additional 4RM lift was attempted. This process was repeated until the subject failed. The best 4RM lift prior to failure was considered the subjects 4RM. Squat depth was required to be at least 90 degrees at the knee and squat depth was consistent within subjects. A 4RM attempt was considered a failure if the subject was unable to achieve appropriate depth or was unable to complete the lift. Previous studies have used similar 4RM testing protocols in college age athletes to predict 1RM back squat loads with reduced injury risk [181].

Pre and post intervention jump testing consisted of bilateral vertical and horizontal CMJ and DJ jump performance. This consisted of three repetitions of each jump type with 30s rest between repetitions. Jump order was randomised with two minutes rest required between each jump type. Vertical and horizontal CMJ were performed with self-selected countermovement depth immediately followed by a jump of maximal intensity [7]. DJ were performed from a drop depth of 40cm [109] immediately followed by a jump of maximal intensity. Instructions were given to minimise contact time while maximising jump height or distance. Subjects were required to place their hands on their hips during all jump tests.

Data for the jump tests was collected using a Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) at a sampling rate of 500Hz. Vertical force, velocity and impulse and horizontal force were recorded and stored for subsequent analysis using a custom designed software program (Objective Design Limited, Auckland, New Zealand). Reliability of jump tests for all kinetic and kinematic jump measures and performance tests used in this research was determined prior to testing, reliability of the tests ranged from ICC: 0.79 to 0.93 and CV%: 5.4 to 8.9% (Chapter three) [168].

Between pre and post-testing a seven week training intervention was implemented consisting of two training sessions per week. Each training session consisted of three to four sets of back squat and horizontal or vertical CMJ training. Athletes were required to lift RM loads. However, as training effects occurred throughout the training phase, athletes were allowed to self-select increases in load. Training sets and repetitions were the same for the experimental and control groups (see Table 6.2). Training protocols were also identical between the experimental and control group with the exception that the experimental training group using complex pairing to elicit a STE response in jump training.

During training, the experimental group completed a set of squats, rested for four minutes and then completed a set of horizontal or vertical CMJ. A rest period of four minutes post squat (4RM) had been found to elicit the greatest STE response in this specific subject group [181]. A rest period of two minutes was required after a set of jumps before the next set of squats was completed.

The control group completed all squat sets consecutively with a rest period of four minutes between sets and all CMJ sets consecutively with a rest period of two minutes between sets. Squat and jump sets were separated in the control group by approximately 30 minutes of upper body weight training. Both the experimental and control groups completed upper body training, however no other lower body weight training, dynamic or sprint targeted training was completed by either training groups.

Table 6.2 Squat and countermovement jump prescription for training intervention

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
Squat Repetitions	4 - 4 - 4		6 - 4 - 4		6 - 4 - 2 - 2		6 - 4 - 4 - 2		6 - 4 - 4 - 4		6 - 6 - 4 - 4		6 - 4 - 4	
Jump Repetitions	4 - 4 - 4		6 - 4 - 4		6 - 4 - 4 - 4		6 - 6 - 4 - 4		6 - 6 - 6 - 4		6 - 6 - 6 - 6		4 - 4 - 4	
Training Days	Tues	Thur	Tues	Thur	Tues	Thur	Tues	Thur	Tues	Thur	Tues	Thur	Tues	Thur
CMJ Direction	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert

CMJ = counter movement jump; Hor = horizontal; Vert = vertical.

6.3.4 *Statistical Analysis*

Changes in all pre to post strength, kinetic and kinematic measures were analysed using a pre-post controlled trial spreadsheet [182]. All data was log-transformed and adjusted to the mean of pre-test values before analysis as a covariate. All statistical analyses were determined to a 90% confidence interval. Data was back transformed for use in analysis. A modified Cohen scale was used to determine the magnitude of the differences between the within-group changes, with <0.2 representing a trivial difference, 0.2 - 0.6 representing a small difference, 0.6 - 1.2 representing a moderate difference and 1.2 - 2.0 a large difference [178]. A performance change was accepted as meaningful if a 75%, or greater likelihood that the true value of the standardised mean difference was greater than the smallest worthwhile effect. The smallest worthwhile change in performance from test to test established as a “small” ES (0.2 × between-participant SD) according to methods outlined previously [178].

6.4 Results

Differences in change of strength between the experimental and control group were not meaningful (ES = 0.03 ± 0.33). The control group had a pre training mean 4RM of 132.5 ± 17.1 kg and a change of 12.0 ± 5.9%; the experimental group had a pre training mean 4RM of 138.0 ± 17.2 kg and a change of 12.6 ± 4.3%.

The experimental group had greater improvements than the control group in both vertical and horizontal jumps measures except time to peak velocity in vertical CMJ (Table 6.3). The greatest difference in pre – post training ES was found in the vertical CMJ peak velocity (ES = 0.84) and mean velocity (ES = 0.62). The experimental group also had greater improvements than the control group in vertical and horizontal DJ measures, however, none of these differences were meaningful (Table 6.4).

Table 6.3 Change in mean (± SD) countermovement jump kinetic and kinematic test results after a training intervention

		Pre Training Result	% Change		Difference in Mean Effect Size
			Control	Experimental	
Horizontal	Peak Force (N)	701.3 ± 86.7	9.1 ± 8.2	16.0 ± 13.6	0.46 ± 0.63^{+}
	Mean Force (N)	349.7 ± 58.3	6.0 ± 12.6	14.8 ± 17.1	0.44 ± 0.61^{+}
Vertical	Peak Force (N)	2243 ± 551	4.1 ± 8.7	14.1 ± 14.1	0.40 ± 0.37^{+}
	Mean Force (N)	1377 ± 208	3.2 ± 7.2	10.2 ± 11.0	0.44 ± 0.47^{+}
	Peak Velocity (m/s)	2.69 ± 0.17	-0.50 ± 6.4	5.6 ± 4.9	0.84 ± 0.66^{+}
	Mean Velocity (m/s)	0.58 ± 0.10	3.9 ± 12.0	15.5 ± 25.5	0.62 ± 0.88^{+}
	TT Peak Velocity (m/s)	0.39 ± 0.10	-4.3 ± 12.9	-13.6 ± 31.0	-0.34 ± 0.59

Results expressed as mean ± SD; TT= time to; $^{+}$= statistically significant.

