

**OPTIMISING TRANSFERENCE OF
STRENGTH AND POWER ADAPTATION
TO SPORTS SPECIFIC PERFORMANCE**

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**A thesis submitted to AUT University in fulfilment of the degree of
Doctor of Philosophy**

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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.

Chapters two to nine of this thesis represent seven separate papers that have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined in the candidate contribution to co-authored papers table and at the beginning of each chapter. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

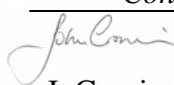


Aaron D. Randell

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Candidate contributions to co-authored papers

Chapter publication reference	Author %
CHAPTER 2: Randell, A., Cronin, J., Keogh, J, and Gill, N. (2010). Optimizing within session training emphasis. <i>Strength and Conditioning Journal</i> , 32(2), 73-80.	AR = 80%; JC = 10%; JK = 5%; NG = 5%
CHAPTER 3: Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2011). Reliability of performance velocity for jump squats under feedback and non-feedback conditions. In press - <i>Journal of Strength and Conditioning Research</i> .	AR = 80%; JC = 10%; JK = 2.5%; NG = 2.5%; MP = 5%
CHAPTER 4: Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2011). Effect of performance feedback during velocity based resistance training. Submitted to <i>Sports Biomechanics</i> (second review).	AR = 80%; JC = 10%; JK = 2.5%; NG = 2.5%; MP = 5%
CHAPTER 5: Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2011). Effect of instantaneous performance feedback during six weeks of velocity based resistance training on sport specific performance tests. <i>Journal of Strength and Conditioning Research</i> , 25(1), 87-93.	AR = 80%; JC = 10%; JK = 2.5%; NG = 2.5%; MP = 5%
CHAPTER 6: Randell, A. D., Cronin, J. B., Keogh, J. W. L., and Gill, N. D. (2010). Transference of strength and power adaptation to sports performance - horizontal and vertical force production. <i>Strength and Conditioning Journal</i> , 32(4), 100-106.	AR = 80%; JC = 10%; JK = 5%; NG = 5%
CHAPTER 8: Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and McMaster, T. (2011). Does exercising involving horizontal component movement affect vertical plane adaptation? Submitted to <i>Journal of Strength and Conditioning Research</i> .	AR = 80%; JC = 10%; JK = 2.5%; NG = 2.5%; TM = 5%
CHAPTER 9: Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Claxton, J. E. (2011). The effect of five weeks training using horizontal component resistance exercise equated for vertical force production on sport specific speed, strength and power. Submitted to <i>Journal of Strength and Conditioning Research</i> .	AR = 80%; JC = 10%; JK = 2.5%; NG = 2.5%; JEC = 5%



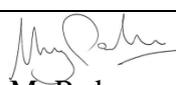
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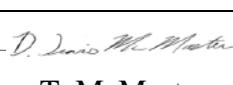
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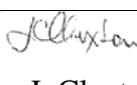
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Abstract

Traditional rugby-specific resistance training programmes typically concentrate on quantifying load via volume or intensity and use lower body exercises that principally work in the vertical plane. The experimental studies in this thesis sought to explore alternatives to such strategies and to establish methods that can be utilised to maximise the development of rugby specific strength, power and speed. The intention of this thesis was to enhance the current understanding of rugby-specific strength and power development therefore professional rugby players were specifically chosen as subjects, mindful of the population specific nature of training adaptation.

Part One investigated the effect of utilising instantaneous performance feedback. Specifically, determining the reliability of jump squat velocity under feedback and non-feedback conditions over three training sessions; quantifying the effect of feedback on jump squat velocity over six training sessions; and quantifying the effect over a six week training block on sport specific performance tests. The first study determined an approximately 50% probability that the provision of feedback was beneficial to consistency of performance in the variable of interest i.e. velocity. Smaller changes in mean peak velocities between Sessions 1-2 and Sessions 2-3 (0.07 and $0.02 \text{ m}\cdot\text{s}^{-1}$ vs. 0.13 and $-0.04 \text{ m}\cdot\text{s}^{-1}$), less random variation ($\text{TE} = 0.06$ and $0.06 \text{ m}\cdot\text{s}^{-1}$ vs. 0.10 and $0.07 \text{ m}\cdot\text{s}^{-1}$) and greater consistency ($\text{ICC} = 0.83$ and 0.87 vs. 0.53 and 0.74) between sessions for the feedback condition were observed. The second study established a 78% chance feedback was practically beneficial in producing superior performances during training. An average 2.1% increase in mean velocity during training was observed with feedback whilst a plateau in velocity occurred once feedback was withdrawn. The third study concluded the provision of feedback provided a greater potential for adaptation and larger training effects. Probabilities feedback was beneficial to increasing performance

of sport specific tests were 45% for vertical jump, 65% for 10 m sprints, 49% for 20 m sprints, 83% for horizontal jump, and 99% for 30 m sprints. It is suggested the provision of feedback is utilised to improve consistency and performance during training and optimise transference to sport specific tests.

Part Two investigated the effect of prescribing lower body exercises with a horizontal component. Specifically, quantifying the effect of training using an equated horizontal component squat exercise for five weeks (vertical vs. horizontal squats) on typical measures of vertical strength and power and other sport specific performance tests. The first study outlined the methodological approach to equating the vertical force production of a vertical squat and horizontal component squat exercise. The second study established that the increased specificity of training did not compromise performance adaptations achieved through traditional vertical based training. Probabilities the horizontal component training had practically reduced adaptive potential were low for squat (11%), deadlift (4%), and powerclean (8%). The third study concluded horizontal component lower body was more effective for improving sprint ability than vertical training. Probabilities there was a practical difference, whereby five weeks of horizontal component training had a superior adaptive potential were large for 30 m (74%), 10-30 m (75%), and 20-30 m (94%) sprint intervals. It is suggested horizontal component lower body exercises are prescribed during training to optimise transference to sprinting performance.

Research outputs and awards arising from this PhD thesis

Published (or in-press) peer-reviewed publications

- Randell, A., Cronin, J., Keogh, J., and Gill, N. (2010). Optimizing within session training emphasis. *Strength and Conditioning Journal*, 32(2), 73-80.
- Randell, A. D., Cronin, J. B., Keogh, J. W. L., and Gill, N. D. (2010). Transference of strength and power adaptation to sports performance - horizontal and vertical force production. *Strength and Conditioning Journal*, 32(4), 100-106.
- Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and Pedersen M. C. (2011). Effect of instantaneous performance feedback during six weeks of velocity based resistance training on sport specific performance tests. *Journal of Strength and Conditioning Research*, 25(1), 87-93.
- Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and Pedersen M. C. (in press). Reliability of performance velocity for jump squats under feedback and non-feedback conditions. *Journal of Strength and Conditioning Research*.

Journal manuscripts currently under peer review

- Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and Pedersen M. C. (2010). Effect of performance feedback during velocity based resistance training. Submitted to *Sports Biomechanics* (second review).
- Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and McMaster, T. (2011). Does exercising involving horizontal component movement affect vertical plane adaptation? Submitted to *Journal of Strength and Conditioning Research*.
- Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and Claxton, J. E. (2011). The effect of five weeks training using horizontal component resistance exercise equated for vertical force production on sport specific speed, strength and power. Submitted to *Journal of Strength and Conditioning Research*.

Conference presentations

- Randell, A. D., Cronin, J. B., Keogh, J. W., Gill, N., and Pedersen M. (2009). *Effect of instantaneous feedback during performance of jump squats*. Poster presentation at the New Zealand Sports Medicine and Science Conference, Rotorua.
- Randell, A. D., Cronin, J. B., Keogh, J. W., Gill, N., and Pedersen M. (2010). *Effect of performance feedback during 6 weeks of velocity based squat jump training*. Poster presentation at the International Society of Biomechanics in Sports Conference, Marquette, Michigan, USA.
- Randell, A. D., Cronin, J. B., Keogh, J. W., Gill, N., and Pedersen M. (2010). *Effect of instantaneous performance feedback on velocity based squat jump training*. Poster presentation at the Sports Performance Research Institute New Zealand Strength and Conditioning Conference, Auckland.

Awards

Sport and Exercise Science New Zealand - *Best Poster Presentation at Conference*,
November 2009.

AUT University, School of Sport and Recreation - *New Investigator Award*, December
2010

CHAPTER 1. PREFACE

Thesis rationale

Rugby is a highly demanding physical sport requiring the development of strength, power, speed and endurance, all of which are critical to the demands of competition (Duthie, Pyne, & Hooper, 2003). The trend of recent rugby-specific conditioning programmes has seen a greater emphasis towards enhancing the development of power through resistance training programmes (Duthie, 2006). Specifically, the ability to produce high levels of force, with increased movement velocity is thought desirable for most rugby players. It is readily apparent that the strength or force component of power is adequately quantified by most strength and conditioning professional by detailing the load or tonnage lifted in a set or a session (kg) and/or intensity (RM or %1RM), however the velocity component has typically been overlooked by practitioners. This is principally due to: 1) the difficulty of measuring this in relation to the force component; and, 2) because it is the component that is more difficult to make substantial training improvements to as compared to force. Nonetheless given that some movements/tasks will benefit from higher movement velocity rather than higher force, this component is important to assess, monitor and/or train.

As intimated above, force is an important component of power also. However, walking into any gym or weight training environment one would observe a great deal of equipment and or exercises dedicated to training in the vertical plane. That is, most gym based movements have little consideration of the horizontal force vectors. Given that most movement involves both horizontal and vertical force vectors, we see this is as a major limitation to optimising transference of gym based resistance training to on-field performance. This thesis therefore explores methods to optimise strength/power adaptation and transference to on- field performance i.e. quantification of other training

parameters such as velocity, and exercising in the vertical as well as horizontal plane.

The use of focussed kinematic and kinetic feedback during resistance training is, for the most part, unexplored. Current monitoring and feedback practices typically provide retrospective quantification or a summary of a resistance training session (Rucci & Tomporowski, 2010; Winchester, Porter, & McBride, 2009). That is, the information collected summarises a completed set or session and is therefore used to modify a subsequent set or session, however, it is not able to be used to affect change within the actual training set or session of interest. Improvements in strength and power when subjects were exposed to visual feedback, outside of a resistance training programme, have been reported (Figoni & Morris, 1984; Kellis & Baltzopoulos, 1996). In addition, advancements in technology have been made whereby the monitoring of kinematic and kinetic variables during resistance training is practical and cost effective. Yet, research investigating the benefit of and the best method of utilising instantaneous performance feedback is limited. If equipment and software can provide valid and reliable instantaneous feedback during training, resulting in goal-orientated movement tasks that improve the mechanical variable of interest, for example velocity of movement, this may optimise the training session goal, such as the development of power, thereby increasing the likelihood of transference to on-field performance.

The training of horizontal propulsive force generation is one aspect of many sports that is not easily simulated with traditional gym-based resistance training methods which principally work the leg musculature in a vertical direction. During sprint performance, force production is necessary in both the vertical and horizontal planes, however, it is the horizontal forces that experience the greatest increase when accelerating to maximal velocity (Brughelli, Cronin, & Chaouachi, 2011; Kyröläinen, Belli, & Komi, 2001;

Munro, Miller, & Fuglevand, 1987). It is proposed that the transference of gym based strength gains to sprint performance may be optimised if exercises were used that involved horizontal force production. However, the effectiveness on sprint performance of a gym based lower body resistance training programme with a horizontal component has not been investigated. Additionally there is a lack of research pertaining to the potential compromise horizontal resistance training techniques may have on vertical performance measures. If a gym based lower body resistance exercise is able to provide a stimulus for horizontal force production, whilst maintaining vertical force production this may result in optimal transference to sprint performance within a sporting context.

Originality of the thesis

There is a paucity of research investigating monitoring practices that allow within session training modification when the focus of a conditioning programme progresses to the development of velocity or power. There is a lack of research specifically investigating the use of dynamometry to provide instantaneous feedback on velocity of movement and its effect on consistency of performance during training. Research quantifying the effect on performance over repeated training sessions is limited. No study has tracked the effect on sport specific performance tests following a training cycle using instantaneous feedback on velocity of movement.

Also there is contradictory research on the direction of force application that is most important in determining running velocity in well-trained athletes. There is limited research addressing this inconsistency within a team sport situation such as rugby union, which may have very different speed requirements to a track athlete i.e. track speed vs. sports speed. No study has investigated the effect of a training cycle using a horizontal component lower body exercise equated for vertical force production on vertical strength performance. Furthermore no study has quantified the effect of such a training technique on sport specific performance tests, including horizontal based movements.

Given the limitations cited in the previous paragraphs the aims of this thesis are to:

Aim 1: Quantify test-retest reliability of jump squat velocity under both feedback and non-feedback conditions.

Aim 2: Quantify the acute effect of instantaneous performance feedback on jump squat velocity during repeated training sessions.

Aim 3: Quantify the longitudinal effect of instantaneous performance feedback on sport specific performance measures.

Aim 4: Quantify vertical and horizontal ground reaction forces and equate vertical force production between two exercises with differing horizontal and vertical components.

Aim 5: Quantify the effect of training using an equated horizontal component exercise on vertical performance measures.

Aim 6: Quantify the longitudinal effect of training using an equated horizontal component exercise on sport specific performance measures.

Thesis organisation

The overarching focus of the thesis is improving understanding related to the development of strength (force), speed (velocity) and subsequently power, and the transference of these variables to rugby specific tests that are used to assess on-field performance. Given the scope of such a topic the research focus has been narrowed to investigate the velocity component of power development as the strength component is an area that is adequately quantified within traditional strength and conditioning practice. Specifically, investigating the importance of optimising the training session with respect to how we train (i.e. maximising training stimulus for the development of velocity), and what we train (i.e. maximising movement plane specificity during velocity based training). Thereby optimising the potential transference of the power adaptations to sport specific performance.

To systematically address the concerns and limitations outlined in the previous sections the thesis has been divided into two parts, each addressing a specific area of interest i.e. quantification and monitoring of within session training parameters to enhance velocity adaptations and exercising in the vertical and/or horizontal plane to optimise transference to the power requirements of sport. Part 1: Chapters Two to Five explore methods by which within session training emphasis (velocity) may be optimised through the use of feedback; Part 2: Chapters Six to Nine explore how exercises using different planes of horizontal and/or vertical force production may optimise training transference to functional activities such as sprinting.

Part Two: Chapter Six, the second review of literature, critiques the research addressing both horizontal and vertical force production and their respective effects on velocity and acceleration. Subsequently future research directions are suggested. Chapters Seven,

Eight, and Nine are the experimental studies that: outline the methodological approach to equating the vertical force production of a vertical squat and horizontal component squat exercise; establish the effect of training using two squat exercises (horizontal vs. vertical) that have an equated vertical component on typical measures of vertical strength and power; and, quantify the effect of such a training programme on running speed and other sport specific performance tests.

The final chapter (Chapter Ten) consists of a summary of the main research findings and delimitations of the thesis. Subsequently, recommendations are made for strength and conditioning practitioners, with regards to practical and rugby-specific methods that can be utilised to maximise the development of strength, power and speed in rugby. To conclude future research directions are presented.

Chapters Two and Six (literature reviews) are presented in the format of the journals for which they were written. Chapters Three, Four, Five, Eight, and Nine (experimental studies) are also presented in the format of the journals for which they were written with the exception that each is preceded by a brief explanatory prelude rather than an abstract (instead, the abstracts are included in appendix seven). All have been published / submitted as stand-alone papers to the respective journals, consequently, there is some repetition between the chapters.

References are included at the end of each chapter and an overall reference list from the entire thesis has been collated at the end of the final chapter. For consistency, all referencing is in APA format. The appendices also present relevant peripheral material including informed consent form, ethics approval and subject information sheets.

Significance of study

The issues relating to the measurement and modification of strength and power performance are seminal to many functional and athletic tasks, and hence central to sport science research. To aid development in this area, research into strength and power needs to be systematic and disseminate findings in relation to: 1) the development of dynamometry and protocols that are reliable and have high internal and external validity that assist in the assessment/monitoring of strength and power; 2) the mechanisms underpinning strength and power production and their modification through training; and, 3) development of new or alternative training strategies that may better develop functional strength and power. The aim of the series of studies presented in this thesis is to contribute to each of these three areas. Even though much of the research is framed within a rugby union context, the findings will have relevance and application to many athletic and sporting activities.

PART 1. OPTIMISING WITHIN SESSION TRAINING EMPHASIS

CHAPTER 2. LITERATURE REVIEW

This chapter comprises the following paper:

Randell, A., Cronin, J., Keogh, J, and Gill, N. (2010). Optimizing within session training emphasis. *Strength and Conditioning Journal*, 32(2), 73-80.

Author contributions - AR: 80%, JC: 10%, JK: 5%, NG: 5%

Summary

Current monitoring practices typically provide retrospective quantification of a resistance training session. That is, the information collected summarises a completed session and is therefore used to modify a subsequent session. When the focus of a conditioning programme progresses to the development of power, having dynamometry that allows athletes to gain instantaneous feedback as to power output or velocity of motion may result in more goal-oriented movement that increases the likelihood of transference to on-field performance or at the very least improves the mechanical variable of interest.

Introduction

Most resistance training programmes quantify and monitor training stress by calculating the load x reps x sets, which equates to the volume lifted for a session. This is appropriate for the strength endurance and strength phases of the conditioning programme where the intention is either to lift heavier loads and/or increase the number of repetitions lifted at the same load. This type of monitoring is used extensively by practitioners due to its simplicity and the absence of expensive equipment. However, when the phase of the conditioning programme moves to power development, other foci may provide better power-specific adaptation. Advances in technology (linear position transducers, rotary encoders, etc.) now enable the direct measurement of many

kinematic (e.g. velocity) and/or kinetic (e.g. power) variables during certain resistance training exercises. While this type of data is used effectively to test the effects of resistance training through assessments, its major benefit may be the ability to continuously monitor and motivate performance during training (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007).

Given that specific training goals change according to individual/positional needs and the time of the training year, it follows that performance feedback needs to parallel the specific training focus. If this is the case we need equipment and software that can give players instantaneous feedback related to the variable of interest during that training phase such as movement velocity or power output. This may result in goal-oriented movement tasks in the gym that increase the likelihood of transference to on-field performance or at the very least improves the capacity of the individual to produce the mechanical variable of interest such as power. This literature review addresses this contention by: 1) briefly investigating the literature on feedback and where possible relate this to strength and conditioning practice; 2) discussing the methods that have been used to quantify strength and power training; 3) critiquing those training studies that have used some form of performance monitoring; and, 4) suggesting future research directions.

Feedback

The use of feedback to provide information about actions attempted in practice or training has been identified as one of the key influential variables in the acquisition of motor skills (Bilodeau, 1966; Kilduski & Rice, 2003). Although originally focusing on reporting of errors, feedback has taken on the general meaning of any kind of sensory information provided as a result of a movement (Schmidt, 1991). Feedback can be

generated from the task itself, classified as inherent or intrinsic feedback, or it may also be provided from external sources, called augmented or extrinsic feedback (Kilduski & Rice, 2003; Schmidt, 1991; Schmidt & Lee, 2005).

Augmented feedback provides the subject with information relative to the execution of the previous movement or action with the objective of enabling modifications to be implemented so that the level of performance may be improved during succeeding attempts (Kilduski & Rice, 2003). Augmented feedback can be further classified into two types: knowledge of results and knowledge of performance. Both types of feedback may be delivered verbally or visually and usually occur after the movement has been completed (Kilduski & Rice, 2003; Schmidt & Lee, 2005).

Knowledge of results can be defined as giving feedback regarding the outcome of the movement in relation to the task goal, such as making a basket, hitting a target, or jumping distance in triple jump. Knowledge of performance consists of information about the movement pattern that led to the performance outcome concerned, for example giving specific kinetic or kinematic feedback such as power output, velocity, or force production during the performance (Kilduski & Rice, 2003; Onate, Guskiewicz, & Sullivan, 2001; Schmidt, 1991; Schmidt & Lee, 2005; van Dijk, Mulder, & Hermens, 2007; Young & Schmidt, 1992). Even though distinctions have been made between these two classes of augmented feedback, an operational distinction between them is sometimes lacking. This may occur where the task requires the performance of one specific movement pattern that is equal to the task goal. As a result, feedback about the movement pattern is essentially equivalent to feedback about the goal achievement. Nevertheless, feedback about the movement pattern contains more information than knowledge of results, which only provides outcome information of the movement.

Therefore the informational content of the feedback is viewed as an important determinant of the success of the ensuing action (Kilduski & Rice, 2003; van Dijk et al., 2007).

Knowledge of results

The most common method of augmented feedback used during resistance training provides knowledge of the results, that is, when the weight is successfully lifted or a set number of repetitions are completed. This feedback is often provided by a supervising strength and conditioning trainer. Although it has been suggested that the increased motivation and competitiveness provided by supervising trainers facilitates an increased training intensity and therefore strength development (Coutts, Murphy, & Dascombe, 2004; Mazzetti et al., 2000), the effect of the feedback itself on the performance has not been thoroughly investigated. A few studies have reported the importance of instructions prior to the performance of a lift or test in order to produce optimal results (Bemben, Clasey, & Massey, 1990; Kawamori et al., 2006). However, there is no mention of the use of feedback to support the instructions given.

Knowledge of performance

Kellis and Baltzopoulos (1996) examined the effects of visual feedback on maximum moment measurements of the knee extensors and flexors during isokinetic eccentric activations. At angular velocities of $30^{\circ} \cdot s^{-1}$ and $150^{\circ} \cdot s^{-1}$ the maximal moments produced during the feedback trials were found to be 7.2% and 6.4% higher for knee extension and 8.7% and 9.0% higher for knee flexion. These results are similar to those reported by Figoni and Morris (1984) who examined the effects of visual feedback during isokinetic knee extension and flexion at $15^{\circ} \cdot s^{-1}$. Mean peak torque values of knee extension under feedback and non-feedback conditions were 156.7 ± 42.5 ft-lb and

139.8 ± 42.3ft-lb respectively, while for knee flexion the values were 104.1 ± 24.0ft-lb and 92.4 ± 21.5ft-lb respectively. The use of visual feedback equated to an increase of approximately 12% in mean peak torque values for both muscle actions.

Graves and James (1990) evaluated the effect of concurrent visual feedback on isometric force output during isometric abduction of the fifth digit. Feedback was provided on alternate contractions and it was reported that peak output was greater during contractions under feedback conditions (4.4 ± 0.29 kg and 4.1 ± 0.26 kg respectively). From these studies it is apparent that the use of visual feedback can improve isokinetic and isometric output and therefore would be beneficial when utilised during movements requiring maximal effort.

Feedback summary

It is fairly conclusive from motor learning theory and the strength and conditioning literature reviewed, that feedback in terms of knowledge of performance and knowledge of results can have a substantial effect on strength and power performance. Of particular interest is the literature citing improvements in strength and power when the subjects were exposed to visual feedback. The effects of this type of feedback during each resistance strength training session is almost totally unexplored and provides exciting possibilities for improved athletic performance.

Monitoring training load / stress

The monitoring and quantification of an individual's training load or stress during resistance training is essential as it can provide information as to the effectiveness of the training programme, identify strengths and weaknesses, and enable the provision of feedback on both results and performance (Borresen & Lambert, 2008; Pyke, 2000). The ability to monitor resistance training becomes even more critical with the

introduction of periodised training programmes, where the manipulation of numerous training variables is seen as vital to achieving a number of training goals and to avoid over-reaching and/or over-training (Day, McGuigan, Brice, & Foster, 2004; Fleck & Kraemer, 2004; Foster, Florhaug et al., 2001; Wathen, Baechle, & Earle, 2000).

Periodisation is widely acknowledged as crucial to optimizing training responses, especially when there are numerous distinct training goals (Fleck & Kraemer, 2004; Gamble, 2006). It is thought that strength and power adaptation is mediated by a number of mechanical stimuli, however, the effect of different combinations of kinematic and kinetic variables and their contribution to adaptation is unclear (Crewther, Cronin, & Keogh, 2005; Hatfield et al., 2006). Central to the theory of periodised plans is the principle of progressive overload, which refers to the practice of continually increasing the mechanical stress placed on the muscle. This may be achieved through a number of methods; increasing repetition speed, changing rest period length between exercises and changing total training volume by altering the number of repetitions, sets, and exercises performed (Fleck & Kraemer, 2004). It is essential to understand how the manipulation of these various acute programme variables and their interactions affect the performance capability of muscle (Abernethy & Wilson, 2000; Cronin, McNair, & Marshall, 2003; Fry, 2004). Therefore as the programmes become more advanced and different training goals are prioritised, monitoring training becomes increasingly important in establishing the optimal stimulus for development of specific strength components within a periodised plan (Fleck & Kraemer, 2004; Hatfield et al., 2006; Tan, 1999).

One problem facing strength athletes, coaches, and researchers is how to monitor the volume and intensity associated with different modes and phases of resistance training.

Unlike aerobic exercise, there is no universally accepted method of monitoring resistance-training exertion (McGuigan & Foster, 2004; Singh, Foster, Tod, & McGuigan, 2007). As stated, resistance training provides a complex model of exercise where factors such as sets, repetitions, rest periods and type of exercise performed are all subject to variation (McGuigan & Foster, 2004). Because of this, resistance training is particularly difficult to quantify and to date, no one method has proven successful in monitoring training output during periodised programmes (Foster, Florhaug et al., 2001).

In the previous section of this review, the literature suggests that feedback during strength and power assessments may improve performance. A natural progression would be to constantly monitor each training session in such a manner, which should result in superior performance gains than a series of sessions in which no feedback is given. The question of interest therefore is what variables should we monitor? This section investigates current methods used for monitoring training and suggests future directions for research in this area.