Table 6.4 Change in mean (± SD) drop jump kinetic and kinematic test results after a training intervention

		Result	Percent Change		Difference in
			Control	Experimental	Mean Effect Size
Horizontal	Peak Force (N)	930 ± 145	4.7 ± 4.9	5.2 ± 9.6	0.03 ± 0.36
	Mean Force (N)	492 ± 67.7	6.8 ± 7.3	8.8 ± 02.5	0.13 ± 0.56
	Contact Time	0.33 ± .06	-1.2 ± 15.4	-9.4 ± 17.2	-0.47 ± 0.73
Vertical	Peak Force (N)	4162 ± 973	3.8 ± 11.4	9.3 ± 9.7	0.20 ± 0.30
	Mean Force (N)	2470 ± 361	3.0 ± 9.5	7.7 ± 9.6	0.30 ± 0.47
	Contact Time	0.28 ± 0.06	-1.6 ± 16.3	-6.6 ± 16.0	-0.22 ± 0.52

Results expressed as mean ± SD.

6.5 Discussion

This study aimed to determine the chronic effect of STE as a training tool. This was achieved by determining the comparative change in strength and jump ability in an experimental, contrast training group and a control, complex training group. The major finding of this study was that the contrast training group showed significantly greater improvement in vertical and horizontal CMJ kinetic and kinematic measures. This shows that using a training protocol which elicits an acute STE response in dynamic training movements produces a chronic improvement in dynamic movements as a training effect. Previous studies have found complex training not to produce significantly greater improvements in strength and dynamic measures more so than traditional training [55-58]. However, although these studies implemented strength and plyometric/dynamic training within the same training session, they did not utilise strength-power complex pairs, that is, a strength set immediately followed by a dynamic or plyometric set. As such, it is unlikely that the aforementioned studies elicited a STE effect in training. Uniquely, this training study implemented a training protocol based on pre loading and rest protocols previously proven to elicit a STE effect in the subject population [181].

Previous studies have found complex training to improve measures of strength and power to a greater extent than traditional training techniques [59-61]. However, in these studies, although the experimental training group completed complex training which including dynamic sprint or jump movements, the control groups in these studies did not complete dynamic training. As such, although these studies show that complex training can be effective in improving strength and power, they do not demonstrate that complex training causes a greater training effect than equivalent training implemented in a non-complex training format.

Additionally, contrast training has also been shown to improve dynamic performance [64; 153]. However, these studies also failed to show that this training method causes a greater training effect than equivalent training implemented in a non-contrast format [64; 153]. Distinctly, this study implemented the same training activities in both the experimental and control groups with the exception of training order i.e. the use of strength-power complex pairs.

It is also interesting to note that, although testing and training procedures took place under laboratory conditions, the training protocol implemented by both the experimental and control group took place within a standard training phase during competition. This demonstrates that, within a functional training environment, the use of strength-power complex pairs can be successfully used as a training tool to elicit greater improvements in dynamic performance than traditional non-complex weighted and dynamic training.

Of further interest is the seemingly non-directionally specific nature of the STE effect elicited from the preloading STE stimulus. Although the back squat was undertaken in the vertical plane of motion, the experimental training group achieved a meaningfully larger training effect in both vertical and horizontal jump kinetics and kinematics. This is important as many traditional loading techniques apply load in the vertical plane of movement, however, horizontal dynamic training movements may have a greater transfer to functional movements e.g. sprint performance, than vertical dynamic training.

The change in squat strength was not meaningfully different between the experimental and control group. This study was not designed to produce a difference in mean change of strength between the experimental and control group, rather to produce a STE effect in dynamic training sets. As such, this finding is of no surprise. It is important to note however, that while the experimental training procedure was beneficial in improving jump kinetic and kinematic variables, it did not negatively affect strength training. The magnitude of improvement in strength in both the control and experimental group was likely due to the relatively untrained nature of the subjects.

Mean changes in DJ kinetic and kinetic measures were greater in the experimental group than the control group. However, none of these changes were meaningful. This does not discount the use of strength-power pairing as an effective training tool but reflects a lack of specificity in training toward the DJ as dynamic training consisted of vertical and horizontal CMJ rather than DJ.

Further research should be implemented into the effect of complex strength-power pair training on other dynamic movements including the DJ.

Additionally, further research regarding complex training designed to elicit STE in an attempt to elicit chronic improvements in dynamic performance, would seem warranted. This should include investigation into the effect of STE as a training tool on other population groups, particularly in elite athletes as research suggests stronger athletes tend to be more likely to elicit an acute STE responses than weaker athletes [52]. It is also important to note that although kinetic and kinematic measures in jump performance improved to a greater extent in the experimental, STE affected, training group, jump height and distance were not measured. Although it may be assumed that improvements in kinetic and kinematic measures may equate to improved jump performance, this has yet to be shown.

6.6 Conclusion

The current research demonstrates that STE can not only be used to improve acute dynamic performance but, when used as a training tool, can also improve chronic dynamic performance. By implementing strength and plyometric complex pairs (contrast training) to elicit improved acute dynamic performance during training through STE, it is possible to cause meaningfully greater chronic improvement in CMJ and DJ kinetic and kinematic than when implementing identical, non-complex, training protocol. These findings will be of interest to strength and conditioning practitioners who are interested in optimising the effectiveness of complex strength-power training. Further research is required into the effect of STE as a training tool to effect acute changes in jump performance in different population groups and in different performance measures.

6.7 Practical Applications

The primary practical application of this study is that the use of STE through contrast training may be considered as a training tool by practitioners. This may be achieved using standard loading techniques, e.g. squatting, to achieve STE in both the vertical and horizontal plane of movement. Such training may be implemented effectively within a standard training phase during competition.

It is important to note however that the STE response to pre intervention loading is complicated and will differ between subject groups depending on their physiological characteristics. As such, it is advised that a STE protocol proven to produce an acute STE effect in the intended training population be determined and utilised in any future contrast training designed to improve chronic dynamic performance through STE.

CHAPTER 7

GENERAL DISCUSSION

7.1 General Discussion

This doctoral thesis was undertaken to improve understanding of power profiling and the development of lower limb dynamic ability, particularly in the horizontal plane of movement, in team sport athletes. By developing greater understanding of horizontal power profiling as well as the acute and chronic effect of STE in horizontal jump performance, this research aimed to improve prognostic and diagnostic understanding of movements in the horizontal plane.