Training volume and training intensity

Training volume and training intensity are the most common methods of monitoring both resistance training and testing (Fleck & Kraemer, 2004). Training volume is a measure of the total amount of work performed in a training session. Although total work in a repetition can be calculated as the resistance force which is equal to the product of mass and acceleration multiplied by the vertical distance the weight is lifted, other variables such as duration, number of sets performed, number of repetitions per set, number of exercises performed per training session, and frequency (number of training session) all have a direct impact on training volume (Foster, Florhaug et al.,

2001). Training volume is commonly expressed as the total product of sets, repetitions and load expressed as a factor of intensity (% 1RM). However, when training for strength and/or power, the use of the volume of training as a monitoring tool may be considered inadequate because of the overriding importance of intensity and velocity of movement (McGuigan & Foster, 2004).

One repetition maximum

Monitoring the intensity of resistance training is traditionally expressed as a specified percentage of a one repetition maximal lift (Fleck & Kraemer, 2004; Fry, 2004). However, many different definitions are often presented for intensity, perhaps due to the complex nature of resistance exercise (Fry, 2004). Intensity for example, can also be defined as a function of power whereby the amount of work performed during a determined time period influences the reported intensity, such that a lift performed at a faster velocity will have a greater exercise intensity (Fleck & Kraemer, 2004; Fry, 2004). The differing definitions can lead to confusion when comparing different programmes and results. In addition the misinterpretation that may arise when intensity can be used to describe either the intensity of a single repetition, a set of a certain number of repetitions, or an entire training session may further confuse the practitioner.

The use of % 1RM requires that the maximal strength in various lifts used in the training programme be evaluated regularly, otherwise the percentage of 1RM used in training will decrease, and therefore the training intensity will be reduced as the athletes become stronger. Another method for quantifying relative intensity is the use of RM loads. Based on the most weight that an individual can lift for a prescribed number of repetitions, RM loads are a convenient method for quantifying the physiological stress encountered (Mayhew, Ball, & Bowen, 1992; Morales & Sobonya, 1996; Ware,

Clemens, Mayhew, & Johnston, 1995). This method allows the individual to change resistances to stay at the target, thereby eliminating the need to regularly re-evaluate their 1RM. However, this approach may not be applicable in lifts that require coordinated movements and optimal power development from many muscles, such as Olympic lifts where drastic reductions in velocity and power output experienced in the last repetition of a true RM set may not be conducive to correct technique and optimal performance gains. Equations are often used to predict the 1RM from the number of repetitions performed with a submaximal load or to help determine an RM from the 1RM resistance (Fleck & Kraemer, 2004). Unfortunately most of these equations assume a linear relationship between these variables and in many instances this is not the case across the spectrum of loads that may be used in training (Fleck & Kraemer, 2004).

From a practical perspective, the use of percentages of 1RM to quantify and monitor intensity may not be the most effective method because of the amount of testing time required and in many instances the prescribed loads are only an estimate of a particular intensity (Foster, Helmann, Esten, Brice, & Porcari, 2001). Furthermore, it has been shown that training loads/intensities that have been planned are often poorly executed (Kelly & Coutts, 2007), which may result in suboptimal performance (McGuigan & Foster, 2004). Also, if we consider intensity to be a measure of how hard the exercise or workout is, we also need to consider other factors, such as rest periods between sets, number of repetitions completed in each set, and speed of the exercise. The combination of all these factors will impact how hard the exercise is perceived to be. When we also add in other variables such as the training status of the individual and the impact of residual fatigue during intense periods of training, it becomes even more complex to quantify the overall intensity of training sessions or phases (Fry, 2004).

Training volume and training intensity

Intensity can also be defined as a percentage of effort thus relying on each individual's perceptions of their levels of exertion to determine intensity (McGuigan, Egan, & Foster, 2004). RPE is based on the understanding that athletes can inherently monitor the physiological stress their body is experiencing during exercise (Borresen & Lambert, 2008; Foster, Daines, Hector, Snyder, & Welsh, 1996). The RPE scale translates the athlete's perception of effort into a numerical score between 0 and 10 with the goal of receiving an uncomplicated response that reflects the athlete's impression of the workout (Borresen & Lambert, 2008; McGuigan & Foster, 2004). A number of studies have suggested that a single session RPE rating can be used effectively during resistance training sessions and that it is a valid measure of exercise intensity (Day et al., 2004; Foster et al., 1996; Foster, Florhaug et al., 2001; Gearhart et al., 2002; Gearhart et al., 2001; McGuigan et al., 2004; Singh et al., 2007; Sweet, Foster, McGuigan, & Brice, 2004).

Session rating of perceived exertion

Day et al. (2004) investigated the reliability of the session RPE scale to quantify exercise intensity during high- (H) (4-5 repetitions at 90% 1RM), moderate- (M) (10 reps at 70% 1RM), and low-intensity (L) (15 reps at 50% 1RM) resistance training. Session RPE was higher for the H than the M and L exercise bouts (6.9 ± 1.4 , 5.2 ± 1.5 , and 3.3 ± 1.4 respectively) indicating that the performance of fewer repetitions at a higher intensity was perceived to be more difficult than performing more repetitions at a lower intensity. These results are similar to those reported by Sweet et al. (2004) who evaluated the use of session RPE while training at different intensities (4 reps at 90% 1RM, 10 reps at 70% 1RM, and 2 sets of 15 reps at 50% 1RM). Session RPE decreased from 6.3 ± 1.4 to 5.7 ± 1.7 and 3.8 ± 1.6 as the percentage of 1RM decreased from 90%

to 70% and then to 50% respectively. It should be noted however, that apart from the 50% 1RM protocol used by Sweet et al., (2004) only one set of each exercise was performed for both the above studies. Singh et al. (2007) evaluated the effectiveness of utilizing session RPE to measure effort during multiple sets of strength (S) (3 sets of 5 reps at 90% 1RM), hypertrophy (HT) (3 sets of 10 reps at 70% 1RM), and power (P) (3 sets of 5 reps at 50% 1RM) training protocols. The session RPE was significantly lower for P (3.2 ± 1.4) than for HT (6.4 ± 1.6) and S (5.9 ± 1.8), however no difference was found between S and HT. McGuigan et al. (2004) also investigated the effectiveness of using the session RPE scale to measure physical effort during multiple sets of high- (H) (6 sets of 10 reps at 75% 1RM) and low-intensity (L) (3 sets of 10 reps at 30% 1RM) resistance training sessions. A significant difference was observed between the session RPE values for the different intensity levels (H 7.1 vs. L 1.9). Although only Day et al. (2004) and McGuigan et al. (2004) reported reliability statistics (interclass correlation = 0.88 and 0.95, respectively) all the authors concluded that the session RPE appeared to be a reliable method for quantifying the intensity of resistance training.

Mean exercise rating of perceived exertion

Of interest are the comparisons of the session RPE value and the mean RPE of the individual exercises. Day et al. (2004) investigated five exercises (bench press, back squat, overhead press, biceps curl, and triceps pushdown) with RPE ratings obtained after each set of the respective exercises. No differences were reported between the mean RPE value and the session RPE value measured after the completion of each intensity (high-, moderate-, and low-intensity). In contrast, Sweet et al. (2004) investigated six exercises (bench press, lat pulldown, shoulder press, leg press, bicep curl, and tricep press) and reported that the session RPE was significantly lower than mean RPE for all three of the intensities (90%, 70%, and 50% 1RM) suggesting the

session RPE may underestimate the average intensity rated immediately after each set. Of note, the lifting only component (RPE-LO) of the session was also rated and the session RPE was significantly lower than the RPE-LO for the 70% and 90% intensities. Similar findings were reported by Singh et al. (2007) using five exercises (squat, leg extension, bench press, and bench pull) where significant differences between mean and session RPE values were found for strength (7.9 ± 0.9 and 5.9 ± 1.8) and hypertrophy (7.5 ± 1.0 and 6.4 ± 1.6) protocols. McGuigan et al. (2004) only used two exercises (squat and bench press) and therefore did not report mean RPE values. However the differences between the two exercises will be discussed later. The previous conclusions as to the effectiveness of session RPE seem somewhat problematic given that the session RPE values did not reflect mean RPE measures.

Individual exercise rating of perceived exertion

The issue of the effectiveness of session RPE is further questioned when the RPE of the individual exercises are compared to the session ratings. Further analysis of the results reported by Day et al. (2004) revealed that while there were no significant differences between the session RPE values for each intensity (H, M, and L) and the mean bench press RPE value or the mean back squat RPE value, significant differences were found to exist between session RPE values and the mean overhead press, biceps curl and triceps pushdown RPE value (Figure 2.1).

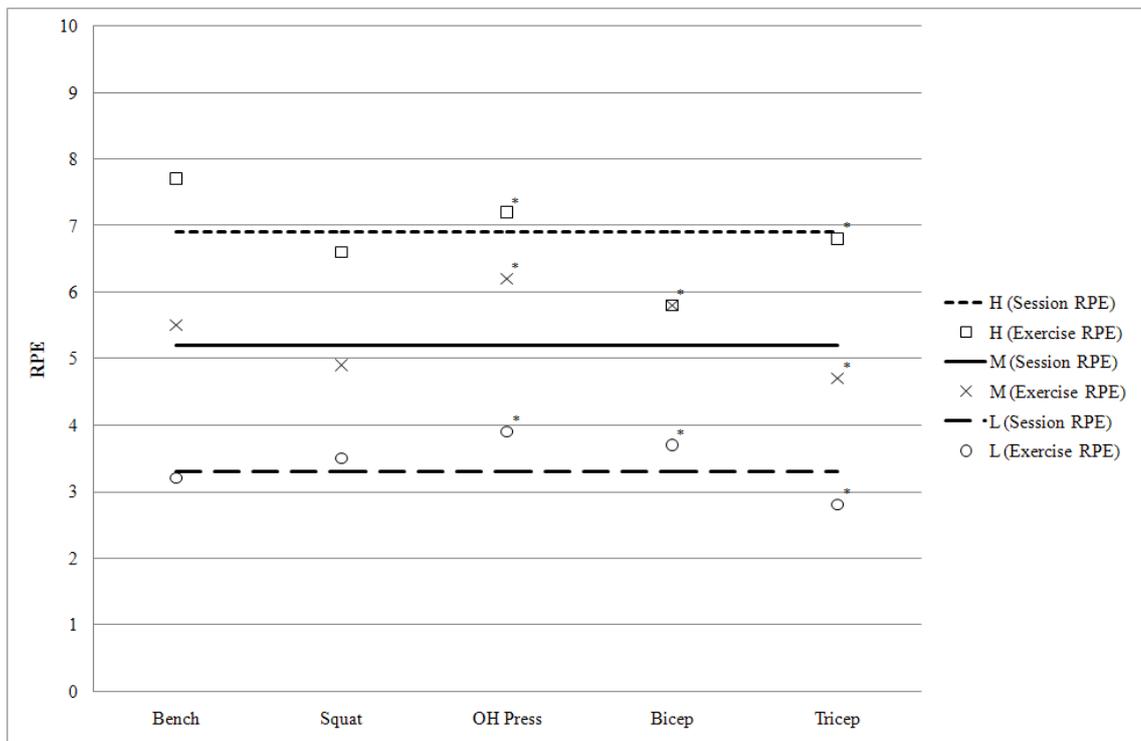


Figure 2.1. Session RPE and individual exercise RPE values for high- (H), moderate- (M), and low-intensity (L) resistance training sessions (* denotes significant difference between individual and session RPE values). Adapted from Day et al. (2004).

Although Sweet et al. (2004) reported exercise RPE values (without SD), no analysis was performed to determine if any significant differences between the values were observed. It was, however, reported, that although the RPE after each of the different resistance training exercises increased with increased percentage of 1RM, the RPE at a given percentage of 1RM varied widely among the six resistance training exercises (Figure 2.2).

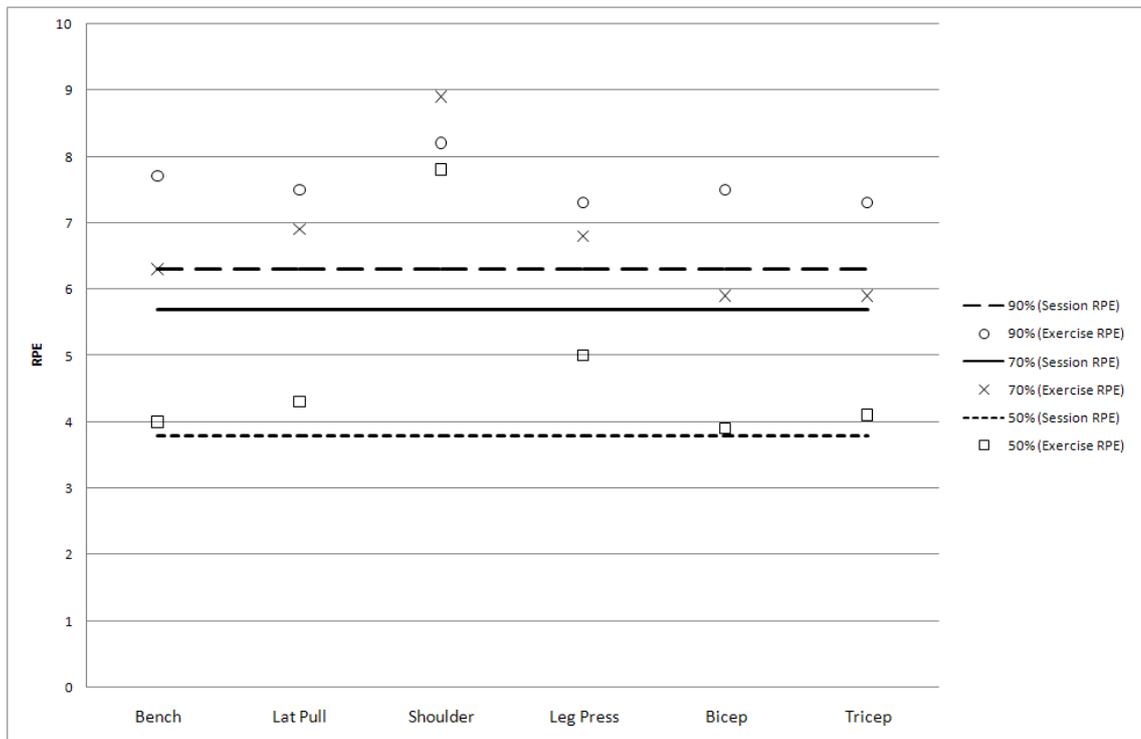


Figure 2.2. Session RPE and individual exercise RPE values for 90% 1RM, 70% 1RM, and 50% 1RM resistance training sessions. Adapted from Sweet et al. (2004).

Singh et al. (2007) did not report the RPE values for the individual exercises, however a significant difference was reported in the average RPE values of all five exercises in the strength protocol compared with session RPE value. Significant differences were observed in the bench press, shoulder press and leg extension for the hypertrophy protocol, and significant differences were observed for squat and leg extension for the power protocol. McGuigan et al. (2004) observed a significant difference between the average RPE value for the bench press exercise and the session RPE value during each intensity, however, there was no significant difference between the average RPE values and the session RPE values for the squat exercise.

There appears to be some uncertainty as to the effectiveness of the session RPE scale to quantify a resistance training session containing a number of different exercises. This is evident in all four of the above studies (Day et al., 2004; McGuigan et al., 2004; Singh et al., 2007; Sweet et al., 2004) where it is apparent that that some of the individual

exercise intensities seem to be misrepresented by the session RPE rating. Given a typical resistance training session consists of a complex arrangement of variables, including the type of exercise performed, it would appear that while session RPE might provide a valid description of the average intensity of the entire workout, its ability to accurately reflect individual exercises may be limited. Therefore there appears to be some benefit in further investigating how sensitive session RPE is to specific exercises within a training session.

Although it has been suggested that the session RPE rating may be used effectively during resistance training sessions as a measure of exercise intensity, it may be possible to have two different intensities result in similar perceptions of effort. Fry (2004), in a review of the role of resistance exercise intensity on muscle fibre adaptations, presented a good illustration. Performing a 1RM versus a 25RM lift resulted in a maximal effort, such that no further repetitions could be completed at either load. That is, muscular fatigue had occurred and the completion of another repetition is impossible. Even though both the 1RM and the 25RM tasks were maximally difficult, different loads were used, different physiological stresses were presented, and the long-term training effects were different and it is quite likely that some individuals would score their RPEs differently. Hence the value of an RPE where there are different foci within a session (strength versus strength endurance) seems problematic.

Although RPE may provide a practical method of quantifying training sessions its value as a tool to either monitor the intensity of specific exercises within a session, different foci (strength endurance, power etc.), or to effectively influence the outcome of a session remains uncertain. In addition its role as a source of immediate feedback after a repetition or a set of exercises appears limited.

Monitoring training load / stress summary

The effects of training are related to the type of exercise used, its intensity, and its volume. Resistance training is particularly difficult to quantify as this type of exercise cannot be objectively evaluated using physiological global measurements such as heart rate. This problem supports the need for a valid and reliable method of monitoring performance output within resistance training. Although the monitoring of training load and or training intensity may provide useful information as to what has been completed its value in affecting positive changes within a session or to quantify and evaluate each session is limited. Therefore it is necessary to develop monitoring systems that can influence the performance of a training session ensuring that the intended performance objectives are met. To provide this optimal training stimulus for adaptation it is hypothesised that monitoring and feedback be provided after each repetition or at least each set for the entire duration of the training session. Currently there is a paucity of research in this area.

Practical applications and future research directions

Current monitoring practices typically provide retrospective quantification of a resistance training session. That is, the information collected summarises a completed session and is therefore used to modify a subsequent session. What has been established however is the value of instantaneous feedback. Therefore the challenge for strength and conditioning coaches is to instrument equipment that can provide real time feedback. Thereafter it is choosing when and what to monitor in relation to athlete needs and the yearly training plan.

What is apparent from the literature is that the strength endurance and strength phases of the training pyramid are adequately quantified via load, intensity, and volume.

However, the ability to relevantly quantify the power phase is an area that is currently lacking and requires future investigation.

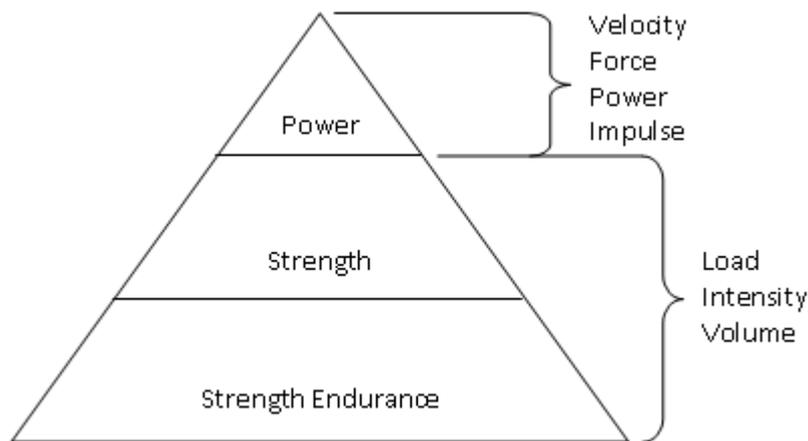


Figure 2.3. Quantification of the training pyramid.

Although, as shown in Figure 2.3, the load or the intensity of the load lifted appears to be an important variable to consider for strength endurance and strength adaptation, other variables could possibly be of greater importance for power adaptation. That is, how the load is actually moved may be more significant in developing and explaining improvements to functional performance (Harris, Cronin, & Keogh, 2007; Hoffman et al., 2005; Kraemer & Newton, 2000). Maximum power output is the product of optimum force and optimum shortening velocity (Fleck & Kraemer, 2004; Zink, Perry, Robertson, Roach, & Signorile, 2006), therefore when training for power development it would seem intuitive to ensure movement velocity and/or force output and/or power output for each repetition of an exercise session is maximised. Also of interest may be the rate of power development as this area remains relatively unexplored. Furthermore the impulse in 100 or 200 ms may be important to quantify given the impulse momentum relationship and that deterministic models detail this as one of the most important variables to improve qualities such as speed (Hay, 1994; Schilling, Falvo, & Chiu, 2008). Therefore it would seem logical to monitor the changes in such a variable.

Traditionally the emphasis on quality of effort has been emphasised for plyometric training and it is becoming obvious that the effectiveness of a power training programme may in fact be related to the quality of each repetition. That is, if a repetition does not achieve a high percentage of the maximal power or force output or maximal velocity possible, its impact on training adaptations may be negligible. By monitoring the variables identified in Figure 2.3 during a session and providing instantaneous augmented feedback the potential power adaptations from a resistance training session may be enhanced. This would also seem applicable to other kinematic and kinetic variables, that is if the focus of a resistance programme shifts to acceleration, or force production, improvements may be better realised if both the monitoring and feedback mirrors this focus. What strength and conditioners practitioners need to determine is whether the provision of such feedback is reliable and is practically beneficial?

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CHAPTER 3. RELIABILITY OF PERFORMANCE VELOCITY FOR JUMP SQUATS UNDER FEEDBACK AND NON-FEEDBACK CONDITIONS

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (in press). Reliability of performance velocity for jump squats under feedback and non-feedback conditions. *Journal of Strength and Conditioning Research*.

Author contributions - AR: 80%, JC: 10%, JK: 2.5%, NG: 2.5%, MP: 5%

Prelude

Current monitoring practices typically provide retrospective quantification of a resistance training session. That is, the information collected summarises a completed session and is therefore used to modify a subsequent session. Advancements in the monitoring of kinematic and kinetic variables during resistance training have resulted in the ability to continuously monitor performance and provide feedback during training. The literature review established that feedback can have a substantial effect on strength and power performance, and of particular interest is the literature citing improvements in strength and power when the subjects were exposed to visual feedback. However, the effects of this type of feedback during each resistance strength training session are for the most part unexplored. Therefore the challenge for strength and conditioning coaches is to instrument equipment that can provide real time feedback. Thereafter it is choosing when and what to monitor in relation to athlete needs and the yearly training plan. The review also highlighted that the ability to relevantly quantify the power phase of the training pyramid is an area that is currently lacking and requires future investigation. If equipment and software can provide reliable instantaneous feedback related to the variable of interest during training it is thought that this may result in goal-oriented movement tasks that increase the likelihood of transference to on-field performance or at the very least improves the mechanical variable of interest. This chapter sought to determine the reliability of jump squat velocity under feedback and

non-feedback conditions over three training sessions.

Introduction

Traditional resistance training programmes have a number of variables manipulated to achieve specific outcomes. Typically these variables include load, repetitions and sets, whereby the volume or overall workload is calculated from these variables for each session. This is appropriate for the strength endurance and strength phases of the conditioning programme where the intention is either to lift heavier loads or increase the number of repetitions lifted at the same load. However, when the phase of the conditioning programme moves to power development, other foci may provide better power-specific adaptation. Advances in technology (linear position transducers, rotary encoders, accelerometers, etc.) now enable the direct measurement of many kinematic (e.g. velocity) and kinetic (e.g. power) variables during certain resistance training exercises. Whilst this type of data is used effectively to assess the effects of resistance training interventions, its major benefit may be the ability to continuously monitor performance and provide feedback during training (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007).

The ability to monitor resistance training becomes even more critical with the introduction of periodised training programmes, where the manipulation of numerous training variables is seen as vital to achieving a number of training goals and to avoid over-reaching or over-training (Baechle & Earle, 2000; Day, McGuigan, Brice, & Foster, 2004; Fleck & Kraemer, 2004; Foster et al., 2001). Given that specific training goals change according to individual and positional needs and the time of the training year, it follows that performance feedback needs to parallel the specific training focus. This may result in goal-oriented movement tasks in the gym that increase the likelihood

of transference to on-field performance or at the very least improves the mechanical variable of interest such as power output. Therefore what is required is equipment integrated with software that can provide reliable instantaneous feedback related to the variable of interest during that training phase such as velocity of motion or power output. To these ends we developed a system and software able to provide such information. The purpose of this study was to determine the reliability of performance velocity for jump squats under feedback and non-feedback conditions using this system over three consecutive training sessions.

Methods

Experimental approach to the problem

Twenty subjects performed a total of three “jump squat” training sessions. Prior to completing these sessions the subjects were randomly allocated to a feedback or non-feedback group. The feedback group received feedback on “peak bar velocity” following every repetition of the training sessions, while the non-feedback group did not. The percent change in the mean, typical error and intraclass correlation coefficients were calculated for each session.

Subjects

Twenty semi-professional rugby players were randomly assigned to one of two groups, feedback (n = 10, age = 23.0 ± 3.6 years, height = 183.5 ± 9.4 cm, weight = 98.0 ± 121.1 kg, training age = 2.6 ± 1.4 years, 1RM squat = 180.1 ± 30.9 kg) and non-feedback (n = 10, age = 20.9 ± 2.9 years, height = 183.5 ± 5.5 cm, weight = 99.2 ± 11.1 kg, training age = 2.2 ± 0.6 years, 1RM squat = 183.6 ± 38.9 kg). All subjects had a minimum of two years resistance training experience and were currently in the pre-season phase of their training programme. All testing procedures and risks were fully

explained and participants were asked to provide their written consent prior to the start of the study. The study was approved by the AUT University Ethics Committee.

Procedures

All participants completed a familiarization session and three separate training sessions. At the beginning of each session participants were required to complete a standardised warm up consisting of five minutes of cycling followed by two sets of eight body weight vertical jumps. In the training sessions, participants performed four sets of eight concentric squat jumps using a barbell with an absolute load of 40 kg. This movement was regularly used by these athletes as part of their off-season and in-season training. The depth of the squat was set at a knee angle of 90° and this was controlled using an adjustable rack that the barbell had to make contact with before the commencement of each repetition. Participants were instructed to perform the movement as fast and explosively as possible. Three minutes rest was given between sets. Participants in group one were given real-time feedback on peak velocity of the jump squat at the completion of each repetition using customised software, whilst those in group two did not receive any feedback. The same testing procedures were replicated two additional times with each session separated by at least 48 hours to minimise the effect of fatigue. All training sessions were completed within two weeks of the first session.