To provide a summary of the existing literature a review of the current knowledge concerning lower limb power profiling and STE (Chapter Two) was completed. This literature review provided an overview of the research in this area and allowed the direction of the research projects within this thesis to be formulated. It was found that there was little research concerning the use of horizontal jumps in power profiling for team sport athletes. Additionally, the reliability of many kinetic and kinematic variables in horizontal jumps was yet to be determined. Therefore, this thesis included a study to determine the reliability of kinetic and kinematic measures contributing to a comprehensive horizontal power profiling test battery (Study One). The kinetic and kinematic variables that were found to be reliable in horizontal CMJ, SJ and DJ were then utilised to determine the relationships between vertical and horizontal power profiling and measures of functional performance (Study Two).

Some of these horizontal power profiling measures were then implemented in determining the acute effect of STE in dynamic movements in the horizontal plane (Study Three). These findings were used to determine the chronic effect of STE when used as a training tool through the implementation of a contrast training protocol known to cause acute STE in the subject population (Study Four). The following discussion summarises the major findings of these areas of research.

Vertical jump movements are amongst the most widely used assessments of lower limb dynamic ability and are commonly used in power profiling [102]. Additionally, measuring kinetic and kinematic variables in vertical jump movements allows the mechanical determinants which contribute to dynamic performance to be isolated [1; 3; 4]. However, these tests do not take into account an athletes' ability to produce force in the horizontal plane of movement, which is critical in many sporting movements [6-8]. As such, the purpose of Study One was to assess the reliability of kinetic and kinematic variables in horizontal jump movements. The results of this study showed many horizontal power profiling measures to be reliable for CMJ, DJ and SJ assessment. Specifically, PF and MF were reliable in all horizontal jumps (ICC range: 0.79 - .97; CV range: 6.6% - 9.1%). CT in the horizontal DJ was also found to be reliable jumps (ICC range: 0.73 - 0.93; CV range: 6.1% - 8.8%). However, PP was generally unreliable in horizontal jumps (ICC range: 0.77 - 0.94; CV range: 9.9% - 19.6%) and RFD and early RFD were also unreliable (ICC range: 0.73 - 0.95; CV range: 8.9% - 16.2%). Measures such as MF, PF and CT show similar reliability of some reported values in commonly used vertical jump measures. For example Melyan et al [7] found CV: 6.7-7.2% in unilateral vertical jump heights. Additionally, bilateral CMJ height in developmental rugby players has been shown have a CV of 5.1% [183]. This indicates that such variables are acceptably reliable and may be of practical use.

Having determined the horizontal power profiling measures which were reliable in Study One, a correlational study determining the relationship between kinetic and kinematic variables measured in vertical and horizontal jumps and measures of functional performance was completed. By comparing the respective relationships, it was possible to determine whether testing in the horizontal or vertical plane of movement had greater diagnostic and prognostic value to measures of functional performance. The findings of Study Two showed that horizontal PF and MF in both bilateral and unilateral jumps, to have a stronger relationship to sprint speeds ($R^2 = 0.13$ to 0.58) than vertical PF and MF ($R^2 = 0.01$ to 0.50). As horizontal jump movements had large correlations to sprint speed, it is likely that using horizontal jumps in training will have a greater transfer to sprint performance than vertical dynamic training. This supports previous research which found net horizontal force applied while running on a treadmill to have a significant correlation to field sprint performance while mean vertical force and total ground reaction force were not [9; 175]. Together, these findings highlight the importance of developing, not only dynamic ability, but the ability to apply force effectively in the horizontal plane of movement.

Furthermore, many movements involve unilateral force production in a combination of horizontal and vertical force production [7; 8]. As such, it has been suggested that unilateral tests of dynamic ability better represent movement patterns such as sprinting [1]. This was supported by the findings of Study Two, namely that unilateral measures of horizontal PF and MF tended to have greater relationships to sprint speed than bilateral measures of horizontal PF and MF. Similarly, research by Nesser et al. [20] found five step horizontal jump distance to have greater correlation to 40m sprint speed than vertical jump height.

No measured power profiling variables in Study Two showed large positive correlations to muscle stiffness or measures of muscle architecture. This is surprising as fascicle length and angle are thought to affect rate of contractile force development [27; 44]. Fascicle length has also been found to be greater in sprint-trained athletes than in distance runners [29] suggesting a link between muscle architecture and dynamic ability. Additionally, muscle stiffness is related to the storage and utilisation of force in the SSC [89] and is thought to be important to dynamic performance and sprint speed [20; 25]. Considering the scarcity of research investigating the relationship between muscle stiffness, muscle architecture, and power profiling variables, particularly in the horizontal plane of movement, it would seem too early to make any definitive conclusions regarding the relationship between these variables.

Previous research has suggested that different vertical jump types rely on different mechanisms in vivo which relate to mechanical characteristics important throughout different phases of a sprint i.e. early acceleration, acceleration and speed maintenance [109]. For example, both DJ and sprint performance at high speed depend heavily on the elastic property of muscles and tendons in the SSC [3; 109]. This was supported by the findings presented in Study Two indicating that MF, PF and velocity in horizontal DJ had progressively stronger correlations to sprint speed over greater distances. As such the horizontal DJ may too be used to isolate physiological mechanisms important to sprint performance at high speed.

In contrast to common understanding which espouses that the SJ is related early concentric contractile force development and the early acceleration phase of a sprint [4; 73], the horizontal SJ showed correlations which were generally as strong over shorter (e.g. 0-5m) and longer distances (e.g. 20-30m). This does not discount the ability of the horizontal SJ to improve the early acceleration phase of a sprint but suggesting that horizontal SJ may be an effective tool in developing both early acceleration and sprint speed over longer distances.

These findings indicate that horizontal jumps may too be used to target physiological adaptation specific to the distinct phases of sprint performance. Considering the seemingly greater importance of horizontal, rather than vertical, force production to sprint performance [9; 175], horizontal jumps may be considered a favored alternative than their vertical counterpart by strength and conditioning practitioners seeking to improve specific aspects of sprint performance.

As well as improving the diagnostic and prognostic value through improved understanding of lower limb dynamic assessment, it is also important to undertake research to explore training techniques to improve both acute and chronic dynamic ability. One such method that may improve acute and potentially chronic dynamic ability is STE [36-38; 40-43; 45]. Research presented in Study Three addressed the acute effect of pre-loading on kinetic and kinematic variables during vertical and horizontal jumps and Study Four addressed the chronic effect of STE as a training tool through the utilisation of contrast training. The overall aim of this research was to improve the understanding of STE as a tool to improve functional performance, particularly in the horizontal plane of movement.

The major finding reported in Study Three was that it is possible to produce an ergogenic effect in horizontal and vertical jump performance from a single set of heavy back squats in developmental rugby union players. This was determined by comparing pre intervention horizontal and vertical jump performance to jump performance at two, four, six and eight minutes post intervention. Improvement in dynamic performance was greatest four minutes post squat intervention with most measures in both horizontal and vertical jumps. Meaningful small improvements were found four minutes post squat in CMJ vertical MF (ES = 0.40) horizontal MF (ES = 0.51), time to peak velocity in vertical CMJ (ES = -0.49), MF in horizontal DJ (ES = 0.45) and vertical DJ contact time (ES = -0.31). As STE was produced in both vertical and horizontal jumps from a single set of heavy back squats this demonstrates that the effect of STE is not confined to the plane of movement of the intervention.

It is of great interest that these results were found in developmental athletes as STE has been found to have a greater effect in highly trained individuals [38; 44; 49; 52; 123; 145]. This is thought to be due to greater volume and proportion of type two muscle fibres [44; 137] and a more efficient fatigue response [145] in such individuals. Furthermore, previous research has found STE not to be significant in moderately trained subjects [45; 47; 158] . However, the findings of Study Three show that, given an appropriate stimulus and recovery period, significant STE may be achieved in developmental athletes, demonstrating that subjects need not be highly trained to achieve STE.

Study Four indicated that STE can also be utilised to improve chronic dynamic performance. This was achieved by implementing strength and plyometric complex pairs to elicit acute STE in dynamic performance during training over a seven week period. Meaningfully greater improvement in chronic CMJ and DJ kinetic and kinematic variables where found as a result of complex training than in an identical, non-complex, training protocol. Specifically, the experimental, contrast training group had greater improvements than the control group in both vertical and horizontal jumps in most measures. The greatest difference in pre – post training was found in the vertical CMJ peak velocity (ES = 0.84) and mean velocity (ES = 0.62). The experimental group also had greater, but not meaningfully different, improvements than the control group in vertical and horizontal DJ measures.

These findings demonstrated that by adjusting exercise order and rest periods in such a way that STE is achieved during training, meaningfully greater improvements in dynamic performance can be achieved. Additionally, this occurred with no detriment to strength gains in the experimental group. These findings should to be of great interest to strength and conditioning specialists.

The research outcomes of this thesis were innovative and contribute to the wider body of research by expanding the methods of assessing and developing lower limb dynamic ability in well trained and developmental rugby players. The development of a reliable horizontal power profiling testing battery demonstrates that these kinetic and kinematic variables can be used alongside their vertical counterparts with confidence. Additionally, considering the generally stronger correlation that horizontal rather than vertical power profile measures have to measures of sprint speed, it would seem that such measures would have potentially greater diagnostic and prognostic value.

Research concerning the acute and chronic effects of STE described in this thesis contributes to the development of this field of research. The findings that acute STE can be achieved in developmental athletes and that STE can be implemented to produce chronic improvements in dynamic performance may be of particular interest to strength and conditioning practitioners and may be used to inform training protocols.

7.2 Limitations

A limitation of this research was the inability of the equipment utilised, i.e. the Triaxial Force Plate (Objective Design Limited, Auckland, New Zealand) to assess horizontal velocity and impulse. This was due to the developmental nature of the technology. Considering the promising nature of velocity in vertical jumps as a diagnostic and prognostic tool in this and other research, determining the reliability of horizontal velocity in a range of horizontal jump types and its correlation to measures of functional performance would have been of great interest.

Statistical power was affected in this research by sample size. Highly trained athletes are constrained by rigorous training and performance schedules. Additionally, rugby players are often affected by injuries of various severities. As such, it was not possible to capture a sample size of highly trained rugby union players as large as was intended. This meant that, although within acceptable limits, statistical power was not as strong as would have been preferred.

Considering the highly complex nature of STE and, subsequently, the highly individualised nature of subjects STE response [39; 48] a limitation in the STE studies was the somewhat homogenous nature of the subject population. That is to say, all subjects were developmental athletes. Although research into such population groups is warranted and of interest, it does mean that only limited inferences can be made between these results and the effect of STE in population groups with differing physiological characteristics e.g. stronger or weaker athletes.

Similarly, in the research undertaken concerning power profiling, only high level developmental rugby players were used as subjects. The physiological characteristics of rugby union players are distinct in many ways from a number of other sports. As such some of the findings of this research may not be directly transferable to athletes of other sporting codes.

Finally, although this research determined that kinetic and kinematic measures in jump performance improved to a greater extent in the experimental, STE affected, training group, jump height and distance was not measured, nor was sprint speed. It may be assumed that improvements in kinetic and kinematic measures may equate to improved jump and sprint performance, but further research to confirm this is required.

7.3 Practical Applications

There are a number of findings in this thesis that are applicable to strength and conditioning practitioners. In particular these concern the prognostic and diagnostic value of horizontal power profiling variables and the use of STE as a training tool to improve acute and chronic performance in the horizontal plane of movement. These practical applications include:

Study 1

- PF and MF are reliable in unilaterally and bilaterally horizontal CMJ, SJ and DJ and can be used with confidence by coaches, athletes and researchers alongside measures of vertical power profiling.
- RFD and early RFD should not be used in power profiling unless reliable testing and calculation protocols can be developed and used.
- PP was found to be unreliable in horizontal jumps and should be used with caution.

Study 2

- Practitioners interested in the prognostic value of kinetic and kinematic variables to functional movements such as sprint speed, should consider using horizontal jumps alongside vertical jumps in testing.
- Strength and conditioning practitioners concerned with improving lower limb dynamic performance, particularly sprint movements, should utilise horizontal jump movements in training due to their strong relationships with sprint speed.
- Strength and conditioning practitioners may use the horizontal DJ as a training tool to improve acceleration at high speed and speed maintenance due to its stronger relationships to sprint speed over longer distances.
- As horizontal SJ had similar correlations to sprint speed over all distances measured, rather than sprint speed over short distances as may have been expected, horizontal SJ may have limited value for targeting concentric force production in early sprint performance.

- Considering the strength of the correlations between the horizontal SJ and all sprint distances measured, this jump modality may be effective as a training tool to improve sprint performance in general.

Study 3

- Utilising preloading in the vertical plane of movement i.e. squatting, may be used to improve horizontal dynamic performance.
- Given an appropriate conditioning contraction and recovery period, STE may be achieved in developmental athletes and improve acute dynamic performance.
- STE can be obtained from a single back squat intervention with a four minute rest period although, as STE is complex, the pre STE intervention and rest period which produces the greatest STE will vary depending on the physical characteristics of any given athlete.