Equipment

A wire from a linear position transducer (Celesco PT5A-150; Chatsworth, CA) was attached to the end of an Olympic barbell. The barbell was loaded with two 10 kg plates for an absolute load of 40 kg. The barbell was placed on an adjustable squat rack which was adjusted to the height of each individual.

Statistical analyses

Peak velocity during the concentric phase for each repetition was recorded using a position transducer with accuracy of $\pm 0.18\%$ and repeatability of ± 0.02 of output (3.81 m) (Celesco Transducer Products Inc, <http://www.celesco.com/datasheets/index.htm>), and customised data acquisition and analysis software (Labview, National Instruments, Austin TX). Velocity was differentiated from the displacement time data which was sampled at 500 Hz and low-pass filtered at 10 Hz.

Change in the means, typical errors (TE), intraclass correlation coefficients (ICC) and 90% confidence limits were used to determine the test-retest consistency of the average set and session peak velocity for both groups (Hopkins, 2000). T tests were used to determine statistically significant differences with further analysis undertaken to make inferences about the true value of the effect statistic with regard to practical significance (Hopkins, 2006, 2007). The chances that the true value of the effect statistic (change in mean) was practically beneficial, trivial or harmful was calculated for velocity by assuming the smallest practically important change velocity was $0.06 \text{ m}\cdot\text{s}^{-1}$. This velocity value was chosen as it is the largest variation that may be attributed to technological error (error arising from apparatus). The TE was used as a measure of absolute consistency and represents the random variation in each subject's measurement between tests, after shifts in the mean have been taken into account. The ICCs were used as a measure of relative consistency and relate to the reproducibility of the rank order of subjects on the retest. The chances that the true value of the effect statistic (difference in TEs and ICCs between feedback and non-feedback groups) were practically positive, trivial or negative were also calculated. The same threshold value used for the difference in means was also used for difference in TEs while a threshold value of 0.1, (Cohen's value of the smallest clinically important correlation) was used

for the differences in ICCs (Hopkins, 2006).

Results

Consistency statistics for the between session feedback and non-feedback conditions can be observed in Table 3.1. In terms of the change in the mean between sessions, there was less change in the feedback condition as compared to the non-feedback conditions between Session 1-2 (0.07 m.s⁻¹ and 0.13 m.s⁻¹) and 2-3 (0.02 m.s⁻¹ and -0.04 m.s⁻¹) respectively. Whilst the difference between the changes in the means was not statistically significantly different ($p = 0.287$ and $p = 0.160$ respectively) further analysis, using a threshold value of 0.06 m.s⁻¹, was undertaken to determine the probability that the differences in the mean changes was practically significant. Percent chances that the benefit of feedback during jump squats is practically beneficial (positive) or trivial on the effect statistics can be observed in Table 3.2. It was found that there was a 48.5% probability that the difference in the change in the means from Sessions 1-2 was practically beneficial, 49.6% that it was trivial and 1.9% that it was harmful. Similarly, there was a 53.6% probability that the difference in the change in the means from Sessions 2-3 was practically beneficial, 45.9% that it was trivial and 0.5% that it was harmful.

With regard to the TE there appeared to be less random variation associated with the feedback condition when averaged over Sessions 1-2 (0.06 m.s⁻¹ to 0.10 m.s⁻¹). However, this difference was minimal when comparisons were made between Sessions 2-3 (0.06 m.s⁻¹ to 0.07 m.s⁻¹). Analysis, using the same threshold values as previously used, was undertaken to determine the probability that the differences in TE between groups was practically significant. It was found that there was a 29.9% probability that the difference in TE between feedback and non-feedback groups for Session 1-2 was

practically positive and 69.3% that it was trivial. With regard to Sessions 2-3, there was a 6.1% probability that the difference in TE between feedback and non-feedback groups was practically positive and 92.1% that it was trivial.

The larger ICCs for the feedback condition across both Sessions 1-2 (ICC = 0.83 vs. 0.53) and Sessions 2-3 (ICC = 0.87 vs. 0.74) may also indicate the feedback condition was more consistent than the non-feedback condition in terms of relative consistency. Analysis, using a threshold value of 0.1 was undertaken to determine the probability that the differences in ICCs between groups was practically significant. It was found that there was a 79.8% probability that the difference in ICC between feedback and non-feedback groups for Session 1-2 was practically positive and 11.5% that it was trivial. Similarly, there was a 58.3% probability that the difference in ICC between feedback and no-feedback groups for Sessions 2-3 was practically positive and 27.6% that it was trivial.

Table 3.1. Mean, SD, change in mean, TE and ICCs of peak velocity (m.s⁻¹) obtained during concentric squat jump with absolute load (40 kg)*.

		Session 1	Session 2	Session 3	Session 1-2			Session 2-3		
		Mean (±SD)	Mean (±SD)	Mean (±SD)	Change in mean (±CI)	TE (±CI)	ICC (±CI)	Change in mean (±CI)	TE (±CI)	ICC (±CI)
Set 1	Feedback	2.37 (0.19)	2.52 (0.13)	2.50 (0.19)	0.14 (0.04 to 0.24)	0.09 (0.06 to 0.18)	0.67 (0.00 to 0.92)	0.02 (-0.05 to 0.09)	0.06 (0.04 to 0.12)	0.84 (0.41 to 0.97)
	Non-Feedback	2.30 (0.17)	2.47 (0.13)	2.43 (0.14)	0.16 (0.09 to 0.24)	0.07 (0.05 to 0.14)	0.76 (0.26 to 0.94)	-0.04 (-0.10 to 0.02)	0.06 (0.04 to 0.11)	0.80 (0.35 to 0.95)
Set 2	Feedback	2.46 (0.19)	2.50 (0.15)	2.53 (0.21)	0.04 (-0.03 to 0.11)	0.07 (0.05 to 0.12)	0.84 (0.44 to 0.96)	0.03 (-0.05 to 0.11)	0.08 (0.05 to 0.14)	0.82 (0.40 to 0.96)
	Non-Feedback	2.39 (0.16)	2.51 (0.14)	2.46 (0.15)	0.12 (0.00 to 0.24)	0.12 (0.08 to 0.21)	0.42 (-0.28 to 0.83)	-0.05 (-0.14 to 0.04)	0.09 (0.06 to 0.14)	0.66 (0.05 to 0.91)
Set 3	Feedback	2.46 (0.15)	2.54 (0.17)	2.54 (0.21)	0.08 (0.00 to 0.16)	0.08 (0.05 to 0.14)	0.77 (0.27 to 0.94)	0.00 (-0.09 to 0.08)	0.08 (0.06 to 0.015)	0.82 (0.39 to 0.96)
	Non-Feedback	2.38 (0.14)	2.52 (0.17)	2.51 (0.16)	0.14 (0.02 to 0.26)	0.12 (0.08 to 0.21)	0.44 (-0.26 to 0.84)	-0.01 (-0.11 to 0.09)	0.10 (0.07 to 0.19)	0.63 (0.00 to 0.90)
Set 4	Feedback	2.47 (0.14)	2.49 (0.18)	2.57 (0.21)	0.02 (-0.08 to 0.12)	0.10 (0.07 to 0.18)	0.64 (0.02 to 0.91)	0.07 (0.01 to 0.14)	0.07 (0.05 to 0.13)	0.88 (0.56 to 0.97)
	Non-Feedback	2.43 (0.12)	2.52 (0.16)	2.46 (0.12)	0.10 (-0.02 to 0.21)	0.11 (0.08 to 0.21)	0.32 (-0.39 to 0.79)	-0.06 (-0.14 to 0.01)	0.07 (0.05 to 0.13)	0.73 (0.18 to 0.93)
Session Average	Feedback	2.44 (0.16)	2.51 (0.15)	2.53 (0.20)	0.07 (0.00 to 0.14)	0.06 (0.04 to 0.12)	0.83 (0.41 to 0.96)	0.02 (-0.04 to 0.09)	0.06 (0.04 to 0.12)	0.87 (0.52 to 0.97)
	Non-Feedback	2.38 (0.14)	2.50 (0.14)	2.46 (0.14)	0.13 (0.03 to 0.23)	0.10 (0.07 to 0.18)	0.53 (-0.16 to 0.87)	-0.04 (-0.11 to 0.03)	0.07 (0.05 to 0.13)	0.74 (0.20 to 0.93)

*TE = typical error; ICC = intraclass correlation coefficient

Table 3.2. Percent chances that the benefit of feedback during jumps squats is practically beneficial (positive) or trivial for changes in means and differences in TEs and ICCs*.

	Change in means	Difference in TE	Difference in ICC
SESSION 1-2			
Beneficial (Positive)	48.5	29.9	79.8
Trivial	49.6	69.3	11.5
SESSION 2-3			
Beneficial (Positive)	53.6	6.1	58.3
Trivial	45.9	92.1	27.6

*TE = typical error; ICC = intraclass correlation coefficient

Discussion

The purpose of this study was to determine the reliability of performance velocity for jump squats under feedback and non-feedback conditions over three consecutive training sessions. Whilst previous studies have investigated the consistency of jump squat velocity using position transducers (Cormie, McBride, & McCaulley, 2007; Hori & Andrews, 2009), none have compared consistency of jump squats under feedback and non-feedback conditions.

The difference in the mean for two tests, i.e. change in the mean, is due to random change (due to sampling error) and systematic change (non-random change, e.g. changes in behaviour, motivation, etc.) (Hopkins, 2000). If the random change (sampling error) is assumed to be constant for both the feedback and non-feedback condition then a smaller change in the mean would suggest a smaller systematic change (change due to influence of feedback condition), therefore implying better stability in the variable of interest (velocity of movement). Similarly the TE consists of technological error (error arising from apparatus) and biological error (due to subject related factors) (Hopkins, 2000). If technological error is assumed to be constant for both the feedback and non-feedback condition, given the exact same equipment was used for each condition, then a smaller TE would suggest smaller biological error, again implying more stability in the variable of interest. If the same criteria is used and it is also assumed that the smallest TE is comprised solely of technological error ($0.06 \text{ m}\cdot\text{s}^{-1}$) then this value would represent the smallest worthwhile difference in the velocities as any difference greater than this would be biological error implying a change due to subject factors. As the ICCs are used as a measure of relative consistency and relate to the reproducibility of the rank order of subjects on the retest then a larger ICC would

also imply more stability in the variable of interest. Cohen's value of the smallest clinically important correlation was used to determine if practical differences in the ICCs existed (Hopkins, 2006).

In terms of the comparisons between Sessions 1-2, using the above criteria it appears from both Table 3.1 and Table 3.2 that feedback provided greater relative and absolute consistency than the non-feedback condition. The smaller change in mean (0.07 vs. 0.13 m.s⁻¹) indicates a 48.5% probability of feedback being practically beneficial in ensuring stability of velocity of movement. There is a 29.9% chance that the smaller TE (0.06 vs. 0.10 m.s⁻¹) is beneficial, and a 79.8% chance the larger ICC (0.83 vs. 0.53) is beneficial suggesting better stability of performance. It would seem that even in a simple test-retest situation the provision of feedback will add consistency to performance in the squat jump. Although there are no preset standards for acceptable reliability measures, it has been suggested that ICC values above 0.75 may be considered reliable (Walmsley & Amell, 1996).

Similar results are seen when making comparisons between Sessions 2-3. The smaller absolute change in mean (0.02 m.s⁻¹ vs. 0.04 m.s⁻¹) indicates a 53.6% probability of feedback being practically beneficial in ensuring stability of velocity of movement. The 6.1% and 92.1% chances that the smaller TE (0.06 vs. 0.07 m.s⁻¹) is beneficial or at worst trivial, and the 58.3% chance the larger ICC (0.87 vs. 0.74) is beneficial again suggest that feedback can potentially provide greater relative and absolute consistency than the non-feedback condition across sets and over the entire session.

These results suggest that there is approximately a 50-50 chance that the effect of feedback on the reliability of performance velocity for jump squats will either be beneficial or trivial. It almost certainly will not have a negative effect on training

outcomes. Given these probabilities the strength and conditioning practitioner is now able to decide whether to instrument various devices to enable the provision of such performance feedback.

Practical applications

With advances in technology (linear position transducers, rotary encoders, etc.) it is now possible to continuously monitor specific kinetic and kinematic performance during training, such as velocity of jump squats as seen in this study. The chances that the provision of feedback being beneficial to the consistency of performance across sessions suggests that this technique may be more advantageous in producing a more consistent performance or training stress. Therefore, it is suggested that by providing athletes instantaneous feedback on the velocity of movement after each repetition, improvements in the consistency of performance may result.

In addition to the potential improvement to the consistency of the training stimulus another possible benefit that may result from the ability to accurately monitor performance during training is the ability to set training performance targets, such as maximum velocity, number of repetitions or sets completed above a pre-determined performance threshold. This may prove to be very motivational when fatigue sets in, in addition to creating competition in the training environment.

It is possible that by optimizing the consistency of training sessions the potential for improving the mechanical variable of interest (jump squat velocity) may also be enhanced. Further research needs to be conducted to investigate the effect of feedback on jump squat performance over consecutive training sessions and on sport specific performance.

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CHAPTER 4. EFFECT OF PERFORMANCE FEEDBACK DURING VELOCITY BASED RESISTANCE TRAINING

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2010). Effect of performance feedback during velocity based resistance training. Submitted to *Sports Biomechanics* (second review)

Author contributions - AR: 80%, JC: 10%, JK: 2.5%, NG: 2.5%, MP: 5%

Prelude

If equipment and software can provide reliable instantaneous feedback related to the variable of interest during training it is thought that this may result in goal-oriented movement tasks that improve the mechanical variable of interest. The previous chapter determined a ~50% probability that the provision of feedback was beneficial to consistency of jump squat velocity over multiple training sessions. It is suggested that by optimising the consistency of training sessions through the use of feedback the potential for improving jump squat velocity during training may also be enhanced. This chapter sought to quantify the effect of instantaneous feedback on jump squat velocity over six consecutive training sessions.

Introduction

The use of feedback to provide information about actions attempted in practice or training has been identified as one of the key influential variables in the acquisition of motor skills (Bilodeau, 1966; Kilduski & Rice, 2003). Although originally focusing on the reporting of errors, feedback has taken on the general meaning of any kind of sensory information provided as a result of a movement which can be generated from the task itself, classified as inherent or intrinsic feedback, or it may also be provided from external sources, called augmented or extrinsic feedback (Kilduski & Rice, 2003; Schmidt, 1991; Schmidt & Lee, 2005). Augmented feedback provides the subject with

information relative to the execution of the previous movement or action, with the objective of enabling modifications to be implemented, such that the level of performance may be improved during succeeding attempts (Kilduski & Rice, 2003). Augmented feedback can be further classified into two types: knowledge of results where feedback is given regarding the outcome of the movement in relation to the task goal, and knowledge of performance (KP) which consists of information about the movement pattern that led to the performance outcome concerned. Both types of feedback may be delivered verbally or visually and usually occur after the movement has been completed (Kilduski & Rice, 2003; Onate, Guskiewicz, & Sullivan, 2001; Schmidt, 1991; Schmidt & Lee, 2005; van Dijk, Mulder, & Hermens, 2007; Young & Schmidt, 1992). Even though distinctions have been made between these two classes of augmented feedback, an operational distinction between them is sometimes lacking. Nevertheless, feedback about the movement pattern (KP) contains more information than knowledge of results, which only provides outcome information of the movement. Therefore the informational content of the feedback is viewed as an important determinant of the success of the ensuing action (Kilduski & Rice, 2003; van Dijk et al., 2007).

The most common method of augmented feedback used during resistance training provides knowledge of the results, that is, reporting when the weight is successfully lifted or a set number of repetitions are completed. Although it has been suggested that the increased motivation and competitiveness provided by personal trainers facilitates an increased training intensity and therefore strength development in their athletes (Coutts, Murphy, & Dascombe, 2004; Mazzetti et al., 2000), the effect of the feedback itself on the performance has not been thoroughly investigated. It is fairly conclusive from motor learning theory that feedback in terms of knowledge of performance, for

example giving specific kinetic or kinematic feedback such as power output, velocity, or force production during the performance, and knowledge of results can have a substantial effect on athletic performance (Bilodeau, 1966; Kilduski & Rice, 2003). Of particular interest is the literature citing improvements in strength and the acute production of force and power when the subjects were exposed to visual feedback. A number of studies have reported an improvement in performance of isokinetic (Figoni & Morris, 1984; Kellis & Baltzopoulos, 1996) and isometric (Graves & James, 1990) actions as a result of visual feedback. However, the effects of this type of feedback during a resistance strength training session is unexplored and provides exciting possibilities for improved athletic performance. That is, the monitoring and quantification of an individual's training load or stress during resistance training is essential as it can provide information as to the effectiveness of the training programme, identify strengths and weaknesses, and enable the provision of feedback on both results and performance (Borresen & Lambert, 2008; Pyke, 2000).

Advances in technology (linear position transducers, rotary encoders, accelerometers, etc.) now enable the calculation of many kinematic (e.g. velocity) and/or kinetic (e.g. power) variables during certain resistance training exercises. Whilst this type of data is used effectively to test the effects of resistance training through assessments, its major benefit may be the ability to continuously monitor performance during training (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007). Although the monitoring of training load and or training intensity may provide useful information as to what has been completed its value in affecting positive changes within a session or to quantify and evaluate each session is relatively unexplored. It is necessary therefore to develop monitoring systems that can influence the performance of a training session ensuring that the intended performance objectives are met. To provide this optimal training

stimulus for adaptation it is hypothesised that monitoring and feedback (KP) be provided after each repetition for the entire duration of the training session. Currently there is a paucity of research in this area.

What is apparent from the literature is that the strength endurance and strength phases of the training pyramid are adequately quantified via load, intensity, and volume. However, the ability to relevantly quantify and provide feedback on the power phase remains relatively unexplored and requires future investigation. Although the load or the intensity of the load lifted appears to be an important variable to consider for strength endurance and strength adaptation, other variables could possibly be of greater importance for power adaptation. That is, how the load is actually moved may be more significant in developing and explaining improvements to functional performance (Harris, Cronin, & Keogh, 2007; Hoffman et al., 2005; Kraemer & Newton, 2000). Maximum power output is the product of optimum force and optimum shortening velocity (Fleck & Kraemer, 2004; Zink, Perry, Robertson, Roach, & Signorile, 2006), therefore when training for power development it would seem intuitive to ensure movement velocity and/or force output and/or power output for each repetition of an exercise session is maximised.

Given the limitations and proposed solutions, a natural progression would be to constantly monitor each training session and provide feedback (KP) using devices such as linear position transducers, which should result in a more consistent and quality performance than during a session in which no feedback was given. However, such a contention needs investigating; therefore the purpose of this study was to quantify the effect of performance feedback and non-feedback on jump squat velocity over six consecutive training sessions.

Methods

Experimental approach to the problem

A randomised cross-over design was used to determine the effect of feedback and non-feedback on the kinematics of squat jumps. Twenty subjects were randomly allocated into a feedback or non-feedback group. The bar velocity during a jump squat was measured on six separate occasions per subject with a linear position transducer. The feedback group received feedback (KP) and the non-feedback group received no feedback on peak velocity for the first three sessions. The groups then crossed over, the feedback group receiving no feedback and the non-feedback group receiving feedback on peak velocity for a further three sessions. Differences between groups and chances (% and qualitative) that the true value of the statistic was practically or mechanistically positive, trivial, or negative were calculated.

Subjects

Twenty semi-professional rugby players were randomly assigned to one of two groups, feedback-non feedback (n = 10, age = 23.0 ± 3.6 years, height = 183.5 ± 9.4 cm, weight = 98.0 ± 121.1 kg, training age = 2.6 ± 1.4 years, 1RM squat = 180.1 ± 30.9 kg) and non feedback-feedback (n = 10, age = 20.9 ± 2.9 years, height = 183.5 ± 5.5 cm, weight = 99.2 ± 11.1 kg, training age = 2.2 ± 0.6 years, 1RM squat = 183.6 ± 38.9 kg). All subjects had a minimum of two years resistance training experience and were currently in the pre-season phase of their training programme. All testing procedures and risks were fully explained and participants were asked to provide their written consent prior to the start of the study. The study was approved by the AUT University Ethics Committee.

Procedures

Participants were randomly assigned to one of two groups with each group completing a familiarization session and six separate testing sessions (three sessions in each phase of the crossover). The familiarization session consisted of the same warm-up and procedures as the testing sessions (without the provision of velocity feedback). At the beginning of each session participants were required to complete a standardised warm up consisting of five minutes of cycling followed by two sets of eight body weight vertical jumps. In the testing session, participants performed four sets of eight concentric squat jumps using a barbell with an absolute load of 40 kg. This movement was regularly used by these athletes as part of their off-season and in-season training. The depth of the squat was set at a knee angle of 90° and this was controlled using an adjustable rack that the barbell had to rest on before the commencement of each repetition. Participants were instructed to perform the movement as fast / explosively as possible with a pause between repetitions to distinguish each movement. Three minutes rest was given between sets. Participants in group one (feedback-non feedback) were given real-time feedback (KP) on peak velocity of the jump squat at the completion of each repetition using customised software, whilst those in group two (non feedback-feedback) did not receive any feedback. The same testing procedures were replicated a further two times with each session separated by at least 48 hours to minimise the effect of fatigue. The groups then crossed over, the first group receiving no feedback and the second group receiving feedback on peak velocity for a further three sessions.



Figure 4.1. Set up of barbell, adjustable rack and linear position transducer for performance of squat jumps.

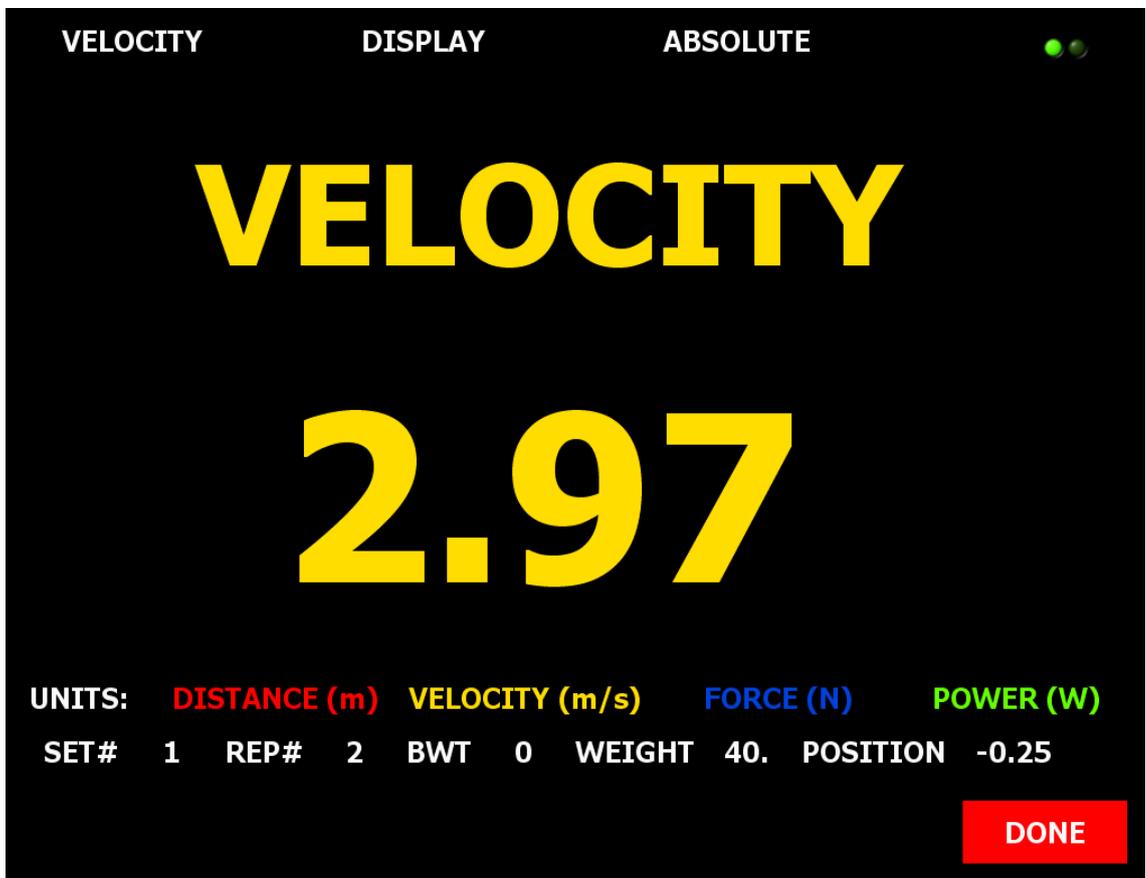


Figure 4.2. Visual display used for peak velocity feedback at completion of each jump

squat repetition for feedback group.

Equipment

A wire from a linear position transducer (Celesco PT5A-150; Chatsworth, CA) was attached to an Olympic barbell. The barbell was loaded with two 10 kg plates for an absolute load of 40 kg. The barbell was placed on an adjustable squat rack which was adjusted to the height of each individual.

Data analyses

Peak velocity during the concentric phase for each repetition was calculated using a position transducer with accuracy of $\pm 0.18\%$ and repeatability of ± 0.02 of output (3.81 m) (Celesco Transducer Products Inc, <http://www.celesco.com/datasheets/index.htm>), and customised data acquisition and analysis software (Labview, National Instruments, Austin TX). Velocity was differentiated from the displacement time data which was sampled at 500 Hz and low-pass filtered at 10 Hz.

Statistical analyses

Mean and standard deviations were used as measures of centrality and spread of data. This data was represented graphically to observe trends, thereafter a spreadsheet for analysis of a post-only crossover trial (Hopkins, 2006) was used to determine differences between the two groups on the dependent variable of interest (average set and session peak velocity). The three sessions each side of the crossover were averaged to give a mean response to feedback and non-feedback and compared using the post-only crossover spreadsheet to determine the percent change between pre cross-over and post cross-over velocities. The chances (% and qualitative) that the true value of the statistic (percent change in velocity) was practically or mechanistically positive, trivial,

or negative was also calculated using the spreadsheet. This approach using probability statistics allows the reader to make decisions around the use of feedback based on its predicted beneficial or harmful effects in addition to statistical significance. Confidence intervals (90% CI) and P-values were also presented where appropriate.