Study 4

- By implementing strength and plyometric contrast training to elicit improved acute dynamic performance, STE can be used to improve long term dynamic performance to a meaningfully greater extent than equivalent non STE affected training.
- As STE response is highly variable between athletes, STE protocol should be proven to cause acute improvement in dynamic performance in a given athlete population before being used in contrast training.

7.4 Future Research

The research undertaken in this thesis has furthered understanding regarding the assessment of lower limb dynamic performance in highly trained rugby union players and development of lower limb dynamic ability in developmental rugby union players. Additionally, this research has helped to inform avenues of future research that will continue to expand and improve our understanding of diagnostic tools to measure and prognostic tools to develop lower limb dynamic ability.

This research has found measures of velocity in vertical jump, particularly in the CMJ and SJ to have strong and very strong correlations to sprint speed. Furthermore, correlations between horizontal rather than vertical jump kinematic measures tended to have stronger relationships to sprint speed. As such, it can be reasonably assumed that measures of velocity in horizontal jumps may have very strong relationships to sprint speed. However, further research is required to prove if this is the case.

This research also showed that vertical but not horizontal SJ tended to show stronger correlations to sprint speed over short distances, i.e. early acceleration, compared to sprint speed over longer distances. This is of interest as these findings are in contradiction to the commonly held understanding that the SJ is thought to isolate the mechanical characteristics which are important to early acceleration during a sprint movement. It may be that vertical SJ isolates such characteristics but that the horizontal SJ does not. However, further research is required in this field.

Additionally, it has been previously suggested, and supported in the findings of this research, that different jump types rely on mechanisms in vivo which relate to physiological mechanisms important throughout different phases of a sprint. This is most strongly demonstrated in the current research which clearly shows PF and MF in horizontal DJ to have stronger correlations to speed over longer rather than shorter distances and, therefore, mechanisms contributing to acceleration at high speed and speed maintenance e.g. the stretch shorten cycle. Of further interest would be longitudinal research designs to investigate the effect of training with specific horizontal jumps types on performance in the different phases of sprint performance.

STE is a promising tool for improving both acute and chronic dynamic performance although it is complex in nature and not yet well understood. As such, future research in this field would seem warranted. The findings of this research challenge the understanding that STE only occurs in highly trained athletes by showing a meaningful acute STE response in developmental athletes. It may be that these athletes require different pre loading interventions and rest periods than highly trained athletes to elicit a STE response. As such, further research is also warranted into the effect of STE in developmental athletes using different STE protocols.

As this research demonstrates that acute STE during training may improve chronic dynamic performance, further research utilising complex training to explore the chronic effect of STE should be undertaken. This should include investigation into the effect of STE as a training tool in more diverse population groups. This may be of particularly interest in elite athletes because, as previously stated, it has been shown that stronger athletes tend to be more likely to elicit STE responses than weaker athletes.

Finally, research into the effect of complex strength power pair training utilising other dynamic training movements, including the DJ, should also be investigated Although Study Four found mean changes in DJ kinetic and kinetic measures were not significantly greater in the experimental group than the control group, this reflects a lack of specificity in training with the DJ i.e. dynamic training consisted of vertical and horizontal CMJ rather than DJ. As such, complex training utilising jump types other than the CMJ may be of interest.

This research has been successful in demonstrating the feasibility, diagnostic value and prognostic significant of utilising horizontal jumps alongside there vertical counterparts in power profiling. Additionally, the acute and chronic effects of STE in horizontal performance were demonstrated. Undertaking the aforementioned research would continue to build on the findings of this thesis and the wider body of literature regarding lower limb dynamic assessment and development of acute and chronic dynamic ability in the horizontal plane of movement.

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APPENDICES

Appendix 1. *Consent Forms*

Appendix 1a. Players Consent Form (Chapters 3 and 4)

Players Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Title: Understanding and Optimising Vertical and Horizontal Force Production for Performance in Team Sport Athletes.

Project Supervisor: ***Dr Nicholas Gill***

Researcher: ***Caleb Dobbs***

- I have read and understood the information provided about this research project in the Information Sheet provided.
- I have had an opportunity to ask questions and to have them answered (please contact the student researcher by phone with any questions: Caleb Dobbs, Ph: 027 842 5235).
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I understand that that my refusal to take part in this research or results of my testing will not affect my standing in the WRU or future selection.
- I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance (or that might be aggravated by the tasks requested), or any infection.
- I agree to take part in this research (please tick one):
  Yes O No O
- I wish to receive a copy of my individual results from this research project (please tick one):
  Yes O No O
- I am willing to allow WRU coaching staff to view my test results (please tick one):
  Yes O No O

Participants signature:...

Participants name:...

Date: / /

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27

Appendix 1b. Legal Guardian Consent Form (chapters 3 and 4)

Legal Guardian Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Title: Understanding and Optimising Vertical and Horizontal Force Production for Performance in Team Sport Athletes.

Project Supervisor: ***Dr Nicholas Gill***

Researcher: ***Caleb Dobbs***

- I have read and understood the information provided about this research project in the Information Sheet dated provided.
- I have had an opportunity to ask questions and to have them answered (please contact the student researcher by phone with any questions: Caleb Dobbs, Ph: 027 842 5235).
- I understand that the dependent concerned may withdraw from the research and/or may withdraw any information that has been provided for this project, at any time prior to completion of data collection, without being disadvantaged in any way.
- I understand that my dependents refusal to take part in this research or the result of any testing that may take place in this research will not affect their standing in the WRU or future selection.
- My dependent does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs their physical performance (or that might be aggravated by the tasks requested), or any infection.
- I agree to allow my dependent to take part in this research (please tick one):

  Yes O No O
- I am willing to allow WRU coaching staff to view my dependents test results (please tick one):
  Yes O No O
- Legal Guardian's Signature:..
- Legal Guardian's Name:..
- Dependant's Name:..

Date: / /

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27

Appendix 1c. Players Consent Form (chapters 5 and 6)

Players Consent Form

Project Title: The Effect of Short Term Enhancement on Horizontal and Vertical Power Production.

Project Supervisor: ***Dr Nicholas Gill***

Researcher: ***Caleb Dobbs***

- I have read and understood the information provided about this research project in the Information Sheet provided.
- I have had an opportunity to ask questions and to have them answered (please contact the student researcher by phone with any questions: Caleb Dobbs, Ph: 027 842 5235).
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I understand that that my refusal to take part in this research or results of my testing will not affect my standing in the HBHS 1st XV or future selection.
- I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance (or that might be aggravated by the tasks requested), or any infection.
- I agree to take part in this research (please tick one):

  Yes O No O

- I wish to receive a copy of my individual results from this research project (please tick one):
  Yes O No O
- I am willing to allow WRU coaching staff to view my test results (please tick one):
  Yes O No O

Participants signature:...

Participants name:...

Date: / /

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27

Appendix 1d. Legal Guardians Consent Form (chapters 5 and 6)

Legal Guardian Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Title: The Effect of Short Term Enhancement on Horizontal and Vertical Power Production.

Project Supervisor: ***Dr Nicholas Gill***

Researcher: ***Caleb Dobbs***

- I have read and understood the information provided about this research project in the Information Sheet dated provided.
- I have had an opportunity to ask questions and to have them answered (please contact the student researcher by phone with any questions: Caleb Dobbs, Ph: 027 842 5235).
- I understand that the dependent concerned may withdraw from the research and/or may withdraw any information that has been provided for this project, at any time prior to completion of data collection, without being disadvantaged in any way.
- I understand that my dependents refusal to take part in this research or the result of any testing that may take place in this research will not affect their standing in the HBHS 1st XV or future selection.
- My dependent does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs their physical performance (or that might be aggravated by the tasks requested), or any infection.
- I agree to allow my dependent to take part in this research (please tick one):
  Yes O No O
- I am willing to allow WRU coaching staff to view my dependents test results (please tick one):
  Yes O No O
- Legal Guardian's Signature:...
- Legal Guardian's Name:...
- Dependant's Name:..

Date: / /

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27

Appendix 2. *Information Sheets*

Appendix 2a. Information Sheet (Chapters 3 and 4)

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced: 6 December 2011

Project Title

Understanding and Optimising Vertical and Horizontal Force Production for Performance in Team Sport Athletes.

Introduction

Caleb Dobbs is a Doctorate candidate with the AUT University in Auckland, in addition to his role as strength and conditioning coach for the Waikato Rugby Union in the Academy programme. As part of his doctoral candidacy Caleb is involved in undertaking research in the areas of power production within the muscle and power testing.

As a current member of the Waikato Academy, High Performance or ITM cup training group, you are being invited to participate in research designed to improve testing procedures for lower leg power.

Please understand that ***you are not obliged to participate in this research and may decline this invitation without any adverse consequence, if you do decide to participate, you may withdraw at any time also without any adverse consequences.*** Withdrawal or refusal to participate will not affect your standing in the WRU or future selection decisions.

What is the purpose of this research?

The purpose of this project is to produce a *reliable* and *valid* group of tests to comprehensively profile force in the horizontal plane of movement and to see what relationships exist between vertical and horizontal measures of power production in the body. *Reliability* means the consistency of a measure, that is, if you perform the same way in two trials, you will get the same result.

Additionally this study aims to determine whether horizontal measures of power are *valid* as predictors of functional performance. *Validity* means that the test measures what it is meant to quantify. This will be achieved by determining whether horizontal force profiling has a stronger relationship to sprint speed over short distances, measures in muscle architecture and measures in muscle stiffness than vertical power profiling measures.

What are the benefits?

To the Athlete.

Force profiling, as will be undertaken in this research, gives an in-depth understanding of not just how powerful an athlete is but also into how they produce their power within the muscle. Force profiling is used by many professional sports teams to more specifically determine individual athletes' muscular characteristics and to program specifically for them. Put simply, force profiling allows for more specific training programmes to be designed for athletes, which should lead to greater training effectiveness.

Additionally, force profiling has not been tested in the horizontal plane of movement until now. As the first athletes to be tested in this way, we will obtain a unique understanding of how you (the athlete) produce power. As such, the force profile obtained during this research will give your strength and conditioning coach a more specific and unique understanding of how you produce power. This will help them program more specifically and effectively for you and should result in greater training effectiveness.

To the Strength and Conditioning Community.

By increasing our understanding of vertical and horizontal force production and testing protocols, this research will be beneficial in developing greater understanding of the relationships between the factors affecting muscular power in the body in the horizontal and vertical planes of movement, as well as increasing our understanding of the likely effects that horizontal power measures will have on functional performance.

What will happen in this research?

Project Outline.

There are two stages involved to this research project. The initial stage of this project is to establish the reliability of the vertical and horizontal tests used in this study. During this phase (starting in early March 2011), each jump test will be repeated on three separate occasions: one familiarisation session and two vertical and horizontal jump testing sessions.

The second stage of this project is designed to determine the strength of relationships between vertical and horizontal jump performance and sprint speed, muscle stiffness and muscle architecture. This will include an additional jump familiarisation and a vertical jump and horizontal test session, as well as a sprint speed and muscle stiffness testing session and an ultrasound test to determine critical measures in muscle architecture.

All testing sessions will take place in or around normal training sessions with the exception of the ultrasound test (muscle architecture), which will take place in a registered ultrasound clinic. All test protocols and duration of testing sessions are set out below.

The tests

Countermovement Jump (CMJ)

The CMJs will consist of a self-selected countermovement depth immediately followed by a jump of maximal intensity. A natural arm swing will be allowed in CMJ tests and instructions will be given to jump to maximal distance or height, depending on the plane of movement that the test is being undertaken in.

Squat Jump (SJ)

The SJ will involve a 3 second static hold at a 90° knee angle followed by a jump of maximal intensity. You will not be allowed to dip deeper than the 90° after the 3 second hold. A natural arm swing will be allowed in the SJ.

Drop Jump (DJ)

The single leg DJ will consist of a drop of 20cm off a box immediately followed by a jump of maximal intensity. You will be instructed to minimise contact time on the ground while maximising jump height or distance. Two legged DJ will consist of the same protocol but will include a drop of 40cm preceding jumps.

> *Each jump will be performed three times both bilaterally (on both legs) and unilaterally (single leg, on your dominant leg). 30 seconds' rest will be required between each jump.*

Muscle Stiffness

Muscle stiffness will be measured using the maximal repeated hop test. This will consist of 10 consecutive maximal effort bilateral hops completed on a force plate. You will be instructed to jump for maximal height while keeping your legs as straight as possible and your hands on their hips. Jump height and contact time will be recorded for each jump.

Muscle Architecture

Muscle architecture, in simple terms, is the arrangement of muscle fibres relative to the axis of force generation. This affects the muscle's ability to produce force. Muscle architecture will be measured on the quadriceps and calf muscle using ultrasound testing. This is a pain free procedure and will be administered by a trained professional.