Results

The mean (\pm SD) for the feedback-non feedback and non feedback-feedback conditions over the six sessions can be observed in Figure 4.1. Using the post-test only crossover analysis, which adjusted for the pre-crossover order effect, it was found that there was an average 2.1% ($p = 0.018$; CI = 0.7 to 3.5) increase in the mean with feedback. The chance that this change would be practically beneficial or positive was 78% (i.e. a likely or probable beneficial effect of using feedback) and there was a 22% chance that the benefits of feedback were trivial.

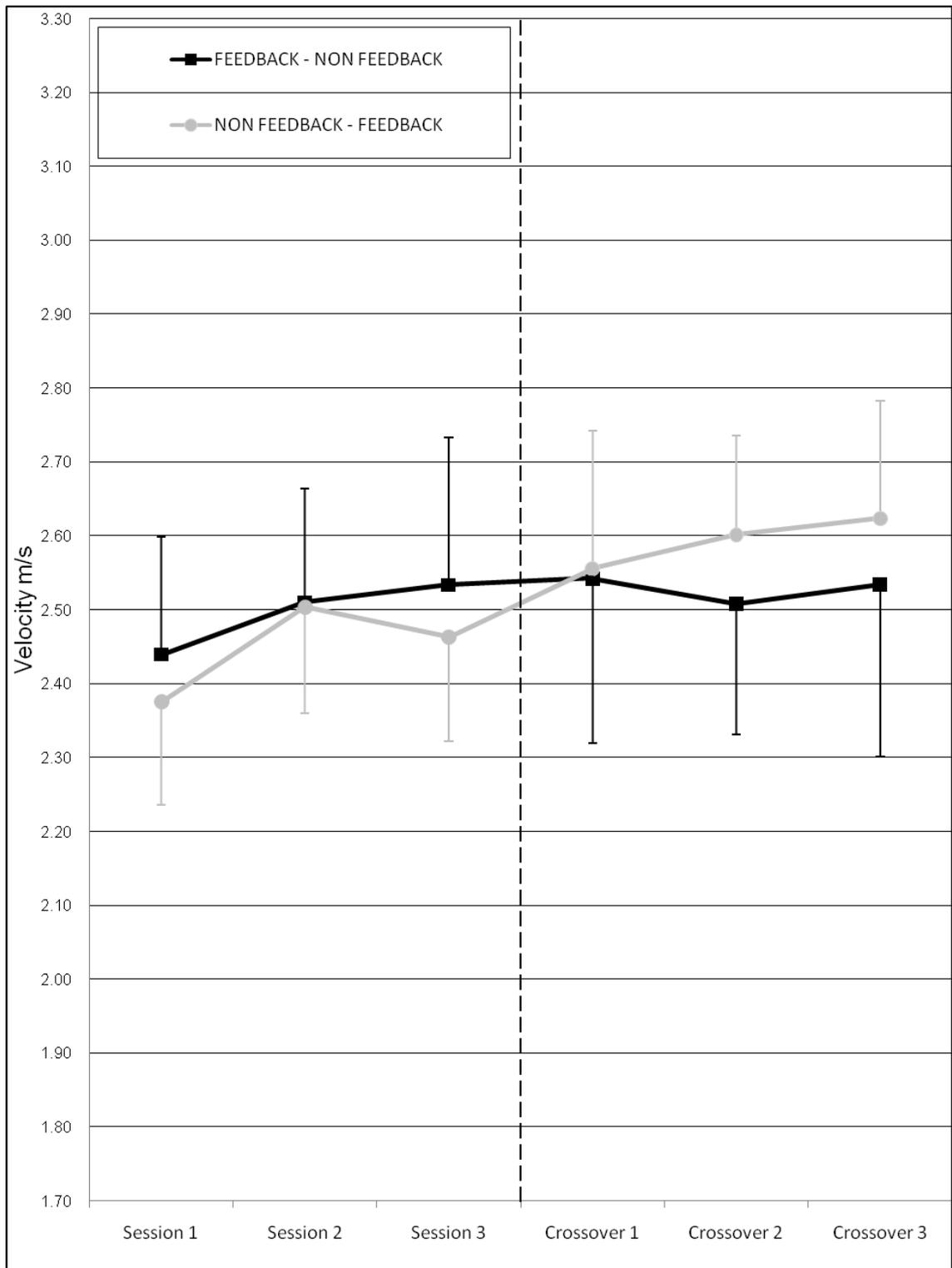


Figure 4.3. Mean (\pm SD) jump squat velocities ($\text{m}\cdot\text{s}^{-1}$) over six sessions (3 pre-crossover and 3 crossover) for the feedback-non feedback (-■-) and non feedback-feedback conditions (-●-).

Discussion

The purpose of this study was to investigate the effect of performance feedback (peak velocity) on jump squat velocity over six consecutive training sessions. Previous work by the authors has shown that the provision of feedback adds consistency to the jump squat and it was suggested that feedback may optimise the training session goal leading to an improvement in jump squat velocity (Randell, Cronin, Keogh, Gill, & Pedersen, In Press).

In terms of a comparison between feedback and non feedback conditions it was found that on average there was 2.1% difference in performance. That is by providing the athletes with instantaneous feedback as to the velocity of each repetition they were able to produce higher velocities during the jump squats. The benefit of feedback has been shown previously in the acquisition of motor skills (Bilodeau, 1966; Kilduski & Rice, 2003) and in the performance of isokinetic (Figoni & Morris, 1984; Kellis & Baltzopoulos, 1996) (6% to 9% and 12% respectively) and isometric actions (7%). It should be noted that these studies performed simple single joint movements using protocols ranging from 1-2 sets of 2-5 repetitions, whereas the current study performed a complex multi joint movement for 4 sets of 8 repetitions. Although a 2.1% increase was observed in jump squat velocity further investigations are required to ascertain whether this increase in velocity translates to a movement or sport specific performance, and if so to what extent.

In terms of the comparisons between feedback and non feedback conditions pre-crossover, it can be observed from Figure 4.3 that feedback resulted in continual improvements in performance over the first three sessions, whereas an initial increase followed by a decrease in performance was observed in the non feedback condition.

The increases noted from session 1-2 in both conditions may be attributed to a learning effect. Even though the athletes were well trained and regularly performed squats as part of their training programme, it appears that performing the squat jump for maximum velocity was a movement that may have required more familiarization. Of particular interest is the difference between conditions for sessions 2-3, where the feedback condition resulted in further improvement in performance whilst squat jump velocity decreased in the non-feedback condition. Previous work by the authors determined that whilst the difference between the changes in the means was not statistically significantly different ($p = 0.160$) there was an approximately 50% probability that the difference in the change in the means was practically beneficial (Randell et al., In Press). As the athletes receiving feedback were aware of all previous performances, they could see when their current performance was levelling off or starting to drop below these levels and attempted to address this. In doing so they were able to maintain velocities greater than or equal to previous sessions. Of interest is whether the increases in performance seen with feedback plateaus such that further improvements in performance are not seen. Furthermore if there is an eventual plateau when does it occur, that is after how many training sessions? This would enable practitioners to prescribe the use of feedback more effectively.

When the three crossover sessions are investigated it can be observed from Figure 4.3 that the withdrawal of feedback lead to a plateau / decrease in jump squat velocity. In contrast the introduction of feedback resulted in an increase in jump squat velocity. While it may be argued that the increase in performance seen in the initial feedback condition pre-crossover may have been due to an extended learning effect, the plateau / decrease in performance following the removal of the feedback suggests that feedback contributed to the observed increases in performance. Another explanation is that the

subjects may have in fact attained a plateau where further improvements in performance were not possible. However, the benefit of feedback is further evident in the observed increases in jump squat velocity for those who did not initially receive feedback but were then given it. These results suggest that while the subjects thought they were producing maximum efforts they had not in fact reached their maximum potential and it was not until they received feedback on their jump squat velocity that they were able to optimise their performance.

Of interest is the observation that some subjects increased performance when feedback was removed and decreased performance when feedback was introduced, suggesting that there may be individual responders. It may be that these individuals who continued to increase jump squat velocities were able to maximise their effort without feedback, whilst those who decreased were distracted by the feedback such that it impacted on their performance. It is also possible that there is a random effect across participants contributing to this variation.

Conclusion

What is of interest about this current study is the observation that the provision of feedback during a resistance strength training session resulted in an improvement in performance. The athletes were aware of decreases in performance, whether technical or motivational, and were able to adjust subsequent repetitions thereby ensuring each session was producing optimal performances. Given it was shown that athletes were able to produce greater velocities during the jump squats as a result of receiving feedback it would seem intuitive to constantly monitor each training session and provide feedback using devices such as linear position transducers and rotary encoders. These devices enable the calculation of many kinematic (e.g. velocity) and/or kinetic

(e.g. power) variables during certain resistance training exercises. By doing so it would appear that the athlete may be better able to optimise the training session goal (e.g. movement velocity, power output, etc.), that is, they are able to produce performances that are consistently better than those achieved without feedback. The use of such monitoring and feedback technologies may be further utilised through the ability to set training performance targets, such as maximum velocity and number of repetitions and/or sets completed above a pre determined performance threshold. This may prove to be very motivational when fatigue sets in, as well as creating competition in the training environment.

It is possible that by optimizing the training session goal through the use of feedback the potential for increasing the transference to on field performance (velocity and power) may also be enhanced. Further research needs to be conducted to investigate the continued use of feedback during a resistance training cycle, and whether the gains seen in movement velocities during training translate to movement or sport specific performance.

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CHAPTER 5. EFFECT OF INSTANTANEOUS PERFORMANCE FEEDBACK DURING SIX WEEKS OF VELOCITY BASED RESISTANCE TRAINING ON SPORT SPECIFIC PERFORMANCE TESTS

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D., and Pedersen M. C. (2011). Effect of instantaneous performance feedback during six weeks of velocity based resistance training on sport specific performance tests. *Journal of Strength and Conditioning Research*, 25(1), 87-93.

Author contributions - AR: 80%, JC: 10%, JK: 2.5%, NG: 2.5%, MP: 5%

Prelude

If equipment and software can provide reliable instantaneous feedback during training, resulting in goal-oriented movement tasks that improve performance of the mechanical variable of interest, this may optimise the training session goal, thereby potentially increasing the likelihood of transference to on-field performance. Chapter Four determined the provision of instantaneous feedback improved consistency of jump squat velocity over multiple training sessions. Subsequently, Chapter Five established a 78% chance that feedback was practically beneficial in producing superior performances during training, with an average 2.1% increase in mean velocity being observed with the provision of feedback. It is suggested that by optimising consistency and performance during training through the use of feedback, the potential for increasing the transference to on-field performance may also be enhanced. This chapter sought to investigate such a contention by quantifying the effect of instantaneous feedback (jump squat velocity) over a six week training block on vertical jump, horizontal jump, and 10 / 20 / 30 m sprint performance.

Introduction

Current monitoring practices typically provide retrospective quantification of a resistance training session. That is, the information collected summarises a completed session and is therefore used to modify a subsequent session. It is fairly conclusive from motor learning theory however, that instantaneous feedback in terms of knowledge of performance and knowledge of results can have a substantial effect on athletic performance and the acquisition of motor skills (Bilodeau, 1966; Kilduski & Rice, 2003). Of particular interest is the literature citing improvements in strength and the acute production of force and power (6-12% improvements) when the subjects were exposed to visual feedback (Figoni & Morris, 1984; Graves & James, 1990; Kellis & Baltzopoulos, 1996). However, the effects of this type of feedback over an entire resistance strength training cycle are unexplored and provide exciting possibilities for improved athletic performance.

Advances in technology (linear position transducers, rotary encoders, etc.) now enable the direct measurement of many kinematic (e.g. velocity) and kinetic (e.g. power) variables during certain resistance training exercises. Whilst this type of data is used effectively to test the effects of resistance training through assessments, its major benefit may be the ability to continuously monitor performance during training (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007). Although the monitoring of training load and or training intensity may provide useful information as to what has been completed its value in affecting positive changes within a session or to quantify and evaluate each session is limited. A natural progression would be to constantly monitor each training session and offer specific, individualised feedback provided by these recent advances in technology, which may result in superior performance gains

than a session in which no feedback was given. In other words, to ensure an optimal training stimulus for adaptation it is hypothesised that feedback should be provided after each repetition over the entire duration of the training session. Currently there is a paucity of research in this area.

What is apparent from the literature is that the strength endurance and strength phases of the training pyramid are adequately quantified via load, intensity, and volume. However, the ability to relevantly quantify and provide feedback on the power phase remains relatively unexplored and requires future investigation. Although the load or the intensity of the load lifted appears to be an important variable to consider for strength endurance and strength adaptation, other variables could possibly be of greater importance for power adaptation. That is, how the load is actually moved may be more significant in developing and explaining improvements to functional performance (Harris, Cronin, & Keogh, 2007; Hoffman et al., 2005; Kraemer & Newton, 2000). Maximum power output is the product of optimum force and optimum shortening velocity (Fleck & Kraemer, 2004; Zink, Perry, Robertson, Roach, & Signorile, 2006), therefore when training for power development it would seem intuitive to ensure movement velocity or force output or power output for each repetition of an exercise session is maximised. Consequently, it would seem logical to monitor and provide feedback for these variables. It is hypothesised that repetition by repetition feedback on bar velocity may enhance the development of power. Therefore, the purpose of the present study was to investigate the effect of instantaneous performance feedback (peak velocity) provided after each repetition of squat jump exercises over a six week training block on sport specific performance tests.

Methods

Experimental approach to the problem

A randomised control training study of six weeks duration was used to determine the effect of a feedback or non-feedback squat jump intervention on functional performance. Thirteen subjects were randomly assigned to a feedback or non-feedback group. The bar velocity during squat jumps was quantified for each training session with a linear position transducer. Given power is the product of velocity and force it is suggested that maximizing the velocity of the movement may enhance the development of power if force remains unaffected. Differences pre to post training in sport specific performance tests and chances (% and qualitative) that the true value of the statistic was practically or mechanistically positive, trivial, or negative were calculated.

Subjects

For the period of the study thirteen professional rugby players were randomly assigned to one of two groups, feedback (n = 7, age = 25.7 ± 3.6 years, height = 188.5 ± 8.2 cm, weight = 104.3 ± 10.0 kg, training age = 3.7 ± 1.0 years, 1RM squat = 176.0 ± 35.6 kg) and non feedback (n = 6, age = 24.2 ± 2.5 years, height = 184.7 ± 7.2 cm, weight = 102.9 ± 14.3 kg, training age = 3.2 ± 1.2 years, 1RM squat = 185.4 ± 28.8 kg). All subjects had a minimum of two years resistance training experience and were currently in the pre-season phase of their training programme. All testing procedures and risks were fully explained and participants were asked to provide their written consent prior to the start of the study. The study was approved by the AUT University Ethics Committee.

Equipment

A wire from a linear position transducer (Celesco PT5A-150; Chatsworth, CA) was attached to an Olympic barbell. The barbell was loaded with two 10 kg plates for an absolute load of 40 kg. The barbell was placed on an adjustable squat rack which was adjusted to the appropriate depth relating to the height of each individual (Figure 5.1). A Vertec (Swift Performance Equipment, Lismore, Australia) was used to measure vertical jump height. Wireless timing lights (Brower Timing Systems LLC, Draper, UT, USA) set at a height of 90 cm were used to record sprint times over 10 / 20 / 30 m.



Figure 5.1. Set up of barbell, adjustable rack and linear position transducer for performance of squat jumps.

Procedures

Participants were matched by playing position and randomly assigned to one of two groups with each group completing a testing sessions at least 48 hours prior to the

commencement of the training study and 48 hours after the completion of training. The testing session was a series of performance tests that the participants completed on a regular basis as part of their conditioning programme, so familiarization was unnecessary. A standardised warm-up was undertaken prior to each testing occasion, which was also performed regularly by the participants. Each testing session consisted of vertical jump, horizontal jump and 30 m timed sprints with split times also taken at 10 m and 20 m.

Vertical Jump

Subjects stood with both feet on the ground shoulder width apart and the maximum vertical reach of a single arm was recorded on the Vertec. A counter movement vertical jump was performed and the maximal reach of the same arm was recorded. The difference between the jumping reach and the standing reach was recorded as the jump height. A minimum of one minute rest was given between trials. The better of two attempts was used for analysis (TE = 0.97 cm, ICC = 0.99).

Horizontal Jump

Subjects stood with feet shoulder width apart with toes behind (touching) a line on the ground. Subjects then performed a counter movement horizontal jump, with arm swing allowed, along the length of a tape measure secured to ground. The landing placement of the feet was recorded and the distance from the heel of the foot back to the start line was recorded as the jump distance. If the subjects landed with one foot ahead of the other the jump was not recorded. The better of two successful attempts was recorded and a minimum of one minute rest was given between trials (TE = 0.04 m, ICC = 0.97).

Timed Sprints

Subjects completed two trials of a 30 m maximal sprint with split times also recorded at 10 m and 20 m. Times were recorded using a series of wireless timing lights. Subjects self started from a stationary split stance start with the front of the leading foot 50 cm back from the first timing light. The better of two trials (based on 30 m time) was recorded and a minimum of two minutes rest was given between trials ($TE = 0.05 \text{ m}\cdot\text{s}^{-1}$, $ICC = 0.92$).

Training Programme

The exercises and sessions prescribed were part of the regular pre-season training programme used by the team (see Table 5.1). Other conditioning sessions involved an energetic and skills focus; however, these sessions were similar for all players. During each session all participants completed the same number of repetitions which was adjusted depending on the exercise (see Table 5.1). The subjects in group one (feedback), were given real-time feedback (visual onto a screen) on peak velocity at the completion of each repetition (Figure 5.2), whilst those in group two (non feedback) did not receive any feedback. Subjects performed three sets of three concentric squat jumps using a barbell with an absolute load of 40 kg. The depth of the squat was set at a knee angle of 90° and this was controlled using an adjustable rack that the barbell had to rest on before the commencement of each repetition. Participants were instructed to perform the movement as fast and explosively as possible with a pause between repetitions to distinguish each movement.

Table 5.1. Six-week pre-season resistance training programme *†

MONDAY	WEDNESDAY	FRIDAY
Shoulder Prehab 4 x 20	Squat jumps 3 x 3 (40 kg)	Squat jumps 3 x 3 (40 kg)
Bent Over Row + Pull Up 3 x 6 RM Or Lat Pull Over 3 x 6	Deadlift + Front Squat + Push Press 4 x 3 RM	Deadlift + Front Squat + Push Press 5 x 6 RM
Bench Press 5 x 6 RM	Deep Squat 4 x 6 RM	Bench Press 5 x (6-1) RM‡
Deep Squat + Shoulder Press 3 x 6 RM Or DB Deadlift + Shoulder Press 3 x 6 RM Or Shoulder Press + Rotation 3 x 6 RM	Calf Raise 4 x 6 RM	Bent Over Row 5 x 6RM
Single Arm Bench Row 3 x 6 RM Or Bent Over Row 3 x 6 RM	Single Leg Press 4 x 6 RM	Deadlift + Shrug + Upright Row 5 x 6RM
Side Bend 3 x 5 RM Or Decline Bench Press 5 x 6 RM Or Triceps Extension 3 x 10 RM	Glute Ham Raise 4 x 6 RM Or Leg Curl 4 x 6 RM	Shoulder Press 3 x 6 RM Or Cable Rotation 3 x 6 RM

*RM = repetition maximum.

†All exercises were performed with 2 minute rest between sets.

‡Weight increased each set, that is, from 6RM to 5RM to 4 RM, etc.

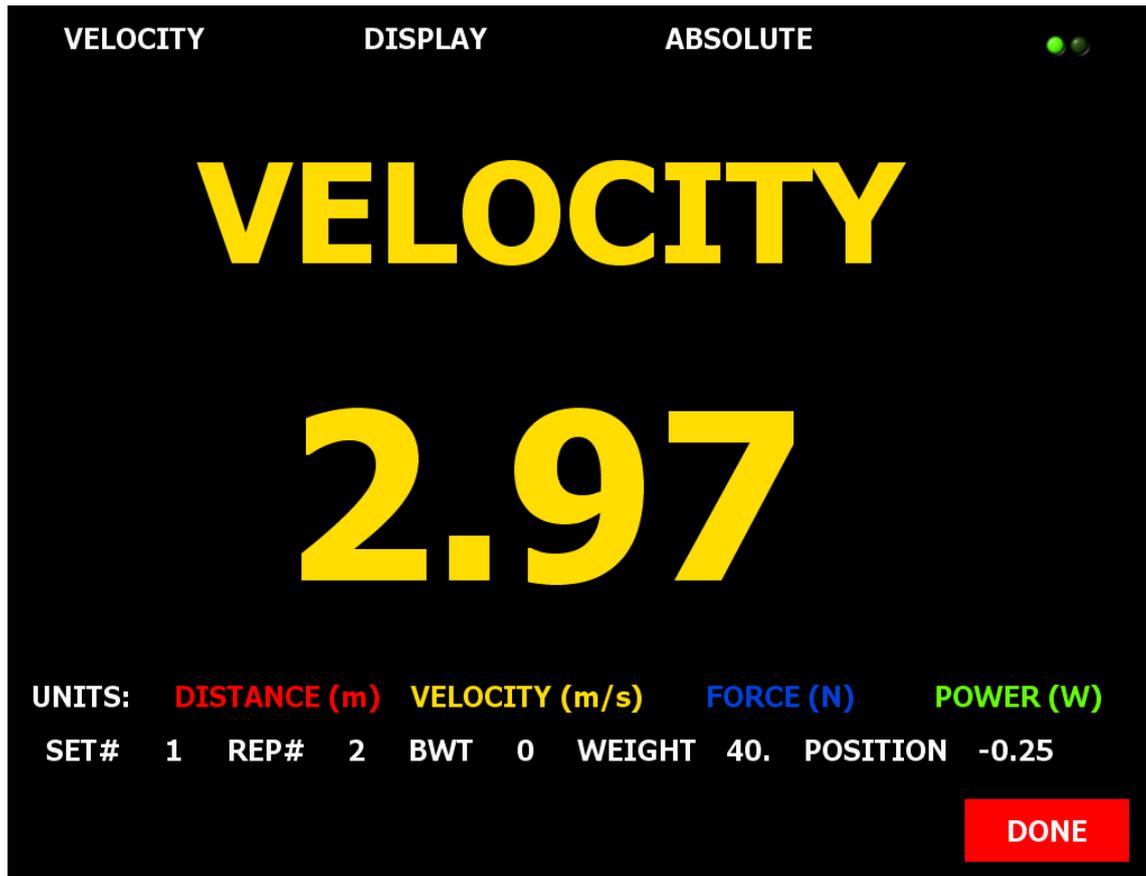


Figure 5.2. Visual display used for peak velocity feedback at completion of each jump squat repetition for feedback group.

Statistical analyses

Peak velocity during the concentric phase for each repetition was recorded using a position transducer with a velocity repeatability of better than $\pm 0.10\%$ of output, and customised data acquisition and analysis software (Labview, National Instruments, Austin TX). Velocity was differentiated from the displacement time data which was sampled at 500 Hz and low-pass filtered at 10 Hz.

Intraclass correlation coefficients (ICC) were used to determine the consistency of effort (i.e. consistency of session average peak velocity) for both groups over the entire training study. A spreadsheet for analysis of a straight forward controlled trial

(Hopkins, 2003) was used to determine the percent change between pre and post training study for each of the variables of interest (vertical jump height, horizontal jump distance and 10/20/30 m sprint times). Cohen effect sizes (ES) were used to determine the relative magnitude of the training effects. Effects less than 0.41 represented a small ES, 0.41 to 0.70 a moderate ES, and greater than 0.70 a large ES (Cohen, 1988). The chances (% and qualitative) that the true value of the statistic (percent change in variable of interest) was practically or mechanistically positive, trivial, or negative was also calculated using the spreadsheet (Hopkins, 2003). This approach using probability statistics allows the reader to make decisions around the use of feedback based on its predicted beneficial or harmful effects in addition to statistical significance. Statistical power was calculated for each outcome variable based on an alpha level of 0.05 and difference in means and standard deviations between groups. An alpha level of 0.05 was also used for statistical significance. Confidence intervals (90% CI) and P-values were also presented where appropriate.

Results

The change in horizontal jump and 30 m sprint time were the only statistically significant differences between training groups ($p = 0.01$ and 0.0008 respectively). The mean (\pm SD) results and percent change of the performance test for the feedback and non-feedback conditions can be observed in Table 5.2. These show that for all tests the feedback condition produced larger percent changes in means (0.9 to 4.6% vs. -0.3 to 2.8%). With regards to practical significance, the chance that these changes were practically beneficial or trivial and the ESs are reported in Table 5.3. The probabilities that the use of feedback during squat jump training was beneficial were 45% for vertical jump performance, 65% for 10 m sprint performance, 49% for 20 m sprint performance, 83% for horizontal jump performance and 99% for 30 m sprint performance. The

relative magnitude (ES) of the training effects for all performance tests were found to be small (0.18 to 0.28), except for the 30 m sprint performance which was moderate (0.46).

The ICC was used as a measure of consistency of effort between days. The ICCs for the feedback condition (0.81 to 0.95) were larger than for the non-feedback condition (-0.52 to 0.14) suggesting that those in the feedback group maintained effort (i.e. average system velocity) to better effect than the non-feedback group.

Table 5.2. Mean (SD), and percent change in mean of vertical jump (m), horizontal jump (m), and 10-/20-/30 m sprints (s) pre and post 6-week squat jump training.