Sprint Speed

During sprint speed test you will be required to start with your preferred foot on a standardised mark 50cm in front of the first timing light, so that you will not cross the first timing light at the start point but in your first stride. You will be instructed to sprint at full speed without slowing until you have passed the last timing light at 30m.

The duration of testing is outlined below:

Study 1:

Testing Sessions	Time		
	Warm Up	Testing	Total
Jump Familiarisation Session	15 mins	30 mins	45 mins
Vertical and Horizontal Jump Test (x2)	15 mins	45 mins	60 mins (x2)

(Total Time: 2 hours 45 minutes)

Study 2:

Testing Sessions	Time		
	Warm Up	Testing	Total
Sprint Speed and Muscle Stiffness	15 mins	20 mins	35 mins
Muscle Architecture	N/A	60 mins	60 mins
Jump Familiarisation Session	15 mins	30 mins	45 mins
Vertical and Horizontal Jump Test	15 mins	45 mins	60 mins

(Total Time: 3 hours 20 minutes)

What are the discomforts and risks?

You are being asked to participate in a range of tests, some of which you may not be familiar with. As with any physical activity, there is a risk of injury. However, the anticipated discomfort and risk from participating in this testing is not significant and will not be greater than your normal training.

The other possible discomfort is a delayed onset of muscle soreness (DOMS) in the day/s following the testing. However, it is unlikely that the DOMS resulting from this testing, if experienced at all, will be significant.

How will these discomforts and risks be alleviated?

To reduce discomforts and risks from testing, you will be asked to physically prepare yourself prior to the first test by undertaking a warm-up consisting of 10 minutes of cycling (at 150W) on a Cycle

Ergometer followed by 5 minutes of prescribed lower limb dynamic stretches. You will also be encouraged to keep warm and drink fluids throughout the testing session. Immediately after each test, you should move about to keep blood circulating and to assist with the breakdown of lactic acid – light rowing or walking is better than standing still or lying down.

Additionally, prior to testing you will have the opportunity to familiarise yourself with the equipment and the testing process. You will also have the opportunity to ask questions and to receive feedback about your technique during your familiarisation session.

If, at any time, you do not feel that you are able to complete the movements requested, you will be encouraged to notify the researcher immediately. Finally, please notify the researcher if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required tasks. For example, a current knee injury would exclude you from the sprint test, a shoulder injury may affect arm swing in jump movements etc.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

The identity and results of each participant will be kept confidential. Only the student researcher (Caleb Dobbs), the primary, secondary and co-supervisor (Dr Nicholas Gill, Dr Mike McGuigan and Dr Dan Smart) will analyse your results.

Only group results will be presented in published research or presentations. However, if you are willing (i.e. give permission in the player consent form) to allow relevant coaching staff to view your test result, a copy of your individual results will be provided to assist with the design of any training programmes or interventions. *Data presented to coaching staff will not be used to influence future selection.*

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for testing. The majority of testing will take place in or around normal training times, with the exception of ultrasound testing.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have plenty of opportunity to approach Caleb around your normal training sessions or to contact him via e-mail or phone (see contact details below). Feel free to ask any questions you would like about the study. The testing for this research will begin in early March 2012.

How do I agree to participate in this research?

If would like to participate in this research, please fill in and sign the attached *Consent Form* and return it to your strength and conditioning coach. This must be completed before you can participate in the research.

Will I receive feedback on the results of this research?

Yes, after the initial reliability phase of the project is completed you can receive a summary of your individual results once the information is ready for distribution (around May 2012). Please tick the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be addressed in the first instance to the Project Supervisor, Dr Nicholas Gill (see contact details below).

Concerns regarding the conduct of the research should be addressed to the Executive Secretary, AUT, Dr Rosemary Godbold, *rosemary.godbold@aut.ac.nz* , 921 9999 ext 6902.

Who should I contact if I want more information about this research?

Please contact Caleb Dobbs.

Who should I contact if I want more information about this research?

Please contact Caleb Dobbs.

Student Researcher Contact Details:

Caleb Dobbs, cbf6270@aut.ac.nz, mobile 027 423 5235.

Project Supervisor Contact Details:

Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 0274 888 699

Dr Mike McGuigan, mcguigan.mike@hpsnz.org.nz, telephone: 021670131

WRU High Performance Manager:

Mike Crawford, telephone: 021 344 562

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27

Appendix 2b. Participant Information Sheet (chapters 5 and 6)

Participant Information Sheet

Date Information Sheet Produced: 7 June 2013

Project Title

The Effect of Short Term Enhancement on Horizontal and Vertical Power Production.

Introduction

Caleb Dobbs is a Doctorate candidate with the AUT University in Auckland, in addition to his role as a strength and conditioning coach for the Waikato Rugby Union in the Academy programme. As part of his doctoral candidacy Caleb is involved in undertaking research in the areas of power production within the muscle and power testing.

As a current member of the HBHS rugby development system, you are being invited to participate in research designed to better understand the effects of short term enhancement on lower limb vertical and horizontal performance.

Please understand that ***you are not obliged to participate in this research and may decline this invitation without any adverse consequence, if you do decide to participate, you may withdraw at any time also without any adverse consequences.*** Withdrawal or refusal to participate will not affect your standing in the HBHS rugby system or future selection decisions.

What is the purpose of this research?

The purpose of this project is to determine the effect that short term enhancement has on power production in the horizontal and vertical plane of movement. Short term enhancement is an improvement in muscular ability which can occur for a short time after a small set (i.e. 1-6 reps) of a strength exercise. This increase in performance is thought to be due to increased blood flow to the muscle and improved ionisation in the muscular contraction process.

Previous research has shown that short term enhancement can improve vertical jump performance. However, to data, not research has been undertaken into whether short term enhancement can improve horizontal jump performance. Additionally, research into the effect of using short term enhancement as training tool and whether it can improve performance outside of its short term effect has not been undertaken. As such, this research aims to determine whether short term enhancement can improve horizontal jump performance and whether short term enhancement, when used as a training tool, can improve jump performance in either the vertical or horizontal plane of movement.

What are the benefits?

To the Athlete

As part of the testing process in this research a power profiling will be taken of the athlete's lower limb. This gives an in-depth understanding of not just how powerful an athlete is but also into how they produce their power within the muscle. Power profiling is used by many professional sports teams to more specifically determine individual athletes' muscular characteristics and to program specifically for them. Additionally, if short term enhancement is shown to have a positive training effect subjects training subject will enjoy the effect of this.

To the Strength and Conditioning Community

By increasing our understanding of short term enhancement, this research will be beneficial in developing greater understanding of how this training technique affecting muscular power in the body in the horizontal and vertical planes of movement both in the short and longer term.

What will happen in this research?

Project Outline

This research will be completed as a training study. A pair matched research design will be implemented over a six or seven week training period with two training sessions per week. All Gym session will take place as per normal although during lower limb training one training group will utilise complex pair to elicited short term enhancement while the other training group will complete the same exercises separately i.e. not in complex pairs. The complex pair training group will complete 3-4 sets of squats (2-8 reps) with a power exercise (e.g. a set of drop jumps) in between each set of squats. The non-complex paired training group will complete the same exercises but separately i.e. all squat sets will be completed in a row after which all power exercises sets will be completed. Subjects will be ranked based on lower limb strength and split into either one of the training groups to insure an even split of subjects ability.

All testing sessions will take place at HBHS. Testing will be non-invasive and will be designed to fit in with existing training requirements. The training study will be designed to work into existing gym sessions and will not affect training load. As such, there is no reason why this training study would negatively affect the rugby performance of participant in the research.

The tests

4RM Squat

The 4RM squat protocol will consist of lifts of 8, 6, 4 repetitions with 5 mins rest between sets. You will be required to work until you fail to lift the bar final effort. If failure occurs at 4 repetitions or less a predicted 1RM will be calculated

Countermovement Jump (CMJ)

The CMJs will consist of a self-selected countermovement depth immediately followed by a jump of maximal intensity. A natural arm swing will be allowed in CMJ tests and instructions will be given to jump to maximal distance or height, depending on the plane of movement that the test is being undertaken in.

Squat Jump (SJ)

The SJ will involve a 3 second static hold at a 90° knee angle followed by a jump of maximal intensity. You will not be allowed to dip deeper than the 90° after the 3 second hold. A natural arm swing will be allowed in the SJ.

Drop Jump (DJ)

The single leg DJ will consist of a drop of 20cm off a box immediately followed by a jump of maximal intensity. You will be instructed to minimise contact time on the ground while maximising jump height or distance. Two legged DJ will consist of the same protocol but will include a drop of 40cm preceding jumps.

The duration of testing is outlined below:

Study 1: PAP Testing

	Time		
Testing Sessions	**Warm Up**	**Testing**	**Total**
4RM and Familiarisation Testing	15 mins	45 mins	1 Hour
PAP Testing	15 mins	45 mins	1 Hour

(Total Time: 2 hours)

Study 2: PAP Training Study

Sessions	Time		
	Warm Up	Session	Total
Training Sessions x 14 (2 per week for 7 weeks)	15 mins	45 mins	1 hour
Post Training PAP Testing	15 mins	45 mins	1 hour

(Total Time: 15 hours)

What Date are Testing and Training?

Testing for study 1 will take place between the 15th and 28nd of July (School Holidays). Training sessions (study 2) will take place between 29th July and 15th September, From the start of term 3 until the end of the HBHS 1stXV Season. The final testing “Post Training PAP Testing” for study 2 will take place between the 9th and 16th of September, the week immediately after the end of the 1stXV season.

What are the discomforts and risks?

You are being asked to participate in a range of tests, some of which you may not be familiar with. As with any physical activity, there is a risk of injury. However, the anticipated discomfort and risk from participating in this testing is not significant and will not be greater than your normal training.

The other possible discomfort is a delayed onset of muscle soreness (DOMS) in the day/s following the testing. However, it is unlikely that the DOMS resulting from this testing, if experienced at all, will be significant.

How will these discomforts and risks be alleviated?

To reduce discomforts and risks from testing, you will be asked to physically prepare yourself prior to the first test by undertaking a warm-up consisting of 10 minutes of cycling (at 150W) on a Cycle Ergometer followed by 5 minutes of prescribed lower limb dynamic stretches. You will also be encouraged to keep warm and drink fluids throughout the testing session. Immediately after each test, you should move about to keep blood circulating and to assist with the breakdown of lactic acid – light rowing or walking is better than standing still or lying down.

Additionally, prior to testing you will have the opportunity to familiarise yourself with the equipment and the testing process. You will also have the opportunity to ask questions and to receive feedback about your technique during your familiarisation session.

If, at any time, you do not feel that you are able to complete the movements requested, you will be encouraged to notify the researcher immediately. Finally, please notify the researcher if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required tasks. For example, a current knee injury would exclude you from the sprint test, a shoulder injury may affect arm swing in jump movements etc.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

The identity and results of each participant will be kept confidential. Only the student researcher (Caleb Dobbs), the primary, secondary and co-supervisor (Dr Nicholas Gill, Dr Mike McGuigan and Dr Dan Smart) will analyse your results.

Only group results will be presented in published research or presentations. However, if you are willing to allow relevant coaching staff to view your test result, a copy of your individual results will be provided to assist with the design of any training programmes or interventions. *Data presented to coaching staff will not be used to influence future selection.*

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for testing. The majority of testing will take place in or around normal training times.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have plenty of opportunity to approach Caleb around your normal training sessions or to contact him via e-mail or phone (see contact details below). Feel free to ask any questions you would like about the study.

How do I agree to participate in this research?

If would like to participate in this research, please fill in and sign the attached *Consent Form* and return it to your strength and conditioning coach. If you are under the age of 18 your legal guardian will also be required to complete a *Legal Guardians Consent Form.* These must be completed before you can participate in the research.

Will I receive feedback on the results of this research?

Yes, after the project is completed you can receive a summary of your individual results once the information is ready for distribution (Early 2014). Please tick the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be addressed in the first instance to the Project Supervisor, Dr Nicholas Gill (see contact details below).

Concerns regarding the conduct of the research should be addressed to the Executive Secretary, AUT, Dr Rosemary Godbold, *rosemary.godbold@aut.ac.nz* , 921 9999 ext 6902.

Who should I contact if I want more information about this research?

Please contact Caleb Dobbs.

Student Researcher Contact Details:

Caleb Dobbs, cbf6270@aut.ac.nz, mobile 027 423 5235.

Project Supervisor Contact Details:

Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 0274 888 699

Dr Mike McGuigan, mcguigan.mike@hpsnz.org.nz, telephone: 021670131

Approved by the Auckland University of Technology Ethics Committee on 13/02/2012 AUTEC Reference number 12/27