	Vertical Jump			Horizontal Jump			10 m Sprint			20 m Sprint			30 m Sprint		
	Pre	Post	Percent Change	Pre	Post	Percent Change	Pre	Post	Percent Change	Pre	Post	Percent Change	Pre	Post	Percent Change
Feedback	0.61 (0.06)	0.64 (0.07)	4.6	2.50 (0.16)	2.56 (0.15)	2.6	1.74 (0.04)	1.73 (0.05)	1.3	3.03 (0.06)	3.00 (0.06)	0.9	4.20 (0.11)	4.14 (0.11)	1.4
Non Feedback	0.66 (0.06)	0.67 (0.01)	2.8	2.58 (0.20)	2.59 (0.20)	0.5	1.79 (0.10)	1.79 (0.09)	0.1	3.06 (0.16)	3.06 (0.15)	0.1	4.25 (0.21)	4.26 (0.19)	-0.3

Table 5.3. Effect sizes and chances (% and qualitative) that the benefit of feedback during jump squats is practically positive or trivial for vertical jump, horizontal jump, and 10-/20-/30 m sprints after 6 weeks of training.

	Vertical Jump	Horizontal Jump	10 m Sprint	20 m Sprint	30 m Sprint
Effect Size	0.18 (Small)	0.28 (Small)	-0.28 (Small)	-0.20 (Small)	-0.46 (Moderate)
Positive	45 (Possibly)	83 (Likely)	65 (Possibly)	49 (Possibly)	99 (Almost Certainly)
Trivial	51	17	33	49	1
Power	0.131	0.851	0.791	0.860	1.000

Discussion

The purpose of this study was to investigate the effect of instantaneous performance feedback (peak velocity) provided after each repetition of squat jump exercises over a six week training block on sport specific performance tests. This contention is subsequently discussed.

In terms of the performance measures, an increase in vertical jump over the 6 weeks was observed in both feedback (4.6%) and non feedback (2.8%) conditions. Although a greater improvement was seen with feedback there was a 51% chance this was trivial and 45% chance of being positive. Given this performance test was very similar to the movement used in training (squat jump) it suggests that improvements were seen as a result of repetition of the movement regardless of the feedback conditions. These results are similar to improvements in vertical jump (3.7%) observed following five weeks of squat jump training using a 70% 1RM load without feedback (Hoffman et al., 2005). Even though the load moved was greater than that utilised in the present study it again appears that repetition of the squat jump movement will result in an increase in vertical jump height. Previous research has also shown that even a squat programme without a dynamic component has a positive effect in increasing vertical jump (Adams, O'Shea, O'Shea, & Climstein, 1992). The authors suggested that the squat was conducive to enhancing neuromuscular efficiency, in turn allowing for excellent transfer to other biomechanically similar movements requiring lower body triple extension movements as seen in the vertical jump. Although increases in vertical jump were seen both with and without the use of feedback the use of feedback was reported to have a 45% chance of a positive effect on performance and produced a small training effect ($ES = 0.18$). This would suggest there is evidence to support the use of feedback during

training to enhance vertical jump performance.

A larger increase in performance with the use of feedback was also observed in the horizontal jump (2.6% vs. 0.5%). As suggested previously it is thought that movements requiring a powerful thrust from hips and thighs can be improved through the prescription of a biomechanically similar movement during training (Adams et al., 1992). It would seem that this has occurred here where the use of squat jumps during training resulted in improvements in horizontal jump performance. Again there appears justification for the use of feedback within training to optimise performance improvements, as the use of feedback was reported have a 83% chance of having a positive effect on horizontal jump performance and a small training effect noted (ES = 0.28).

Improvements in sprinting speed were observed over 10 m (1.3%), 20 m (0.9%) and 30 m (1.4%) distances. Again these were larger than those observed from the feedback group (0.1%, 0.1% and -0.3% respectively).

The results from the non-feedback group are in agreement with the findings of previous research using jumps without feedback. Loads of 70% 1RM (Hoffman et al., 2005) and 30% (Wilson, Newton, Murphy, & Humphries, 1993) were also reported not to have produced significant increases in speed, questioning the effectiveness of squat jumps, regardless of relative load, in eliciting speed improvements. Although there have been reports of improvements in 10 m (1.6%) and 20 m (0.9%) times following eight weeks of squat jump training using a 30% 1RM load without feedback (McBride, Triplett-McBride, Davie, & Newton, 2002), it should be noted the subjects were recreationally active, involved in some type of club-level activities, whereas the present subjects were professional athletes. The pre training times for the current non feedback subjects were

considerably faster (1.79 s vs. 1.91 s and 3.06 vs. 3.27 s respectively) suggesting the current athletes had less scope for improvement.

What is of significance in the present study is the increases in speed observed through the use of feedback during training. Feedback was reported to have a 65% and 49% chance of having a positive effect on 10 m and 20 m sprint performance respectively, with small training effects ($ES = -0.28$ and -0.20 respectively). In addition feedback was reported to have a 99% chance of having a positive effect on 30 m performance, with a moderate training effect ($ES = 0.46$). This may be due to the use of feedback during training enabling a greater consistency in the peak velocity achieved during the squat jumps. It has been suggested that the actual velocity of training is a vital component of producing high velocities (McBride et al., 2002). In addition peak velocity during traditional squats has been shown to be significantly correlated to sprint time ($r = 0.40$, $p = 0.029$) (Sleivert & Taingahue, 2004). Similarly it has also been suggested that exercises with greater rate of force development (RFD) lead to greater improvements in sprinting (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005), and whilst RFD was not measured in the present study consistently higher peak bar velocities were seen with feedback. Therefore it would appear that optimizing the training session through the use of feedback leads to increases in sprint performance that may not have been realised using traditional training strategies.

Previous work by the authors has shown that the provision of feedback adds consistency to the performance of squat jumps (Randell, Cronin, Keogh, Gill, & Pedersen, In Press) and increases peak velocity of squat jumps (Randell, Cronin, Keogh, Gill, & Pedersen, 2010). It was suggested that these benefits may be transferred to movement or sport specific tasks if applied over a training phase. With regards to the motivational aspects

of feedback it seems that the feedback condition resulted in consistency of effort and performance throughout the programme as highlighted by the reported ICC values. The feedback condition ICCs ranged from 0.81 to 0.95 whereas the non-feedback condition ICs ranged from -0.52 to 0.14. Given the ICCs relate to the reproducibility of the rank order of subjects on a subsequent training session it appears that the feedback conditions enabled subjects to perform consistently in relation to the other subjects whereas the non-feedback subjects varied greatly in their performance from session to session.

A number of limitations need to be acknowledged prior to the concluding remarks. First the sample size in each group was relatively small but this represented all the professional players in the region. The aim was to use well trained players as it is much more difficult to elicit adaptation and performance enhancement in well trained athletes. As a result of the small sample size the probability that the findings were practically significant were calculated. To many practitioners such a statistic is invaluable, given that some results may not be statistically significant but there may be a high probability that the intervention is practically or clinically beneficial as was the case for the 10 m sprint. That is, even though there was no significant difference between feedback and non-feedback conditions, there was a 65% probability that the use of feedback was beneficial to 10 m sprint performance. Given those odds most practitioners would choose to use feedback even though not statistically significant.

A final limitation was the duration of the training study i.e. six weeks. Longer exposure to the intervention may have resulted in larger training effects. However, given that most training cycles are of four to six week durations the duration of this study seems to have face or logical validity. Once more the results of this study (i.e. ~1-5% changes in the performance measures of the feedback group) are noteworthy, given the duration of

the intervention and training status of the subjects.

Practical applications

Of particular interest to the strength and conditioning practitioner is the observation that the provision of feedback on a single exercise (squat jump) during a resistance strength training programme resulted in an improvement in the performance of movement and sport specific tests. Given athletes were also able to improve performance over a six week training programme, it would seem intuitive to monitor multiple exercises of each training session and provide feedback, which should provide greater potential for adaptation and larger training effects. The use of such monitoring and feedback technologies may be further utilised through the ability to set training performance targets, such as maximum velocity and number of repetitions or sets completed above a pre determined performance threshold. This has the potential to eliminate the performance of repetitions that may be contributing to fatigue without providing a positive training effect e.g. power training. In addition, this may prove to be very motivational when fatigue sets in, as well as creating competition between athletes in the training environment.

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PART 2. TRANSFERENCE OF STRENGTH AND POWER ADAPTATION TO SPORTS PERFORMANCE - HORIZONTAL AND VERTICAL FORCE PRODUCTION.

CHAPTER 6. LITERATURE REVIEW

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., and Gill, N. D. (2010). Transference of strength and power adaptation to sports performance - horizontal and vertical force production. *Strength and Conditioning Journal*, 32(4), 100-106.

Author contributions - AR: 80%, JC: 10%, JK: 5%, NG: 5%

Summary

The training of horizontal propulsive force generation is one aspect of many sports that is not easily simulated with traditional gym-based resistance training methods which principally work the leg musculature in a vertical direction. Given that most motion involves an integration of both vertical and horizontal force production, transference of gym based strength gains may be improved if exercises were used that involved both vertical and horizontal force production.

Introduction

Running velocity over short distances is an important factor for successful performance in most team sports (Baker & Nance, 1999; Rimmer & Sleivert, 2000; Young, James, & Montgomery, 2002). Velocity is the product of stride length and stride rate or frequency, and in order to increase velocity at least one, if not both, of these parameters must be increased (Spinks, Murphy, Spinks, & Lockie, 2007; Weyand, Sternlight, Bellizzi, & Wright, 2000). From the deterministic model depicted in Figure 6.1, it can be observed that both stride length and frequency are products of the amount and duration of force exerted. That is, the fundamental factors relating to optimizing

velocity are the application of force and the time over which it is applied.

What is not apparent from the model is the direction of force application that is most important. That is, is the application of horizontal or vertical force of more importance to increase velocity? Within the literature there are differing views as to the significance of each during sprint performance. Further ambiguity is added to this issue when additional sport specific factors need to be considered, such as those encountered during contact situations in rugby and rugby league. Therefore, it is not entirely clear which force component is more important in affecting increased velocity within a sporting situation such as rugby and rugby league.

The velocity requirements of the sport also need to be considered, such as the distances or durations over which players are commonly required to sprint. In sports where average sprint distances range from 10-30 m it would appear that the ability to achieve maximum velocity within the shortest timeframe is more important than the maximal velocity itself. That is, acceleration rather than maximum velocity would seem to be of greater importance to many sportsmen and women. This leads to the question of whether there are different directional requirements to force application when considering maximum velocity and maximum acceleration.

This literature review addresses this contention by: 1) investigating the literature on horizontal force production and its effect on velocity and acceleration; 2) investigating the literature on vertical force production and its effect on velocity and acceleration; 3) suggesting future research directions.

Horizontal vs. vertical force production

Determinants of velocity

Velocity is the product of stride rate or frequency and stride length, and in order to increase velocity at least one, if not both, of these parameters must be increased without a proportionately similar or larger decrease in the other (Hunter, Marshall, & McNair, 2004; Nummela, Keranen, & Mikkelsen, 2007; Spinks et al., 2007; Weyand et al., 2000).

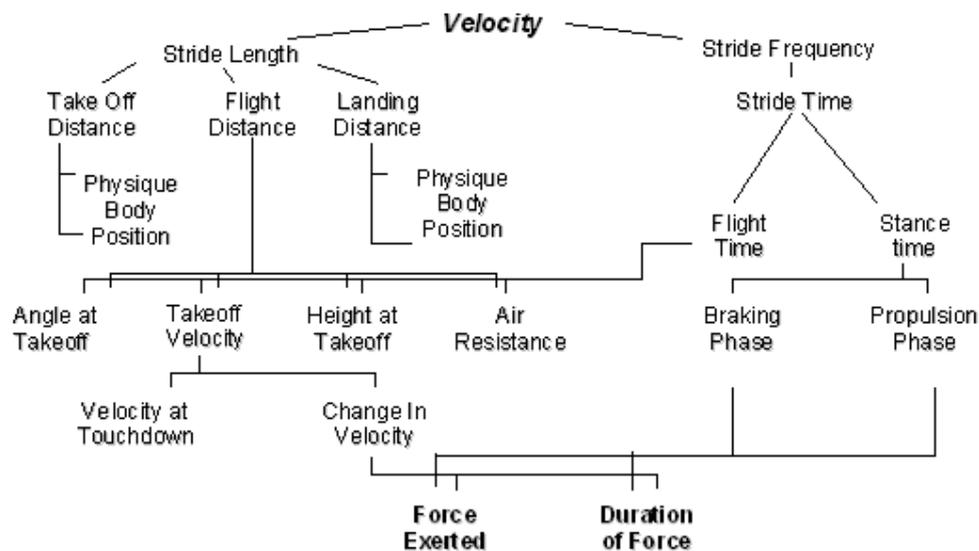


Figure 6.1. Deterministic model of velocity. Adapted from Hay (1993).

If velocity is simply the product of the frequency and length of a runner's stride (Figure 6.1), it would be possible to attain faster top running velocities simply by increasing the frequency of steps. Weyand et al. (2000) reported that at top velocity during level treadmill running stride frequencies were 1.16 times greater for a runner with a top velocity of $11.1 \text{ m}\cdot\text{s}^{-1}$ vs. $6.2 \text{ m}\cdot\text{s}^{-1}$ (1.8 fold range) ($r^2 = 0.30$). However, when the same researchers investigated the individual variation at top velocity on -6° decline and $+9^\circ$ incline treadmill inclinations no significant difference in stride frequency (4.38 ± 0.08 steps/s vs. 4.34 ± 0.08 steps/s respectively) was observed despite a significant difference

in top velocity ($9.96 \pm 0.30 \text{ m}\cdot\text{s}^{-1}$ vs. $7.10 \pm 0.31 \text{ m}\cdot\text{s}^{-1}$ respectively). Hunter et al. (2004) reported that step rate was not significantly related to sprint velocity ($r = -0.14$), as did Brughelli, Kinsella, and Cronin (2008) who reported a trivial correlation between maximum running velocity and stride frequency ($r = 0.02$). Heglund and Taylor (1998) suggested that the range of stride frequencies used at different velocities tends to be narrow, however these results were based on animal studies using quadrupeds ranging in body size from a mouse to a horse.

Stride frequency is directly influenced by the stride time, which in turn is comprised of swing time or flight time and contact time or stance time (Nummela et al., 2007). That is,

$$\text{Stride frequency} = 1 / (\text{flight time} + \text{stance time})$$

Given swing time comprises the majority of the total stride time at top velocity (approximately 75% of stride time for maximum velocities of $6.2 \text{ m}\cdot\text{s}^{-1}$ to $11.1 \text{ m}\cdot\text{s}^{-1}$) (Weyand et al., 2000), the relatively weak relationship between top velocity and maximal stride frequency may be the result of runners with different top velocities repositioning their legs in similar periods of time. That is, similarities between minimum swing times minimise the extent of possible variation in maximal stride frequencies. Regression relationships presented by Weyand et al. (2000) showed minimum swing times were only 8% (0.03 s) shorter for a runner with a top velocity of 11.1 vs. $6.2 \text{ m}\cdot\text{s}^{-1}$ ($r^2 = 0.06$) during level treadmill running. In contrast swing times at the slower velocities attained during inclined running were actually 8% shorter than those of the faster decline running ($0.331 \pm 0.005 \text{ s}$ and $0.359 \pm 0.004 \text{ s}$ respectively). This difference, however, was attributed to interruption of the limb's arc due to the inclination of the running surface rather than differences in velocity.

If it is indeed the case that both fast and slow runners and fast and slow running velocities present similar swing times then differences in maximal stride frequencies between fast and slow runners may result from the contact portion of the stride being shorter in faster runners and/velocities. Brughelli et al. (2008) reported a low correlation between maximum running velocity and contact time ($r = 0.14$), however this is in contrast to other research. Nummela et al. (2007) reported that maximal running velocity had a significant negative relationship with ground contact times ($r = -0.52$). In support of this finding, the contact times at maximum velocity observed by Weyand et al. (2000) were significantly shorter for the faster decline running compared to the slower incline running (0.098 ± 0.003 s and 0.130 ± 0.004 s respectively). Kyröläinen, Belli, and Komi (2001) reported that as running velocity increased from $3.45 \text{ m}\cdot\text{s}^{-1}$ to $8.25 \text{ m}\cdot\text{s}^{-1}$ contact times shortened from 0.227 ± 0.011 s to 0.115 ± 0.007 s. Munro, Miller, and Fuglevand (1987) also reported a decrease in contact time as running velocity increased (0.27 ± 0.020 s at $3.0 \text{ m}\cdot\text{s}^{-1}$ and 0.199 ± 0.013 s at $5.0 \text{ m}\cdot\text{s}^{-1}$). It would seem that an increase in velocity due to an increase in stride frequency may be attributable to a decrease in the time the athlete is in contact with the ground.

As stated previously, if velocity is simply the product of the frequency and length of a runner's stride (Figure 6.1), then it would also be possible to attain faster top running velocities simply by increasing the stride length. Weyand et al. (2000) reported that during level treadmill running stride lengths at top velocities were 1.69 times greater (4.9 m vs. 2.9 m) for a runner with a top velocity of 11.1 vs. $6.2 \text{ m}\cdot\text{s}^{-1}$ ($r^2 = 0.78$). It was also reported that stride lengths during maximal velocity decline running (4.6 ± 0.14 m at $9.96 \pm 0.30 \text{ m}\cdot\text{s}^{-1}$) were significantly greater than those of maximal velocity incline running (3.3 ± 0.10 m at $7.10 \pm 0.31 \text{ m}\cdot\text{s}^{-1}$). This is in agreement with other researchers (Brughelli et al., 2008; Hunter et al., 2004) who reported significant correlations

between maximum running velocity and stride length ($r = 0.66$ and $r = 0.73$, respectively).

Stride length is the sum of the takeoff, flight and landing distance. However, Weyand et al. (2000) reported that contact lengths did not differ between fast and slow runners with regression equations indicating that contact lengths were only 1.10 times greater for a runner with a top velocity of 11.1 vs. 6.2 $\text{m}\cdot\text{s}^{-1}$ ($r^2 = 0.30$). Furthermore, when these results were analyzed within groups of males and females, it was reported that contact lengths varied little or not at all in relation to top velocity. Nummela et al. (2007) reported an increase stride length was related to an increase in both vertical force ($r = 0.58$) and horizontal propulsion force ($r = 0.73$), suggesting that an increase in stride length is achieved by increasing both vertical and horizontal ground reaction forces (GRF). These results would tend to suggest that the predominant mechanism utilised by runners to achieve greater stride length is through greater application of GRF. That is, stride length is determined by the product of force exerted during foot-ground contact and the duration of the applied force (Spinks et al., 2007; Weyand et al., 2000).

It would appear that the major determinants of velocity are the forces applied to the ground and the time of foot-ground contact. That is the attainment of greater velocity requires the application of greater support forces during briefer contact periods. Ground reaction forces can be broken down into three components, however, typically the horizontal (anterior-posterior) and vertical components are of most interest (Hunter, Marshall, & McNair, 2005). Mero and Komi (1986) have shown a relationship between running velocity and average net resultant force (vertical and horizontal), when related to body weight ($r = 0.65$), but there are numerous hypotheses regarding the relative

importance of various GRF components to sprint performance. It has been shown that faster running velocity are associated with increased vertical force production (Arampatzis, Bruggemann, & Metzler, 1999; Brughelli et al., 2008; Keller et al., 1996; Kyröläinen et al., 2001; Munro et al., 1987; Nigg, Bahlsen, Luethi, & Stokes, 1987; Weyand et al., 2000), whilst a relationship to horizontal force production has also been shown (Brughelli et al., 2008; Hunter et al., 2005; Kyröläinen et al., 2001; Munro et al., 1987; Nummela et al., 2007). This section investigates the relationship of both components, and suggests future directions for research in this area.

Vertical force production

It has been theorised that during constant velocity running there is no or very little horizontal resistance to overcome and that the propulsive forces that increase the body's forward velocity before takeoff simply offset the braking forces that decrease the body's velocity on landing (Munro et al., 1987; Weyand et al., 2000). Furthermore, it is the vertical portion of stride that needs assistance due to the need to overcome gravity, therefore applying greater forces in opposition to gravity would increase vertical velocity on takeoff, translating to an increased running velocity.

Weyand et al. (2000) reported an increase in vertical force production was the predominant mechanism utilised by runners to attain faster top velocities. Regression equations showed that at top velocity mass-specific forces applied to oppose gravity were 1.26 times greater for faster runners compared with slower runners ($r^2 = 0.39$). Furthermore when comparing the same subject at different velocities, significant differences in vertical forces were observed between the faster top velocities achieved during decline running and the slower top velocities of incline running (2.30 ± 0.06 and 1.76 ± 0.04 BW respectively). Munro et al. (1987) reported that as running velocities

increased from 3 m.s⁻¹ to 5 m.s⁻¹ peak vertical GRF (relative to body weight) increased from 1.40 ± 0.11 to 1.70 ± 0.08 BW. Similar findings were reported by Nigg et al. (1987) whereby vertical forces were found to significantly increase as velocity increased from 3 m.s⁻¹ to 6 m.s⁻¹ (1331 ± 225 N to 2170 ± 489 N respectively). Using the subject's reported mean body weight these equate to estimated values of 1.9 and 3.0 BW respectively. Similarly Kyröläinen et al. (2001) demonstrated changes in the ground reaction forces as velocity increased from 3.45 to 8.25 m.s⁻¹. Maximal vertical force values increased from 1665 ± 219 to 2134 ± 226 N. As results were not reported by gender, relative values were not able to be calculated. Arampatzis et al. (1999) also reported an increase in maximum vertical GRF (N.kg⁻¹) between velocities of 2.5 and 6.5 m.s⁻¹, although values were not presented. These findings support the theory of an increase in running velocity being achieved through an increase in vertical ground reaction forces.

Horizontal force production

In contrast to the above, it has been suggested that the critical factor in maximal sprint running is an increase in horizontal propulsive forces. In order to maintain velocity the horizontal propulsive force must be equal to the braking force, however, to increase velocity the propulsive force must be greater than the braking force (Hunter et al., 2005; Mero, Komi, & Gregor, 1992; Nummela et al., 2007), suggesting horizontal propulsive forces play an important role in velocity development and acceleration.

Using multiple linear regression, Hunter et al. (2005) found relative propulsive impulse explained 57% ($r^2 = 0.57$) of the variance in sprint velocity, whereas relative vertical impulse did not explain any further variance in sprint velocity. These findings are supported by those of Nummela et al. (2007) who also reported a significant correlation

between maximal running velocity and mass-specific horizontal forces during the propulsion phase ($r = 0.66$). Once again mass-specific vertical force was not found to be related to the maximal running velocity. Munro et al. (1987) reported propulsive impulses, normalised by body weight, increased 79% from 0.14 ± 0.01 BWI to 0.25 ± 0.2 BWI as velocity increased from 3.0 m.s^{-1} to 5.0 m.s^{-1} . Over the same velocity range vertical GRF only increased 21%. Kyröläinen et al. (2001) also demonstrated changes in the GRFs with increasing velocity. As velocity increased from 3.45 m.s^{-1} to 8.25 m.s^{-1} maximal forces in the horizontal direction increased 175% from $235 \pm 42\text{N}$ to $675 \pm 173 \text{ N}$, whereas vertical forces only increased 30%. As mentioned previously, the estimation of relative values was not possible due to the non-separation of results by gender. Increases in horizontal forces were also reported by Brughelli et al. (2008). As running velocity increased from 40% to 100% of maximum relative horizontal forces increased 105% from $0.21 \pm 0.02 \text{ N.kg}^{-1}$ to $0.43 \pm 0.06 \text{ N.kg}^{-1}$ whilst vertical forces only increased 18%. These findings seem to suggest that horizontal force production is more important than vertical force production in allowing an increase in running velocity.

It is worth noting the differences in methodologies employed by the various studies. Results from studies utilizing motorised (Weyand et al., 2000) and non motorised (Weyand et al., 2000) treadmills have been presented alongside those obtained from ground running (Arampatzis et al., 1999; Hunter et al., 2005; Kyröläinen et al., 2001; Munro et al., 1987; Nigg et al., 1987; Nummela et al., 2007). While it may be questionable as to whether constant velocity running on a motorised treadmill is an accurate way of deducing cause and effect for over ground running, of greater interest may be the conclusion presented by Weyand et al. (2000) reporting an increase in vertical force production was the predominant mechanism utilised by runners to attain faster top velocities when only vertical force production was measured. This is also true

of Arampatzis et al. (1999) and Nigg et al. (1987) who reported vertical forces were found to significantly increase as velocity increased. Of the studies who measured both vertical and horizontal force, Kyröläinen et al. (2001) and Munro et al. (1987) reported increases in both components with an increase in velocity, whereas Hunter et al. (2005) and Nummela et al. (2007) reported significant relationships only with the horizontal forces.

Vertical vs. horizontal

When the vertical and horizontal components are compared it is apparent that the magnitude of the vertical forces is the larger of the two. Munro et al. (1987) reported at velocities ranging from 3.0 m.s^{-1} to 5.0 m.s^{-1} peak vertical-GRFs are typically 5-10 times greater than the peak horizontal forces. At 3.0 m.s^{-1} and 5.0 m.s^{-1} horizontal propulsive impulses were 10% and 15% of average vertical ground reaction forces respectively. From the results presented by Kyröläinen et al. (2001) at 3.45 m.s^{-1} and 8.25 m.s^{-1} horizontal forces were 14% and 32% respectively of vertical GRFs. This apparent difference in magnitude is also supported by Brughelli et al. (2008) who reported that at 40%, 65%, and 100% of maximum velocity relative horizontal forces were 9%, 12% and 18% respectively of relative vertical forces which can be attributed to vertical acceleration i.e. 9.81 m.s^{-2} .

Although there does appear to be a difference between vertical and horizontal force production, it seems that the magnitude of this difference decreases as velocity increases. If horizontal components of GRF are expressed as a percentage of the vertical component, then an increase in the reported percentage would imply that the horizontal component has increased proportionally more so than the vertical component. This increase in the percentage contribution of the horizontal component of GRF as

speed increases is evident in the studies by Munro et al. (1987), 10% at 3.0 m.s⁻¹ increased to 15% at 5.0 m.s⁻¹, Kyröläinen et al. (2001), 14% at 3.45 m.s⁻¹ increased to 32% at 8.25 m.s⁻¹, and Brughelli et al (2008), 11% at 40% maximum velocity increased to 19% at 100% of maximum velocity.

In addition to a non-uniform increase in the two main components of GRF is also evident that the increases in vertical forces with increasing velocity may not be linear. Although Munro et al. (1987) and Nigg et al. (1987) indicated that the increases in the vertical GRFs were linear with increasing velocity in the range of 3-6 m.s⁻¹, and Keller et al. (1996) noted similar linear increases up to 3.5 m.s⁻¹, above these velocities the relationship has been reported to be non-linear, and in some cases there is no further increase in vertical forces. Brughelli et al. (2008) reported that as running velocity increased from 40% to 65% of maximum velocity, relative horizontal forces increased 38% (0.21 ± 0.02 to 0.29 ± 0.03 N.kg⁻¹), and relative vertical forces increased 17% (1.98 ± 0.23 to 2.31 ± 0.18 N.kg⁻¹). However, as running velocity increased from 65% to 100% relative horizontal forces increased a further 48% (0.29 ± 0.03 to 0.43 ± 0.06 N.kg⁻¹), whereas relative vertical forces remained relatively constant and only increased 1% (2.31 ± 0.18 to 2.33 ± 0.30 N.kg⁻¹). These findings are similar to those of Nummela (2007) who also reported that relative vertical force remained constant after approximately 65% max velocity. It was observed that vertical force increased with the increasing velocity until the velocity of 7 m.s⁻¹, thereafter the velocity was increased without further increase in vertical force. As mentioned previously Keller et al. (1996) reported a linear increase in relative vertical forces at lower velocities (1.23 ± 0.10 BW at 1.5 m.s⁻¹ to 2.45 ± 0.28 BW at 3.5 m.s⁻¹), however as velocity increased from 3.5 m.s⁻¹ to 6 m.s⁻¹ there were no significant increases in relative vertical forces (2.45 ± 0.28 BW to 2.38 ± 0.28 BW respectively). Furthermore, a decrease was observed at the

highest velocity of $8.0 \text{ m}\cdot\text{s}^{-1}$ ($1.89 \pm 0.49 \text{ BW}$) although this only represented values for three trials from one subject at this high velocity. Of interest are the findings of Hunter et al. (2005) who also reported that the relationship between relative vertical impulse and sprint velocity showed signs of nonlinearity. In this case, however it was shown that after a certain magnitude any further increases in relative vertical impulse did not correspond to an increase in sprint velocity. Although these results were only reported in graphical form they would seem to suggest that a ceiling effect may exist with regard to vertical force production, that is, past a certain point velocity is no longer increased by increasing vertical GRFs.

It has been shown that in order to reach faster maximum running velocities increases in both vertical and horizontal GRFs are required. Whilst it appears that the vertical component is the larger of the two GRFs, it is suggested that running velocity is more dependent on horizontal than vertical force as the velocities increase towards maximal. This is evident given linear relationships were not observed between vertical force and running velocity at higher velocities. The significance of the horizontal component seems to be logical since one cannot increase horizontal velocity by increasing vertical force, but acceleration and deceleration of running velocity is produced mainly by changing horizontal force. The next section considers the contribution of vertical and horizontal force production with regards to acceleration.

Acceleration

Although velocity is very important in most sporting situations, acceleration is of relatively greater importance when covering only short distances at maximal effort (Deutsch, Kearney, & Rehrer, 2007; Spinks et al., 2007). Therefore it would appear that the ability to achieve maximum velocity within the shortest timeframe is more

important than maximal velocity itself. That is acceleration becomes an essential focus when investigating the requirements of many sports.

As discussed previously there are numerous hypotheses regarding the relative importance of various GRF components to sprint performance. The velocity time-curve can be divided into three phases, acceleration, constant velocity and deceleration (Mero et al., 1992), and many of these hypotheses were intended to be the most applicable to the constant velocity phase of a sprint (Hunter et al., 2005). It has been suggested that during constant velocity running the propulsive forces that increase the body's forward velocity before takeoff simply offset the braking forces that decrease the body's velocity on landing (Munro et al., 1987; Weyand et al., 2000). In contrast, acceleration is achieved by changing horizontal force such that the propulsive force is larger than the braking force (Nummela et al., 2007). This leads to the question of whether there is a different directional requirement to force application when considering peak velocity and peak acceleration.

When investigating vertical and horizontal GRF characteristics, Mero (1988) compared the acceleration phase of sprinting (velocity = $4.65 \text{ m}\cdot\text{s}^{-1}$) to that of previous work investigating maximal sprinting (velocity = $9.85 \text{ m}\cdot\text{s}^{-1}$) (Mero, Komi, Ruskho, & Hirvonen, 1987). The respective average vertical forces were equal ($431 \text{ N} \pm 100 \text{ N}$ and approximately 563 N respectively), whereas the horizontal forces produced during the acceleration phase of sprinting were about 46% greater than those produced during constant velocity maximal sprinting ($526 \pm 75 \text{ N}$ and $360 \pm 42 \text{ N}$ respectively). It should be noted that the average vertical force from Mero et al. (1987) was estimated from the stated value ($1286 \pm 61 \text{ N}$), which was inclusive of body weight, minus the mean subject body weight (73.7 kg).

The vertical and horizontal values during acceleration obtained from Mero (1988) at 4.65 m.s⁻¹ can be expressed relative to bodyweight using the mean bodyweight and compared to the norms reported by Munro et al, (1987) at corresponding velocities of 4.5 m.s⁻¹ and 4.75 m.s⁻¹. Again it can be seen (Table 6.1) that the respective relative vertical forces during acceleration and constant velocity were equal at comparable velocities, whereas the horizontal force during acceleration was greater than those recorded during constant velocity. These results suggest a greater emphasis on horizontal force during acceleration than there is during constant velocity running.

Table 6.1. Horizontal and vertical forces during acceleration and constant velocity.

Study	Running Phase	Running Velocity	Vertical Force	Horizontal Force
Mero (1988)	Acceleration	4.65 m.s ⁻¹	1.60 BW	0.73 BW
Munro et al. (1987)	Constant velocity	4.5 m.s ⁻¹	1.65 BW	0.23 BW
		4.75 m.s ⁻¹	1.68 BW	0.24 BW

Hunter et al. (2005) reported that both simple and multiple regression results showed a relatively strong trend for faster athletes to produce greater magnitudes of relative propulsive impulse ($r^2 = 0.57$). It was thought that athletes with the ability to produce higher horizontal propulsive forces would undergo larger increase in horizontal velocity during each stance phase, thereby accelerating faster. This finding is in agreement with the research of Mero and Komi (1986) who reported a positive relationship between average resultant GRF during propulsion and sprint velocity between 35 m and 45 m marks ($r = 0.84$), and with those of Mero (1988) who reported a high correlation between horizontal force production in the propulsion phase and running velocity ($r = 0.69$). These results further emphasise the importance of the propulsion phase during the acceleration phase of sprinting.

Hunter et al. (2004) suggested that a high vertical GRF, and therefore a high vertical velocity of takeoff, had a positive effect on step length, however, it also had a negative effect on step rate. In addition there was evidence of a strong negative interaction between step length and step rate ($r = -0.78$). That is, those athletes who had a high step rate tended to have a shorter step length and vice versa. It was thought that more frequent ground contacts, via a low vertical GRF and short flight time, would allow a greater opportunity to accelerate. If flight time is increased during acceleration, as determined by a large relative vertical GRF, this would correspond to a decrease in the percentage of time spent in contact with the ground. Given an athlete can only influence their sprint velocity when in contact with the ground this would be a disadvantage (Hunter et al., 2005). That is, the most favourable magnitude of vertical GRF is one that creates a flight time only just long enough for repositioning of the lower limbs. If the athlete can reposition the limbs quickly, then a lower relative vertical GRF is sufficient, and all other strength reserves should be applied horizontally. It is only when an athlete cannot achieve or maintain a high step rate such as when fatigued, that a greater relative vertical GRF becomes more important (Hunter et al., 2005).

Therefore, during the acceleration phase of a sprint greater increases in horizontal propulsion are required to achieve high acceleration (Hunter et al., 2005). Consequently, it is proposed it would be of advantage to direct most training effort into producing a high horizontal GRF, not vertical GRF.

Conclusions and future research direction

It is generally accepted that maximal running velocity requires high force production (Baker & Nance, 1999; Mero et al., 1992; Mero, Luhtanen, Viitasalo, & Komi, 1981).

As such, strength and power training methods are almost universally promoted as a means of training to improve running velocity (Baker & Nance, 1999; Delecluse et al., 1995; Spinks et al., 2007). Therefore the relationship between strength and power and velocity are of considerable interest in attempting to identify possible mechanisms for the enhancement of running performance (Baker & Nance, 1999; Delecluse et al., 1995; Young, Hawken, & McDonald, 1996; Young, McLean, & Ardagna, 1995).

It is also generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance (Delecluse et al., 1995; Rimmer & Sleivert, 2000; Sale & MacDougall, 1981) and as such athletes who require power in the horizontal plane, engage in exercises containing a horizontal component, whereas athletes who require power to be exerted in the vertical direction, train using vertical exercises (Chu, 1998; Rimmer & Sleivert, 2000). Given that a variety of training regimes are commonly used to improve muscular force output with the ultimate goal of enhancing sprinting performance (Rimmer & Sleivert, 2000; Spinks et al., 2007), it would seem intuitive to focus on the enhancement of the forces which are the most important in improving velocity.

From the literature, while it is apparent that force production is necessary in both the vertical and horizontal planes, it is the horizontal forces that experience the greatest increase when accelerating to maximal velocity. This becomes even more valid when the demands of rugby, league or American football are taken into consideration. That is the need to accelerate quickly over short distances, where increases in horizontal propulsive forces are essential, and the need to overcome large horizontal resistances, in the form of contact from opposing players. It would, therefore, seem critical that a movement-specific approach be applied to the design of strength and power resistance

programmes for such sports.

Currently, most gym based resistance programmes focus on exercises that principally work the leg musculature in a vertical plane. It is proposed that the transference of gym based strength gains may be improved if exercises were used that involve both vertical and horizontal force production. That is, if successful performance requires force, velocity, and power (product of force and velocity) in the horizontal plane, improvements may be realised if the design of the resistance training programme focuses on horizontal movement-specific exercises as well as traditional vertical exercises. To date, however, the effectiveness of a gym based lower body resistance training programme with a horizontal component has not been investigated.

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CHAPTER 7. EQUATING THE VERTICAL LOAD BETWEEN A VERTICAL CABLE SQUAT AND A CABLE SQUAT WITH A HORIZONTAL COMPONENT

Prelude

The training of horizontal propulsive force generation is one aspect of many sports that is not easily simulated with traditional gym-based resistance training methods which principally work the leg musculature in a vertical direction. The literature review established that while force production is necessary in both the vertical and horizontal planes, it is the horizontal forces that experience the greatest increase when accelerating to maximal velocity. It is proposed that the transference of gym based strength gains to sprint performance, particularly maximum velocity, may be optimised if exercises were used that involved high levels of horizontal force production. However, it is important to ensure that vertical force production is not compromised, especially when performance also relies on vertical force production. Therefore it would seem intuitive to ensure that the production of vertical forces is maintained during any horizontal exercises prescribed. Subsequently this chapter sought to outline the methodological approach to equating the vertical force production of a vertical squat and horizontal component squat exercise.

Introduction

It is generally accepted that maximal running velocity requires high force production (Baker & Nance, 1999; Mero, Komi, & Gregor, 1992; Mero, Luhtanen, Viitasalo, & Komi, 1981) and as such, resistance training is promoted as a means of training to improve running velocity (Baker & Nance, 1999; Delecluse et al., 1995; Spinks, Murphy, Spinks, & Lockie, 2007). It is also generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance (Delecluse et al., 1995; Rimmer & Sleivert, 2000; Sale &

MacDougall, 1981). Therefore, athletes who require force or power in the horizontal plane should engage in exercises containing a horizontal component, whereas athletes who require force or power to be exerted in the vertical direction should predominantly train using vertical exercises (Chu, 1998; Rimmer & Sleivert, 2000). However, it is apparent that during running force production is necessary in both the vertical and horizontal planes and there are differing views as to the significance of each during sprint performance. Researchers using a cross-sectional approach have cited the importance of horizontal force production in sprint performance (Brughelli, Cronin, & Chaouachi, 2011; Hunter, Marshall, & McNair, 2005; Munro, Miller, & Fuglevand, 1987; Nummela, Keranen, & Mikkelsen, 2007) whilst other researchers have reported the importance of vertical force production (Arampatzis, Bruggemann, & Metzler, 1999; Keller et al., 1996; Kyröläinen, Belli, & Komi, 2001; Nigg, Bahlsen, Luethi, & Stokes, 1987; Weyand, Sternlight, Bellizzi, & Wright, 2000). Cross-sectional studies have certain limitations and it is apparent that longitudinal training studies are needed to establish the importance of vertical and/or horizontal force production in sprint performance. The challenge prior to implementing a training study however, is to find a methodological approach that allows the contribution of vertical and horizontal force production on sprint performance to be disentangled. One possible method is to quantify the vertical and horizontal forces associated with various exercises and thereafter equate the forces in one plane so that the influence of the other plane can be disentangled. The purpose of this study therefore is to pilot whether such a methodological approach is viable by investigating the kinematics and kinetics associated with two squat exercises.

Methods

Subjects

Five semi-professional rugby players participated in this study (age = 20.0 ± 0.8 years, weight = 91.6 ± 10.1 kg, 1RM squat = 145.0 ± 19.1 kg). All subjects had a minimum of two years resistance training experience and were currently in the in-season phase of their training programme. All testing procedures and risks were fully explained. The study was approved by the AUT University Ethics Committee.

Equipment

Both the vertical and the horizontal exercises were performed using a standard pin loaded weight stack with a ground level pulley. A portable tri axial force plate (Advanced Mechanical Technology Inc. Acupower, Watertown, MA) utilising a sampling frequency of 400 Hz was used to measure vertical and horizontal GRF during the exercises.

Procedures

The testing session was performed immediately prior to a scheduled team strength training session. Subjects completed a five minute dynamic warm-up consisting of hip, knee and ankle stretches, as well as ten body weight squats and five vertical and horizontal jumps. The two exercises investigated were a traditional squat movement (vertical) and an angled squat movement (horizontal). Subjects had been given the opportunity to familiarise themselves with both movements at prior training sessions. Both exercises were performed using a standard pin loaded weight stack with a ground level pulley. The cable from the weight stack was attached to the subjects using a standard sled towing shoulder harness with the resistance set to 38 kg (this equated to a

load at the attachment end of the cable of 28.5 kg). The vertical squat was a traditional squat movement with the subject facing away from the pulley (see Figure 7.1). The horizontal squat was a similar movement pattern however the concentric phase of the movement was performed at the largest possible angle (measured from vertical) that subjects were able to perform in a controlled manner (see Figure 7.1). An incline bench was placed 1.50 m from the subject to provide a catching mechanism that the subject used to prevent themselves falling over once they had reached the end range of the concentric phase (full hip and knee extension). The eccentric phase of both exercises was consistent and was performed to a set depth whereby the knee angle was 90°. During both exercises the subjects were instructed to maintain foot contact with the ground at all times. During the horizontal exercise subjects were also instructed not to touch the ground with their hands and make contact with the bench only at the completion of full hip and knee extension. If any of these conditions were not met or subjects lost their balance the lift was repeated. Subjects completed two repetitions of each of the two lifts while standing on the force plate.

Data analyses

At the completion of testing the resultant GRFs (N), lift angles from vertical (°), and ratios of repetitions to equate vertical load were calculated. Resultant GRFs were calculated using the following trigonometric equation;

$$\text{Resultant GRF} = \sqrt{(\text{vertical GRF}^2 + \text{horizontal GRF}^2)}$$

The lift angles (°) were calculated using the following trigonometric equation;

$$\text{Lift angle} = 90 - (\tan^{-1} (\text{horizontal GRF} / \text{vertical GRF}))$$

The repetition ratio for the vertical and horizontal squat exercise to be used during training was calculated using the following formula;

$$\text{Repetition ratio} = \text{mean vertical GRF} / \text{mean horizontal GRF}$$

This allowed the formation of a table detailing the number of horizontal repetitions required to equate vertical GRF for a given number of vertical repetitions (see Table 7.1). Using these numbers estimates of total set vertical GRFs were calculated and were checked for significant differences. Only pairings where the horizontal repetition number was ± 0.1 of a whole number were used and this number was rounded to the nearest whole number for the calculation.

$$\text{Set GRF} = \text{rep number} \times \text{single rep GRF}$$

Statistical analyses

Means and standard deviations are used as measures of centrality and spread of data. Independent sample t-tests were used to determine statistically significant differences between the vertical and horizontal exercises using an alpha level of 0.05.

Results

The mean (\pm SD) GRFs and lift angles for the vertical and horizontal exercises can be observed in Table 7.2. Vertical GRFs were significantly higher ($p = 0.05$) for the vertical exercise (2034-2663 N vs. 1602-1980 N), whereas, horizontal GRFs were significantly higher ($p < 0.001$) for the horizontal exercise (836-1141 N vs. 221-425 N). There was no significant difference ($p = 0.25$) between the vertical and horizontal exercise with regard to the calculated resultant GRFs (2064-2672 N vs. 1811-2285 N).

Due to the positioning of the cable attachment a small forward lean was observed during the vertical movement (4.7° - 11.3°) which explains the presence of the small horizontal GRFs observed. However this angle was significantly smaller ($p < 0.001$) than the angle of lift for the horizontal exercise (24.2° - 29.9°).

The repetition ratio calculated from the vertical and horizontal GRFs was 1.23, that is, for every vertical rep prescribed 1.23 horizontal repetitions need to be completed to equate for total vertical GRF over the set. This ratio was used to generate a table of equated repetitions. From Table 7.1 it can be observed that the following set repetition ratios (vertical : horizontal) could be used (4 : 5), (5 : 6), (9 : 11), (13 : 16), (17 : 21), and (18 : 22). There were no significant differences for the estimated set vertical GRFs between the two exercises for any of the set pairings ($p = 0.77$ to 0.99).



Figure 7.1. Set up (end of concentric phase) of vertical and horizontal squat.

Table 7.1. Set repetition numbers required to equate vertical GRFs between vertical and horizontal cable squat exercises.

Vertical Repetitions	Horizontal Repetitions
1	1.2
2	2.5
3	3.7
4	4.9
5	6.1
6	7.4
7	8.6
8	9.8
9	11.1
10	12.3
11	13.5
12	14.8
13	16.0
14	17.2
15	18.4
16	19.7
17	20.9
18	22.1
19	23.4
20	24.6

Table 7.2. Mean (SD) vertical, horizontal and resultant GRFs and lift angle for vertical and horizontal squats performed on cable stack machine.

	Vertical GRF (N)	Horizontal GRF (N)	Resultant GRF (N)	Lift Angle (°)
Vertical	2220 (298)	339 (85)	2248 (286)	8.9 (2.9)
Horizontal	1805 (159)	919 (148)	2026 (197)	26.9 (2.5)
Statistically Significant Difference	Yes p = 0.05	Yes p < 0.001	No p = 0.25	Yes p < 0.001

Discussion

The aim of this study was to investigate a proposed methodological approach to quantify the GRFs associated with a vertical and horizontal exercise and thereafter equate the forces in the vertical plane so that the influence of the horizontal plane can be disentangled. Originally there were significant differences between the exercises with regard to both the vertical and horizontal GRFs. Using the initial information (quantification of respective GRFs) we were able to calculate prescription guidelines (repetitions) that enabled the equating of vertical GRF between the vertical and horizontal exercises. The subsequent set GRF calculations supported the contention that the vertical GRFs had been equated, thereby providing a methodological approach that allows the contribution of vertical and horizontal force production on performance to be disentangled when utilising training studies.

The calculation of the lift angles provides a tool that that can be utilised to ensure the validity of the method is maintained. If the lift angle is consistent throughout the horizontal exercise then it can be assumed that the vertical GRFs also remain constant. This consistency can be achieved more easily in the practical training setting using goniometers or protractors as opposed to using force plates to monitor actual GRFs. Maintaining the lift angle would also allow for the prescription of different loads given the ratio of vertical to horizontal remains constant regardless of the size of the resultant.

A number of limitations need to be acknowledged. Firstly, this study investigated a bilateral horizontal squat performed on a pin loaded cable machine. Therefore the findings from this study may not translate to other common squat exercises performed with free weights or on other machines, or unilateral lower body leg exercises such as single leg squats. It is suggested that this methodology be investigated on a number of

different exercise such that it is able to be used for numerous exercises with a resistance programme.

Secondly the lift angle must remain constant to ensure the equating calculations remain valid. Furthermore while claims are made with respect to the transference of this methodology to differing loads, this was done so based upon principles of trigonometry. Therefore, it would seem intuitive to investigate this fully in a practical environment.

Thirdly, the calculation of the repetition ratio results in the prescription of repetitions for the horizontal exercise which are not whole numbers. As it is not practically possible to perform such numbers there are a limited number of repetition combinations available. A solution to this may be to alter the lift angle such that the ratio used for calculation of repetitions is altered. Further investigation is required to determine the effect of lift angle on repetition ratios and whether this also impacts on lift performance.

Finally the prescription of repetition ratios was based on mean calculation for the group following single repetitions of the respective exercises. It is possible that individual variations may occur with respect to performance technique of the respective exercises, such that GRFs are not accurately equated. Additionally, the use of a single repetition does not allow for potential errors occurring during a single lift. An ideal, although time restricted, approach may be to produce repetition tables for each individual based on the performance of multiple repetitions.

Practical Applications

The use of this methodological approach allows the contribution of vertical and horizontal force production to be separated. Subsequently, this allows the hypothesis that transference of gym based strength gains to sprint performance, particularly

maximum velocity, may be optimised if exercises were used that involved horizontal force production to be investigated.

The calculation of a repetition table allows for this approach to be utilised throughout different cycles of a periodised plan. That is, as the focus shifts from endurance to strength to power, repetitions can be prescribed that fit within the accepted guidelines for these foci. By ensuring the consistency of the lift angle this approach may also be used for prescription of different resistances. This would allow loads to be matched to the respective training foci, and may also enable prescription of loads dictated by potential velocity specific adaptations.

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CHAPTER 8. DOES EXERCISING INVOLVING HORIZONTAL COMPONENT MOVEMENT AFFECT VERTICAL PLANE ADAPTATION?

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and McMaster, T. (2011). Does exercising involving horizontal component movement affect vertical plane adaptation? Submitted to *Journal of Strength and Conditioning Research*.

Author contributions - AR: 80%, JC: 10%, JK: 2.5%, NG: 2.5%, TM: 5%

Prelude

Of interest in this section of the thesis is the transference of gym based strength gains to functional performance. Of particular interest is whether exercises with a horizontal component may optimise this transference. The previous chapter outlined the methodology to ensure vertical force production was equated during loading with a horizontal component exercise, however there is a lack of research pertaining to the potential compromise that horizontal resistance training techniques may have on vertical performance measures. Therefore, this chapter sought to quantify the effect of training using an equated horizontal component squat exercise for five weeks (vertical vs. horizontal squats) on vertical movements such as the 1RM squat, deadlift, and powerclean performance.

Introduction

It is generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance (Delecluse et al., 1995; Rimmer & Sleivert, 2000; Sale & MacDougall, 1981). As such athletes who require power in the horizontal plane, engage in exercises containing a horizontal component, whereas athletes who require power to be exerted in the vertical direction, train using vertical exercises (Chu, 1998; Rimmer & Sleivert, 2000). Currently, most gym based resistance programmes focus on exercises that principally work the leg

musculature in a vertical plane. It is proposed that the transference of gym based strength gains may be improved if exercises were used that involved both vertical and horizontal force production. That is, if successful performance requires strength, speed, and power in the horizontal plane, improvements may be better realised if the design of the resistance training programme focuses on horizontal movement-specific exercises, where the magnitude of the horizontal contribution may vary from a single exercise to a suite of exercises, as well as traditional vertical exercises. However, it is important to ensure vertical force production is not compromised as vertical forces are still the largest forces needed to be overcome i.e. gravity. To date, however, the effectiveness of a gym based lower body resistance training programme with a horizontal component has not been investigated. Therefore, the purpose of the present study was to investigate the effect of training using equated vertical component exercises on typical measures of vertical strength and power.

Methods

Experimental approach to the problem

To determine the effect of a horizontal component exercise on functional vertical performance, thirteen subjects were randomly assigned to a vertical or horizontal training group. The total vertical GRF for the respective exercises used during training were equated for both groups however the horizontal component exercise was associated with greater horizontal GRFs. Differences pre to post training (six weeks) in vertical performance tests and chances (% and qualitative) that the true value of the statistic was practically or mechanistically positive, trivial, or negative were calculated.

Subjects

For the period of the study thirteen semi-professional rugby players were randomly

assigned to one of two groups vertical ($n = 6$, age = 19.7 ± 0.8 years, weight = 91.9 ± 9.4 kg, 1RM squat = 148.3 ± 16.0 kg) and horizontal ($n = 7$, age = 19.7 ± 1.1 years, weight = 105.5 ± 5.2 kg, 1RM squat = 160.0 ± 16.3 kg). All subjects had a minimum of two years resistance training experience and were currently in the in-season phase of their training programme. All testing procedures and risks were fully explained and participants were asked to provide their written consent prior to the start of the study. The study was approved by the AUT University Ethics Committee.

Equipment

Both the vertical and the horizontal exercises were performed on a standard pin loaded weight stack with a ground level pulley. A portable tri axial force plate (Advanced Mechanical Technology Inc. Acupower, Watertown, MA) with a sampling frequency of 400 Hz was used to measure vertical and horizontal GRF during the testing session.

Procedures

Participants were matched by playing position and randomly assigned to one of two groups with each group completing a testing session at least 48 hours prior to the commencement of the training study which was repeated 48 hours after the completion of training study.

All sessions were preceded by a five minute dynamic warm-up consisting of hip, knee and ankle stretches, as well as ten body weight squats and five vertical and horizontal jumps. The two exercises utilised by the respective groups were a traditional squat movement (vertical) and an angled squat movement (horizontal). Both exercises were performed using a standard pin loaded weight stack with a ground level pulley. The cable from the weight stack was attached to the subjects using a standard sled towing

shoulder harness with the resistance at the attachment end of the cable set to 28.5 kg. The vertical squat was a traditional squat movement with the subject facing away from the pulley (Figure 8.1). Due to the positioning of the cable attachment a small forward lean was observed during the movement which equated to approximately 10° from vertical. The horizontal squat was a similar movement pattern however the concentric phase of the movement was performed at an angle of approximately 30° from vertical (Figure 8.1). An incline bench was placed 1.50 m from the subject to provide a catching mechanism that the subject used to prevent themselves falling over once they had reached the end range of the concentric phase (full hip and knee extension). The eccentric phase of both exercises was consistent and was performed to a set depth whereby the knee angle was 90° . During both lifts the subjects were instructed to maintain foot contact with the ground at all times.

The testing session consisted of a standardised warm-up and assessment of three vertical performance tests (1RM squat, 1RM deadlift and 1RM power clean) that the participants completed on a regular basis as part of their conditioning programme, so familiarization was unnecessary. Procedures for all 1RM tests were similar to those described by Baker and Nance (1999). The assessment procedures were reproduced after six weeks of training.

At the completion of testing the repetition ratio for the vertical and horizontal squat exercise to be used during training was calculated. This meant that the vertical GRF for both exercises during the training study were equated. With regards to equating the vertical GRF, subjects completed two repetitions of each of the two lifts while standing on the force plate. The lift was repeated if the subjects lost balance or did not maintain contact with the ground. The mean (\pm SD) GRFs and lift angles for the vertical and

horizontal exercises can be observed in Table 8.1. There were no significant differences between the exercises with regard to the calculated resultant force ($p = 0.143$), however the horizontal exercise resulted in lower vertical GRF ($p = 0.026$), higher horizontal GRF ($p = 0.001$), and was performed at a greater lift angle ($p < 0.001$). Resultant GRFs, lift angles and the ratio of repetitions required to equate vertical GRF between the two lifts were calculated from this data - see Table 8. 1.

Table 8.1. Mean (SD) vertical, horizontal and resultant GRFs and lift angle for vertical and horizontal squats performed on cable stack machine.

	Vertical GRF (N)	Horizontal GRF (N)	Resultant GRF (N)	Lift Angle (°)
Vertical	2217 (258)	342 (74)	2245 (248)	9.0 (2.5)
Horizontal	1805 (159)	953 (132)	2029 (129)	28.0 (3.4)
Statistically Significant Difference	Yes $p = 0.026$	Yes $p = 0.001$	No $p = 0.143$	Yes $p < 0.001$

Training Programme

The exercises and sessions prescribed were part of the regular in-season training programme used by the team. Other conditioning sessions involved an energetic and skills focus; however, these sessions were similar for all players. During each session all participants completed the same exercises, in the same order, with the same number of sets and repetitions, however the reps for the respective vertical and horizontal exercises differed to ensure total vertical GRFs were equated. The vertical group performed three sets of seven vertical squats whilst the horizontal group performed three sets of eight horizontal squats. Both groups had 90 s rest between sets. The subjects completed a maximum of four resistance training sessions per week however as this was an in-season programme there was only one lower body session per week during which the

respective exercises were completed.



Figure 8.1. Set up (end of concentric phase) of vertical and horizontal squat.

Statistical analyses

Percent change between pre and post training study for each of the variables of interest (1RM squat, 1RM deadlift and 1RM power clean) was calculated and independent sample T-tests were used to determine statistically significant differences between groups using an alpha level of 0.05. Cohen effect sizes (ES) were used to determine the relative magnitude of the training effects. Effects less than 0.41 represented a small ES, 0.41 to 0.70 a moderate ES, and greater than 0.70 a large ES (Cohen, 1988). To make inferences with regard to practical significance a spreadsheet for analysis of a straight forward controlled trial was used, with the chances (% and qualitative) that the true value of the statistic (percent change in variable of interest) was practically or mechanistically positive, trivial, or negative calculated (Hopkins, 2003). This approach using probability statistics allows the reader to make decisions around the use of horizontal component training based on its predicted beneficial or harmful effects in addition to statistical significance.

Results

The mean (\pm SD) results and percent change of the performance test for the vertical and horizontal conditions can be observed in Table 8.2. None of the differences between the two groups with regard to percent changes pre to post-training were statistically significant for any of the performance tests ($p = 0.32$ to 0.72). With regards to practical significance, the chance that these changes were practically beneficial, trivial or negative and the ESs are reported in Table 8.3. The probabilities that the use of horizontal component training was trivial were 88% for 1RM squat, 95% for 1RM deadlift, and 90% for 1RM power clean. The relative magnitude (ES) of the training effects for all performance tests were found to be small (0.12 to 0.26).

Table 8.2. Mean (SD), and percent change in mean of 1RM squat (kg), deadlift (kg), and power clean (kg) pre and post 6-week training.

	1RM Squat			1RM Deadlift			1RM Power clean		
	Pre	Post	% Change	Pre	Post	% Change	Pre	Post	% Change
Vertical	148.3 (16.0)	155.0 (17.3)	5.3	168.3 (21.4)	172.5 (28.7)	1.3	93.3 (13.3)	91.3 (11.1)	0.8
Horizontal	160.0 (16.3)	168.3 (14.7)	2.0	187.1 (13.8)	185.0 (16.4)	-0.9	105.0 (10.4)	102.5 (6.1)	-1.2

Table 8.3. Effect sizes and chances (% and qualitative) that the benefit of horizontal component training is practically positive, trivial or negative for 1RM squat, 1RM deadlift, and 1RM power clean after 6 weeks of training.

	1RM Squat	1RM Deadlift	1RM Power clean
Effect Size	-0.26 (small)	-0.21 (small)	-0.12 (small)
Positive	1 (almost certainly not)	0 (almost certainly not)	3 (very unlikely)
Trivial	88 (likely)	95 (very likely)	90 (likely)
Negative	11 (unlikely)	4 (very unlikely)	8 (unlikely)

Discussion

In terms of the performance tests, there was no statistically significant difference with regard to percentage change between the vertical and horizontal exercise for any of the tests ($p = 0.32$ to 0.72). While the use of statistical significance is common within the literature to exclude potential differences, what is often overlooked is the concept of practical significance. To many practitioners such a statistic is invaluable, given that some results may not be statistically significant but there may be a high probability that the intervention is practically or clinically beneficial to performance. This is especially relevant in field of high performance sport where even the smallest change may have a large influence on outcome or performance. Therefore in this study it was important to further analyze the data to ensure even the smallest potential difference between the respective exercises would not be detrimental to performance. Whilst not statistically significant the percentage changes for all of the squat, deadlift and power clean performance do appear to be larger for the vertical exercise (5.3% vs. 2.0%, 1.3% vs. -0.9%, and 0.8% vs. -1.2% respectively). However, the probabilities that there is actually a practical difference, whereby horizontal component training has reduced adaptive potential, are low (11%, 4%, and 8% respectively). This would therefore suggest there is evidence to support the use of horizontal component provided vertical GRFs are equated. This could enable potential horizontal plane adaptation while ensuring vertical performance is not compromised.

A number of limitations need to be acknowledged prior to the concluding remarks. First the sample size in each group was relatively small but this represented all the professional players in the region. The aim was to use well trained players as it is much more difficult to elicit adaptation and performance enhancement in well trained athletes. As a result of the small sample size the probability that the findings were practically

significant were calculated. A second limitation was the duration of the training study i.e. six weeks. Longer exposure to the intervention may have resulted in larger training effects. However, given that most training cycles are of four to six week durations the duration of this study seems to have face or logical validity. The final limitation pertains to the use of one exercise for one session per week, which intuitively would have minimal effect. However, if research is to be practical and applied then the constraints of in-season training in a combative sport need to be taken into account i.e. only one leg session per week for players. Once more larger training effects may have been observed at different times of the season where larger leg training volume can be implemented.

Practical applications

Of particular interest to the strength and conditioning practitioner is the observation that the use of a horizontal component lower body exercise during a resistance strength training programme did not negatively affect the performance of vertical based performance tests. Therefore if the focus of training during a periodised training plan shifts from the development of strength or power in the vertical plane to that in the horizontal it would appear that, provided vertical GRFs are equated, more movement specific exercises, such as those emphasizing horizontal force production, could be utilised without compromising previous training gains. What needs to be established to fully support the use of horizontal component training is whether this training specificity produces practical benefits in the movement or activity of interest e.g. horizontal force production required for running.

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CHAPTER 9. THE EFFECT OF FIVE WEEKS TRAINING USING HORIZONTAL COMPONENT RESISTANCE EXERCISE EQUATED FOR VERTICAL FORCE PRODUCTION ON SPORT SPECIFIC SPEED, STRENGTH AND POWER.

This chapter comprises the following paper:

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Claxton, J. E. (2011). The effect of five weeks training using horizontal component resistance exercise equated for vertical force production on sport specific speed, strength and power. Submitted to *Journal of Strength and Conditioning Research*.

Author contributions - AR: 80%, JC: 10%, JK: 2.5%, NG: 2.5%, JEC: 5%

Prelude

If a gym based lower body resistance exercise is able to provide a stimulus for horizontal force production, whilst maintaining vertical force production this may result in optimal transference to sprint performance within a sporting context. The previous chapter established that the probabilities that horizontal component training reduced adaptive potential for a number of vertical performance tests (1RM squat, deadlift, and powerclean) were low (11%, 4%, and 8% respectively) provided vertical GRFs were equated. Therefore vertical performance adaptations were not compromised as compared to traditional vertical based training. The literature review proposed that the transference of gym based strength gains to sprint performance may be optimised if exercises were used that involved both a horizontal and vertical component. However, what needs to be established to fully support the use of horizontal component training is whether this training specificity produces practical benefits in horizontal force production resulting in improved running performance. This chapter sought to quantify the effect of training using an equated horizontal component squat exercise for five weeks (vertical vs. horizontal squats) on running speed and other sport specific performance tests.

Introduction

Within the strength and conditioning profession it is generally accepted that the attainment of greater speed requires the application of greater ground reaction forces (GRFs) during briefer contact periods (Brughelli, Cronin, & Chaouachi, 2011; Heglund & Taylor, 1988; Hunter, Marshall, & McNair, 2004; Kyröläinen, Belli, & Komi, 2001; Munro, Miller, & Fuglevand, 1987; Nummela, Keranen, & Mikkelsen, 2007; Spinks, Murphy, Spinks, & Lockie, 2007; Weyand, Sternlight, Bellizzi, & Wright, 2000). As such, strength and power training methods are almost universally promoted as a means of training to improve running speed (Baker & Nance, 1999a; Delecluse et al., 1995; Spinks et al., 2007). It is also generally accepted that the more specific a training exercise to a competitive movement, the greater the transfer of the training effect to performance (Delecluse et al., 1995; Rimmer & Sleivert, 2000; Sale & MacDougall, 1981). As such athletes who require power in the horizontal plane, engage in exercises containing a horizontal component, whereas athletes who require power to be exerted in the vertical direction, train using vertical exercises (Chu, 1998; Rimmer & Sleivert, 2000). Given that a variety of training regimes are commonly used to improve muscular force output with the ultimate goal of enhancing sprinting performance (Rimmer & Sleivert, 2000; Spinks et al., 2007), it would seem intuitive to focus on the enhancement of the forces which are the most important in improving velocity. However, while it is apparent that during running force production is necessary in both the vertical and horizontal planes there are differing views as to the significance of each during sprint performance. That is, is the application of horizontal or vertical force of more importance to increase velocity?

Whilst it appears that the vertical component is the larger of the two GRFs, it is suggested that running velocity is more dependent on horizontal than vertical force as

the velocities increase towards maximal (Brughelli et al., 2011; Kyröläinen et al., 2001; Munro et al., 1987). This is evident given linear relationships were not observed between vertical force and running velocity at higher velocities (Brughelli et al., 2011; Hunter, Marshall, & McNair, 2005; Keller et al., 1996; Nummela et al., 2007). The significance of the horizontal component seems to be logical since one cannot increase horizontal velocity by increasing vertical force, but acceleration and deceleration of running velocity is produced mainly by changing horizontal force (Hunter et al., 2005; Mero, Komi, & Gregor, 1992; Nummela et al., 2007). However, most of the research cited have used cross-sectional designs which have inherent limitations and it is apparent that longitudinal training studies are needed to establish the importance of vertical and/or horizontal force production on sprint performance.

Currently, most gym based resistance programmes focus on exercises that principally work the leg musculature in a vertical plane. It is proposed that the transference of gym based strength gains may be improved if exercises were used that involve both vertical and horizontal force production. That is, if successful performance requires strength, speed, and power in the horizontal plane, improvements may be realised if the design of the resistance training programme focuses on horizontal movement-specific exercises as well as traditional vertical exercises. However, it is important to ensure vertical force production is not compromised. To date, however, the effectiveness of a gym based lower body resistance training programme with a horizontal component has not been investigated. Therefore, the purpose of the present study was to investigate the effect of a horizontal component lower body resistance exercise on running speed (timed sprints) and other sport specific performance tests.

Methods

Experimental approach to the problem

To determine the effect of horizontal component exercise on speed and sport specific performance tests, seventeen subjects were randomly assigned to a vertical or horizontal training group. The total vertical GRF for the respective exercise of interest used during training was equated for both groups however the horizontal component exercise was associated with greater horizontal GRFs. Given that during running force production is necessary in both the vertical and horizontal planes it was hypothesised that including a horizontal component to lower body training may enhance the development of speed. Differences pre to post training (five weeks) in performance tests and percent chances that the true value of the statistic was practically or mechanistically positive, trivial, or negative were calculated.

Subjects

For the period of the study seventeen semi-professional rugby players were randomly assigned to one of two groups vertical ($n = 9$, age = 18.1 ± 0.3 years, height = 1.81 ± 0.03 m, weight = 95.9 ± 10.0 kg, training age = 2.0 ± 0.0 years, 1RM squat = 146.7 ± 17.7 kg) and horizontal ($n = 8$, age = 19.3 ± 1.2 years, height = 1.84 ± 0.06 m, weight = 96.1 ± 11.7 kg, training age = 2.5 ± 0.5 years, 1RM squat = 140.6 ± 31.7 kg). All subjects had a minimum of two years resistance training experience and were currently in the pre-season phase of their training programme. All testing procedures and risks were fully explained and participants were asked to provide their written consent prior to the start of the study. The study was approved by the AUT University Ethics Committee.

Equipment

Both the vertical and the horizontal exercises were performed on a standard pin loaded weight stack with a ground level pulley (see Figure 9.1). A SmartSpeed jump mat (Fusion Sport, Brisbane, QLD, Australia) was used to record vertical jump height. SmartSpeed wireless electronic timing lights (Fusion Sport, Brisbane, QLD, Australia) set at a height of 90 cm were used to record sprint times over 10 / 20 / 30 m.

Procedures

Participants were matched by playing position and randomly assigned to one of two groups with each group completing a testing session at least 48 hours prior to the commencement of the training study which was repeated 48 hours after the completion of training study.

All sessions were preceded by a dynamic warm-up consisting of a five minute light jog, two sets of five body-weight squats, three forward and backward hurdle walks, six-step walking lunge, three vertical jumps and three horizontal jumps. The two exercises utilised by the respective groups were a traditional squat movement (vertical) and an angled squat movement (horizontal). Both exercises were performed using a standard pin loaded weight stack with a ground level pulley. The cable from the weight stack was attached to the subjects using a standard sled towing shoulder harness with the resistance set to 60 kg. The vertical squat was a traditional squat movement with the subject facing away from the pulley (see Figure 9.1). Due to the positioning of the cable attachment a small forward lean was observed during the movement which equated to approximately 10° from vertical. The horizontal squat was a similar movement pattern however the concentric phase of the movement was performed at an angle of approximately 30° from vertical (see Figure 9.1). A bench was placed 1.50 m

from the subject to provide a catching mechanism that the subject used to prevent themselves falling over once they had reached the end range of the concentric phase (full hip and knee extension). The eccentric phase of both exercises was consistent and was performed to a set depth whereby the knee angle was 90°. During both lifts the subjects were instructed to maintain foot contact with the ground at all times.

The testing session consisted of 30 m timed sprints with split times also taken at 10 m and 20 m, 1RM squat, vertical jump (VJ) and horizontal jump (HJ). All tests were completed by the subjects on a regular basis as part of their conditioning programme, so familiarization was unnecessary. Test-retest reliability for all performance tests are reported. Typical errors (TE) are used as a measure of absolute consistency, representing the random variation in each subject's measurement between tests. Intraclass correlation coefficients (ICC) are used as a measure of relative consistency and relate to the reproducibility of the rank order of subjects on the retest.

Timed Sprints

Subjects completed three trials of a 30 m maximal sprint with split times also recorded at 10 m and 20 m. Times were recorded using a series of wireless timing lights. Subjects self started from a stationary split stance start with the front of the leading foot 50 cm back from the first timing light. A minimum of two minutes rest was given between trials and the best of three trials (based on the 30 m time) was used for analysis. Average velocities for the respective intervals were calculated from these times and used for analysis (TE = 0.03 m.s⁻¹, ICC = 0.96).

1RM Squat

Procedures for the 1RM squat test were similar to those described by Baker and Nance (Baker & Nance, 1999b). Subjects performed a standard warm up as described above followed by submaximal sets of 3-5 repetitions gradually building toward an estimated 1RM load. They then attempted a single repetition at the estimated load that had been predetermined by their strength and conditioning coach, based upon recent training history and previous maximum test results. If the athletes were successful with this load, they were allowed to attempt another load or loads until both the athlete and the strength coach were confident that a 1RM had been attained (TE = 5.08 kg, ICC = 0.96).

Vertical Jump

Subjects stood with both feet on the jump mat shoulder width apart. A counter movement vertical jump was performed, with arm drive permitted, and the maximal height was recorded. A minimum of one minute rest was given between trials. The best of three trials was used for analysis (TE = 1.67 cm, ICC = 0.93).

Horizontal Jump

Subjects stood with feet shoulder width apart with toes behind (touching) a line on the ground. Subjects then performed a counter movement horizontal jump, with arm swing, along the length of a tape measure secured to ground. The landing placement of the feet was recorded and the distance from the heel of the foot back to the start line was recorded as the jump distance. If the subjects landed with one foot ahead of the other the jump was not recorded. The best of three successful attempts was recorded and a minimum of one minute rest was given between trials (TE = 0.04 m, ICC = 0.96).

Training Programme

The exercises and sessions prescribed were part of the regular pre-season training programme used by the team (see Table 9.1). Other conditioning sessions involved an energetic and skills focus; however, these sessions were similar for all players. During each session all participants completed the same exercises, in the same order, with the same number of sets and repetitions, however the reps for the respective vertical and horizontal exercise of interest differed to ensure total vertical GRFs were equated. The vertical group performed three sets of seven vertical squats whilst the horizontal group performed three sets of eight horizontal squats. The subjects completed three full body resistance training sessions per week with the respective exercises completed during the first two sessions of each week.



Figure 9.1. Set up (end of concentric phase) of vertical and horizontal squat

Statistical analyses

Percent change between pre and post training study for each of the variables of interest (10 / 20 / 30 m timed sprints, 1RM squat, VJ, and HJ) were calculated for both groups and paired sample t-tests were used to determine statistically significant pre-post

differences using an alpha level of 0.05. Cohen effect sizes (ES) were used to determine the relative magnitude of the training effects. Effects less than 0.41 represented a small ES, 0.41 to 0.70 a moderate ES, and greater than 0.70 a large ES (Cohen, 1988). To make inferences with regards to the practical significance of the training effects within each group a spreadsheet was used to calculate the percent chances that the true value of the statistic (percent change in variable of interest) was practically positive, trivial, or negative (Hopkins, 2007).

Between group differences in percent changes for each of the variables of interest were also calculated, with independent sample t-tests were used to determine statistically significant differences using an alpha level of 0.05. Cohen effect sizes (ES) were used to determine the relative magnitude of the training effects. To make inferences with regard to the practical significance of differences between possible training effects for the respective groups a spreadsheet for analysis of a straight forward controlled trial was used. The percent chances that the true value of the statistic (percent change in variable of interest) was practically or mechanistically positive, trivial, or negative were calculated (Hopkins, 2003). This approach using probability statistics allows the reader to make decisions around the use of horizontal component training based on its predicted beneficial effects in addition to statistical significance.

Table 9.1. Six-week pre-season resistance training programme *†

MONDAY	WEDNESDAY	FRIDAY
WARM UP / PREHAB		
DB Turkish Get-Up 2 x 2 ES	Overhead Squat 2 x 5	Good Morning Combo 2 x 5
DB Cuban Press 2 x 5	Hurdle Walking 2 x 6 (fwd & back)	Press-Up with Twist 2 x 3 ES
Overhead Squat 2 x 5	Kettle Bell Swings (release) 2 x 3 ES	Kettle Bell Swings (release) 2 x 3 ES
MAIN EXERCISES		
BB Power Clean 3 x 5-1 @ 70-95% 1RM ‡ (+ Ankle Jumps; 3 x 8)	BB Power Snatch 3-4 x 3-2 @ 70-90% 1RM ‡ Horizontal/Vertical Squat 3 x 8/7 @ 60 kg (+ Vertical Jumps; 3 x 2)	BB Clean & Jerk 3 x 3 @ 70-90% 1RM ‡ DB Power Lunge 3 x 5-3 @ 70-90% 1RM ‡ (+ SL Box Plyos; 3 x 3 ES)
Horizontal/Vertical Squat 3 x 8/7 @ 60 kg	DB Lunge Walk 3-4 x 10-6 @ 70-85% 1RM ‡ (+ Horizontal Jump; 3 x 2)	DB SL Deadlifts 3 x 5 ES @ 70% 1RM
BB Military Press 3 x 8RM	BB Good mornings 3 x 6 @ 70-80% 1RM ‡	BB Bench Press 3 x 8RM
DB Bench Press 3-4 x 10-6 @ 70-90% 1RM ‡	SB Hamstring Curls 3 x 8	BB Bench Row 3 x 8RM
Chin Ups 3 x 8RM		

*RM = repetition maximum; ES = each side; DB = dumbbell; BB = barbell; SB = Swiss ball; SL = single leg

†All exercises were performed with 90 second rest between sets.

‡Weight increased and repetitions decreased each session e.g. 5 reps @ 70% 1RM for first session to 1 rep @95% 1RM for final session

Results

The mean percent change (\pm SD) of the performance tests for the vertical and horizontal conditions can be observed in Tables 9.2 and 9.3 respectively. Average performance changes following training ranged from a 1.1% decrease to a 1.6% increase for the vertical group and 0.9% decrease to a 2.7% increase for the horizontal group. However, none of the pre- to post-training changes within the two groups were statistically significant for any of the performance tests ($p = 0.11$ to 0.99).

With regard to practical significance, the ESs and the chance that these changes were practically beneficial or trivial are also reported in Tables 9.2 and 9.3. A negative ES following training represents a decrease in performance (e.g. an increase in sprint time or a decrease in jump distance or 1RM squat load). Vertical training resulted in performance increases in four of the nine variables (10-20 m, 10-30 m, VJ and HJ) with ESs ranging from 0.03 to 0.19. The largest ES was reported for HJ with a 49% chance that this training effect was practically beneficial. The chance the other performance increases were practically beneficial ranged from 36% to 43%. The ES of the other variables where performance decreased as indicated by a negative ES, (10 m, 20 m, 30 m, 20-30 m, and 1RM squat) ranged from -0.02 to -0.15 with chances of a practical benefit from vertical training ranging from 22% to 32%.

With respect to the horizontal training group performance increases were observed in four of the variables (30 m, 10-30 m, 20-30 m, and HJ) with ESs ranging from 0.04 to 0.81. The largest ES was reported for the 20-30 m sprint interval with an 89% chance this was practically beneficial. The chance the other performance increases were practically beneficial ranged from 37% to 65%. The ES of the other variables where performance decreased (10 m, 20 m, 10-20 m, and VJ) ranged from -0.01 to -0.35 with

chances of a practical benefit from horizontal training ranging from 13% to 21%.

The between group differences for each of the variables of interest were calculated and are reported in Table 9.4. A positive difference for the performance tests suggest horizontal training resulted in better performance changes. Horizontal training produced better pre-to post-testing percentage changes in five of the measures (10 m, 30 m, 10-30 m, 20-30 m, and 1RM squat; difference = 0.2 to 2.9), with vertical training producing better changes in remaining four (20 m, 10-20 m, VJ, and HJ; difference = 0.5 to 1.3). However, none of the differences in the percentage pre- to post-training changes were statistically significant for any of the performance tests ($p = 0.05$ to 0.83). With regard to practical significance, the ESs and the chance that these differences were practically beneficial or trivial are also reported in Table 9.4. The ES for the 20-30 m sprint interval was large (0.98) with a 94% chance the horizontal training was practically beneficial. ESs for the other measures where horizontal training was deemed superior ranged from 0.13 to 0.52 with probabilities of practical benefit ranging from 44% to 75%. With regard to the superiority of the vertical training, the ES for HJ was the largest (0.67) with the other variables of interest ranging from 0.01 to 0.54. The highest chance of practical benefit from vertical training was again HJ (84%) with the others 42% to 76%.

The average interval velocity, calculated from split times, for each group significantly increased ($p < 0.05$) over subsequent intervals, that is average 20 m-30 m velocity (8.60 - $8.64 \text{ m}\cdot\text{s}^{-1}$) was faster than 10-20 m (7.88 - $8.13 \text{ m}\cdot\text{s}^{-1}$), which was faster than 0 m-10 m (5.96 - $6.03 \text{ m}\cdot\text{s}^{-1}$).

Table 9.2. Vertical group mean percent change (SD) pre- to post-training, effect sizes and percent chances that 5-week training cycle is practically positive for timed sprints and performance tests.

	% Change	(SD)	p Value	Effect Size		% Beneficial	% Trivial
10 m	-0.7	1.7	0.74	-0.15	small	22	32
20 m	-0.2	1.5	0.92	-0.04	small	30	34
10-20 m	0.4	2.4	0.79	0.12	small	43	33
30 m	-0.2	0.9	0.94	-0.03	small	30	34
10-30 m	0.2	1.4	0.93	0.04	small	36	34
20-30 m	-0.1	3.0	0.97	-0.02	small	32	34
Vertical Jump	0.5	5.3	0.95	0.03	small	36	34
Horizontal Jump	1.6	1.9	0.68	0.19	small	49	31
1RM Squat	-1.1	5.9	0.77	-0.13	small	23	32

Table 9.3. Horizontal group mean percent change (SD) pre- to post-training, effect sizes and percent chances that 5-week training cycle is practically positive for timed sprints and performance tests.

	% Change	(SD)	p Value	Effect Size		% Beneficial	% Trivial
10 m	-0.5	1.4	0.68	-0.20	small	21	29
20 m	-0.7	1.2	0.46	-0.35	small	13	24
10-20 m	-0.9	2.4	0.54	-0.30	small	15	56
30 m	0.3	0.9	0.69	0.19	small	49	30
10-30 m	0.9	1.1	0.42	0.39	small	65	23
20-30 m	2.7	2.6	0.11	0.81	large	89	8
Vertical Jump	-0.1	4.9	0.99	-0.01	small	33	32
Horizontal Jump	0.2	2.0	0.94	0.04	small	37	32
1RM Squat	0.5	5.5	0.96	0.00	small	34	32

Table 9.4. Horizontal vs. vertical between group differences in pre- post-training percent changes (90% CI), effect sizes and percent chances that a 5-week horizontal training cycle is practically positive for timed sprints and performance tests.

	Difference	(90%CI)	p Value	Effect Size		% Horizontal Positive	% Trivial
10 m	0.2	± 1.3	0.78	0.13	small	44	32
20 m	-0.5	± 1.2	0.50	0.32	small	14	26
10-20 m	-1.3	± 2.0	0.14	0.54	moderate	7	17
30 m	0.5	± 0.8	0.29	0.51	moderate	74	18
10-30 m	0.7	± 1.1	0.28	0.52	moderate	75	18
20-30 m	2.9	± 2.4	0.05	0.98	large	94	5
Vertical Jump	-0.6	± 4.4	0.83	0.10	small	26	32
Horizontal Jump	-1.4	± 1.7	0.17	0.67	moderate	4	12
1RM Squat	1.5	± 4.9	0.59	0.26	small	55	28

Discussion

It was proposed that the transference of gym based strength gains may be improved if exercises were used that involve both vertical and horizontal force production. The purpose of the present study was to investigate the effect of a horizontal component lower body resistance exercise on running speed (timed sprints) and other sport specific performance tests. While the use of statistical significance is common within the literature to identify potential differences, what is often overlooked is the concept of practical significance. To many strength and conditioning practitioners such a statistic is invaluable, given that some results may not be statistically significant but there may be a high probability that the intervention is practically or clinically beneficial to performance. This is especially relevant in field of high performance sport where even the smallest change have a large influence on outcome or performance. Therefore in this study it was important to further analyze the data to ensure even the smallest potential difference between the respective exercises was identified. Although the performance changes pre- to post-training for both groups, and the differences between the groups with respect to these changes were not reported as statistically significant, what is of interest is the probabilities that there is actually a practical difference post training, and whether horizontal training has increased potential performance adaptations to a greater extent than vertical training. These contentions are subsequently discussed.

The results from the horizontal jump tests showed small increases in jump distance for both vertical and horizontal groups ($ES = 0.19$ and 0.04) with 49% and 37% probabilities that the respective trainings had a beneficial impact on performance. It is possible that the small improvements in HJ distance may be related to the absence of a

fast eccentric contraction in both of the respective movements used in training. If a fast eccentric component coupled with a fast transition into concentric contraction (fast stretch shortening cycle) is absent during training then the transference to an explosive performance test is likely to be minimal due to a lack of movement pattern and contraction velocity specificity (Young, 2006). Furthermore, the probability that horizontal training was more effective in producing positive change with regard to HJ distance was small (4%). It is suggested that the joint moments and range of movement (ROM) around the hip are quite different between the two exercises used in training (see Figure 9.1), resulting in different length tension and force-velocity relationships in the musculature of interest. It is possible that the similarities in hip joint ROM between the vertical exercise and HJ movements are sufficient to allow transference of strength gains. It has been suggested movements requiring a powerful thrust from hips and thighs can be improved through the prescription of a biomechanically similar movement during training (Adams, O'Shea, O'Shea, & Climstein, 1992). However, the analysis of the biomechanical aspects of the respective lifts was outside the scope of this study and the somewhat surprising findings of poor transference of horizontal training to HJ distance may require further investigation.

Although the production of horizontal force appears essential in sprint performance, it is also important to remember that successful sporting performance often relies on other activities that may require force or power to be exerted in the vertical direction (Deutsch, Kearney, & Rehrer, 2007; Duthie, Pyne, & Hooper, 2003). For this reason it is important to ensure vertical force production is not compromised as a consequence of focusing on the development of horizontal force or power. The results from the vertical jump tests show very small changes in jump height for both vertical and horizontal groups (ES = 0.3 and -0.01 respectively), with 36% and 33% probabilities that the

respective training protocols had a beneficial impact on performance. The probability that horizontal training was more effective in producing positive change with regards to VJ height was small (26%). Again it is suggested that the similarities in hip joint ROM between the vertical exercise and VJ movements are sufficient to allow transference of strength gains. Improvements in VJ have been reported following squat training without a dynamic component, suggesting the squat movement pattern is conducive to enhancing neuromuscular efficiency, in turn allowing for transfer to other biomechanically similar movements (Adams et al., 1992).

With regard to the 1RM squat results it is interesting to note that the horizontal group maintained pre-post 1RM levels whereas the vertical group actually decreased (ES = 0.00 and -0.13). Subsequently a 55% probability that horizontal training was more beneficial to 1RM squat was reported. Even though the 1RM is performed in the vertical plane it is possible that the muscle activations required to perform a heavy load squat, especially those of the lower back e.g. erector spinae, are more similar to those of a horizontal squat. It is possible the attachment of the cable during the vertical squat assists in the movement of these muscles thereby reducing the training load placed upon them resulting in a level of deconditioning (see Figure 9.1). Therefore it was potentially the strength of musculature other than those of the lower limb that limited 1RM squat performance. Evidence the horizontal group 1RM squat performance was not compromised lends support to the use of equated horizontal component training as a method of maintaining vertical performance whilst focusing on the enhancement of horizontal performance.

The results from the timed sprints show an increase in sprint times for both groups over the 10 m and 20 sprints (ES = -0.35 to -0.04) with only small probabilities that the

respective training had beneficial impact on performance (13% to 30%). Previous research has also reported an increase in sprint times following eight weeks of periodised resistance training (Moir, Sanders, Button, & Glaister, 2007). Similarly it has been reported that bilateral lower body strength is not a good predictor of sprint times over short distances (Baker & Nance, 1999a; Bissas & Havenetidis, 2008). The velocity specificity principle of training may explain the extent of the change in sprint times, whereby the greatest gains in sprinting may occur when the velocity of training closely approximates the velocity of movement occurring during the muscle actions associated with sprinting (Behm & Sale, 1993a, 1993b; Rimmer & Sleivert, 2000). Additionally it has been suggested that the rate of force production is more important in sprinting rather than maximum force (Bissas & Havenetidis, 2008).

Of interest is the observation that the horizontal group did not increase sprint times to the same extent as did the vertical group ($ES = 0.13$), with a 44% probability horizontal training was more beneficial to 10 m performance than vertical training. Although 10 m sprint times did increase in the horizontal group, for the reasons postulated previously, the smaller relative increase in sprint times may be due to the larger horizontal force production associated with horizontal training. It has been suggested that during the first 10 m of sprinting high horizontal and low vertical forces are required, whereby athletes with the ability to produce higher horizontal propulsive forces would undergo larger increase in horizontal velocity during each stance phase, thereby accelerating faster (Hunter et al., 2005; Mero, 1988; Mero & Komi, 1986). Furthermore it has been proposed that more frequent ground contacts, via a low vertical GRF would allow a greater opportunity to apply horizontal propulsive forces (Hunter et al., 2004). If the vertical force production between groups was equated whilst horizontal force production was greater for the horizontal group then it stands to reason that during the

stance phase the horizontal group is able to apply greater horizontal propulsive forces. The significance of the horizontal component seems to be logical since one cannot increase horizontal velocity by increasing vertical force, but acceleration and deceleration of running velocity is produced mainly by changing horizontal force (Hunter et al., 2005; Mero et al., 1992; Nummela et al., 2007). Therefore while the manner by which force was produced during training (i.e. rate of force development) may not have been conducive to increasing initial acceleration, the direction of force application (i.e. horizontal vs. vertical) appears to have had an influence on initial acceleration performance.

The results from the 20-30 m interval show that while vertical training lead to an increase in sprint times (ES = -0.02), horizontal training resulted in a decrease in sprint times (ES = 0.81), with a 94% probability that horizontal training was superior to vertical training. Of note is the observation that average interval velocities for both groups increased over subsequent intervals (5.96-6.03 m.s⁻¹ vs. 7.88-8.13 m.s⁻¹ vs. 8.60-8.64 m.s⁻¹; $p < 0.05$), such that the fastest velocities were reported for the 20-30 m interval. Whilst the vertical component is the larger of the two absolute GRFs during running, it is suggested that running velocity is more dependent on horizontal than vertical force as the velocities increase towards maximal (Brughelli et al., 2011; Kyröläinen et al., 2001; Munro et al., 1987). This is further evident given linear relationships are not observed between vertical force and running velocity at higher velocities (Brughelli et al., 2011; Hunter et al., 2005; Keller et al., 1996; Nummela et al., 2007). That is, as running velocity increases so too does the relative contribution of horizontal GRFs (Brughelli et al., 2011; Kyröläinen et al., 2001; Munro et al., 1987). This was also evident in the results of the full 30 m distance and the 10-30 m interval where the probabilities of horizontal training being more beneficial than vertical

training were 74% and 75% respectively. As was suggested previously, the horizontal force production was greater for the horizontal group during training leading to a greater potential to produce horizontal propulsive forces. Therefore the direction the forces were applied (i.e. horizontal vs. vertical) appears to have had an influence on sprint performance at higher velocities.

A number of limitations need to be acknowledged prior to the concluding remarks. First the sample size in each group was relatively small but this represented all the professional players in the region. The aim was to use well trained players as it is much more difficult to elicit adaptation and performance enhancement in well trained athletes. That is, even though there was no significant differences between the horizontal and vertical training group, the probabilities that horizontal training was more beneficial, or at the least of trivial benefit, when compared to vertical training were 76% for 10 m, 92% for 30 m, 93% for 10-30 m and 99% for 30 m sprint performance. In addition the probabilities that vertical performance was at least equal to that achieved through vertical training were 58% for vertical jump and 83% for 1RM squat. Given those odds most practitioners would choose to use horizontal training even though not statistically significant. A second limitation was the duration of the training study i.e. five weeks. Longer exposure to the intervention may have resulted in larger training effects. However, given that most training cycles are of four to six week durations the duration of this study seems to have face or logical validity. Once more the results of this study are noteworthy, given the duration of the intervention and training status of the subjects.

Practical applications

The findings from this suggest that the development of horizontal force production during resistance training is an import prerequisite for increasing sprint performance

over short distances. This assertion becomes even more valid when the demands of rugby, league or American football are taken into consideration, which require the need to accelerate quickly over short distances, in addition to the need to overcome large horizontal resistances in the form of contact from opposing players. Of particular interest to the strength and conditioning practitioner is the observation that the use of a horizontal component lower body exercise during a resistance strength training programme did not negatively affect the performance of vertical based performance tests.

If successful performance requires force production in the horizontal plane, whereby the focus of training during a periodised training plan shifts from the development of strength or power in the vertical plane to that in the horizontal, improvements may be realised if the design of the resistance training programme focuses on horizontal movement-specific exercises as well as traditional vertical exercises. It would, therefore, seem critical that a movement-specific approach be applied to the design of strength and power resistance programmes for such sports.

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CHAPTER 10. CONCLUSIONS

Summary

This PhD thesis sought to improve understanding related to the development of strength, power and speed and the transference of these variables to rugby specific tests that are used to assess on-field performance. Specifically, examining the use of feedback to optimise within session training emphasis, and investigating the use of exercises involving horizontal and vertical force production to optimise training transference.

Part One of this thesis investigated the effect of utilising instantaneous performance feedback. A review of the literature (Chapter Two) revealed several key areas to be considered in the design of the experimental studies within this section. Firstly, feedback can have a substantial effect on strength and power performance, particular through the use of visual feedback, however, the effects of this type of feedback during a resistance strength training session, over repeated training sessions, and over an entire training cycle are for the most part unexplored. Secondly, most monitoring practices typically provide retrospective quantification of a resistance training session whereby the information collected summarises a completed session and is therefore used to modify a subsequent session. Currently there is a paucity of research investigating monitoring practices that allow within session training modification. Furthermore the ability to quantify the power phase of the training pyramid as the focus of a conditioning programme progresses from strength development is an area that appears under-researched and requires additional investigation. It was identified that there was a need for research specifically investigating the use of dynamometry to provide instantaneous feedback on movement velocity and its effect on consistency of performance during training; research quantifying the effect of instantaneous feedback

over repeated training sessions; and, research tracking the effect on sport specific performance tests following a training cycle using instantaneous feedback.

The first experimental study in this section (Chapter Three) sought to address the question regarding the effect of instantaneous feedback on consistency of performance during training by determining the reliability of jump squat velocity under feedback and non-feedback conditions over three training sessions. Smaller changes in mean peak velocities between Sessions 1-2 and Sessions 2-3 for the feedback condition (0.07 and 0.02 m.s⁻¹ vs. 0.13 and -0.04 m.s⁻¹) suggest better stability of performance. Smaller typical errors (0.06 and 0.06 m.s⁻¹ vs. 0.10 and 0.07 m.s⁻¹) also imply less random variation in each subject's measurement between tests for the feedback condition and greater absolute consistency. Larger ICCs (0.83 and 0.87 vs. 0.53 and 0.74) also indicated superior relative consistency for the feedback condition. It was suggested that the provision of feedback added consistency to a simple test-retest situation both within individual sets and across multiple sets and training sessions. Subsequently it was concluded that there is approximately a 50-50 chance that the effect of feedback on the velocity of jump squats would be beneficial or trivial, and it almost certainly did not have a negative effect on training outcomes.

If equipment and software can provide reliable instantaneous feedback related to the jump squat velocity during training it was thought that this may result in improvements in the velocity of jump squats during training. The second experimental study in this section (Chapter Four) sought to address the issue of quantifying the effect of instantaneous feedback over repeated training sessions. An average 2.1% increase in mean jump squat velocity during training was observed with feedback whilst a plateau in velocity occurred once feedback was withdrawn. It was established that a 78%

chance existed that feedback was practically beneficial in producing superior velocities for jump squats during training.

If the provision of instantaneous feedback related to jump squat velocity results in improvements in the consistency and performance velocity of jump squats during training, this may optimise the training session goal, thereby the potential for increasing the transference to on-field performance may be enhanced. The final experimental study in this section (Chapter Five) sought to address the issue of quantifying the effect of instantaneous feedback over a six week training block on vertical jump, horizontal jump and 10, 20 and 30 m sprint performance. The relative magnitude of the training effects for all performance tests were found to be small ($ES = 0.18$ to 0.28), except for the 30 m sprint performance which was moderate (0.46). In comparison to traditional methods of training (no feedback), the probabilities that the use of feedback during a periodised cycle of squat jump training was beneficial to increasing performance of sport specific tests was 45% for vertical jump, 65% for 10 m sprints, 49% for 20 m sprints, 83% for horizontal jump, and 99% for 30 m sprints. Of interest was the observation that in addition to improving consistency of training performance over subsequent training session within a week, the provision of feedback also maintained consistency of jump squat velocity over an entire training cycle ($ICCs = 0.81$ to 0.95 vs. -0.52 to 0.14)

From this section it can be concluded that the provision of instantaneous feedback related to velocity of jump squats improves consistency of jump squat performance during repeated training sessions; improves velocity of jump squats during training; and optimises the transference of this increased velocity of movement during training to sport specific performance tests.

Part Two of this thesis investigated the effect of prescribing lower body exercises with a horizontal component. A review of the literature (Chapter Six) found several key areas to be considered in the design of the experimental studies within this section. Firstly, while force production is necessary in both the vertical and horizontal planes, it is the horizontal forces that experience the greatest increase when accelerating to maximal velocity, however, the effectiveness of a gym based lower body resistance training programme with a horizontal component has not been investigated. Secondly, it is important to ensure that vertical force production is not compromised, especially when successful performance may also rely on vertical force production. Currently there is a paucity of research addressing this issue of direction of force production within such sporting situations. It was identified that there was a need for research specifically investigating the methodology of equating vertical force production of a horizontal exercise with a vertical exercise; research investigating the effect of a training cycle using a horizontal component lower body exercise equated for vertical force production on vertical strength performance; research tracking the effect on sport specific performance tests, including horizontal based movements, following a training cycle using horizontal training.

The first experimental study in this section (Chapter Seven) sought to address the issue regarding vertical force production during a horizontal exercise by outlining the methodological approach to equating the vertical force production of a vertical squat and horizontal component squat exercise. Originally there were significant differences between the conditions with regard to both the vertical and horizontal GRFs (2034-2663 N vs. 1602-1980 N, $p = 0.05$; and 836-1141 N vs. 221-425 N, $p < 0.001$). However through the quantification of respective GRFs, prescription guidelines (repetitions) that enabled the equating of vertical GRF between the vertical and horizontal exercises were

calculated. The use of this methodology allows the contribution of vertical and horizontal force production to be disentangled when utilising training studies involving the horizontal squat exercise.

If vertical force production during a horizontal squat exercise can be equated with a vertical squat exercise it is thought that this may ensure vertical force production is not compromised during training with a horizontal exercise. The second experimental study in this section (Chapter Eight) sought to address the issue of quantifying the effect of utilising an equated horizontal squat exercise over a training cycle on vertical strength performance (1RM squat, deadlift and a power clean). The training effects for all performance tests were found to be small (ES = 0.00 to 0.26). Therefore, the probabilities that there was actually a practical difference, whereby horizontal component training had reduced adaptive potential, were low (11%, 4%, and 8% for the squat, deadlift and power clean respectively). It was suggested that the use of horizontal squat exercise over a training cycle did not compromise vertical performance adaptations as compared to traditional vertical based training.

If a horizontal squat exercise can be equated for vertical force production during training, without compromising vertical performance, this may allow development of horizontal force adaptations, thereby the potential for increasing the transference to on-field performance may be enhanced. The final experimental study in this section (Chapter Nine) sought to address the issue of quantifying the effect of utilising an equated horizontal squat exercise over a training cycle on sport specific performance tests, including horizontal based movements. The training effects for both groups for all performance tests were found to be small (ES = -0.35 to 0.39), except for the horizontal group 20-30 m interval which was large (ES = 0.81). In comparison to traditional

methods of training (vertical), the probabilities that horizontal training was more beneficial, or at the least of trivial benefit, were 76% for 10 m, 92% for 30 m, 93% for 10-30 m and 99% for 30 m sprint performance. In addition the probabilities that vertical performance was at least equal to that achieved through vertical training were 58% for vertical jump and 83% for 1RM squat.

From this section it can be concluded that the use of a horizontal compared to vertical squat exercise enables greater horizontal force production; does not negatively affect vertical based performance tests; and, optimises the transference of this increased horizontal force production during training to sport specific performance tests.

Limitations

It is important to be conscious of the following limitations when interpreting the results of this thesis:

Because the intention of this thesis was to enhance the current understanding of rugby-specific strength and power development professional rugby players were specifically chosen as subjects, mindful of the population specific nature of training adaptation. Due to the demanding schedules of professional rugby players, regular access to large number of players at any time throughout the duration of this research (regardless of training season) was problematic.

Findings from Chapters Three to Five are specific to the weighted concentric squat jump only, hence may not translate to other common squat derivative exercises, such as bodyweight squat jumps or countermovement squat jumps.

The exclusive functional performance measures investigated in Chapter Five were vertical jump, horizontal jump, and 10 m, 20 m, and 30 m timed sprints. Findings may not be applicable to other common measures of performance.

Findings from Chapters Seven to Nine are specific to the movement performed (cable squat at approximately 30°), hence may not translate to other horizontal component exercises, such as sled tows, or movements performed at different lift angles.

The exclusive functional performance measures investigated in Chapter Eight were 1RM squat, 1RM deadlift and 1RM powerclean. Findings may not be applicable to other common measures of performance.

The exclusive functional performance measures investigated in Chapter Nine were 10 m, 20 m and 30 m timed sprints, vertical jump, horizontal jump and 1RM Squat. Findings may not be applicable to other common measures of performance.

The total volume of the training intervention performed by either group during the training studies (Chapters Five, Eight, and Nine) constituted a single exercise within a periodised resistance training programme. Typically, training involves multiple exercises; training adaptations and performance outputs may differ between multiple and single exercises. In addition it is conceivable that the other training exercises and conditioning sessions performed by each group were partly responsible for any observed changes in performance measures.

The duration of the training studies (Chapters Five, Eight, and Nine) were short i.e. five to six weeks. Longer exposure to the intervention may have resulted in larger training effects and greater between-group or condition effects. However, given that most professional rugby resistance training cycles are of four to six week durations the duration of these studies seems to have face or logical validity.

The sample sizes in the experimental studies (Chapters Three, Four, Five, Eight, and Nine) were relatively small but this represented all the available professional and semi-professional players in the region. Increasing numbers by including subjects other than squad members with the intention of providing greater statistical power would have compromised the validity of the study in terms of extrapolating findings to other similar high-level athletes. Also the aim was to use well trained players as it is much more difficult to elicit adaptation and performance enhancement. In addition, because of the ethical issues in relation to using professional athletes as subjects, no non-training control groups were allocated, instead control groups used standard training techniques.

Practical applications

While the use of statistical significance is common within the literature to identify potential differences, what is often overlooked is the concept of practical significance. To many strength and conditioning practitioners such a statistic is invaluable, given that some results may not be statistically significant but there may be a high probability that the intervention is practically or clinically beneficial to performance. This is especially relevant in high performance sport where even the smallest change may have a large influence on outcome or performance. Therefore through this thesis additional statistical analysis of the data was performed to ensure even the smallest potential difference between the variables of interest were identified. The provision of a probability that a particular intervention is of practical or clinical benefit enables strength and conditioning practitioners to make informed decisions whether to implement the strategies presented.

With advances in technology it is now possible to continuously monitor specific kinetic and kinematic performance during resistance training. The use of such technologies to subsequently provide instantaneous feedback during resistance training was reported to be beneficial to improving both the consistency and performance of jump squat velocity. It was theorised that because athletes were now conscious of decreases in performances, whether technical or motivational, they were able to modify subsequent repetitions thereby ensuring each session was producing an optimal training stimulus. Therefore, it is suggested that strength and conditioning practitioners use instantaneous feedback to continuously monitor specific kinetic and kinematic performance during resistance training to optimise training adaptations. Additional applications arising from the ability to accurately monitor and modify performance during training are the ability to; 1) set training thresholds, whereby sets are terminated once performance

decreases to a predetermined level, potentially eliminating performance of repetitions that may be contributing to fatigue without providing a positive training effect e.g. power training; 2) set performance targets, whereby the number of repetitions to be completed above a pre-determined performance threshold are prescribed, potentially providing maximal exposure to an optimal training stimulus; and, 3) create competition within the training environment, whereby athletes are aware of the performance of team members, potentially providing motivation when fatigue sets in.

Furthermore, it is reported that the provision of instantaneous feedback during resistance training optimises the transference of the movement of interest to rugby specific performance tests. Given the advances in monitoring technology enabling the calculation of many kinematic (e.g. velocity) and/or kinetic (e.g. power) variables, instantaneous feedback can be provided for different movements (i.e. exercises) and movement parameters (i.e. force, velocity, power). Given the ability to produce high levels of force, with increased movement velocity is thought desirable for most rugby players, the practical application of such capabilities is that as the foci of the periodised training plan shifts, strength and conditioning practitioners may also be able to adjust the focus of feedback to better correspond with the specific training goal.

The training of horizontal propulsive force generation is one aspect of many sports, such as rugby, that is not easily achieved with traditional vertical based resistance training methods. Compounding this is the potential compromise to vertical force production if the direction of force application is manipulated. This thesis presented a methodological approach to equate vertical force production for horizontal resistance exercises, such that vertical performance adaptations were not compromised when compared with traditional vertical based training. Applications arising from the use of

this methodological approach are; 1) the ability to calculate vertical: horizontal repetition ratios, whereby the prescription of set repetitions can be altered to correspond with guidelines for different foci within the cycles of a periodised plan; and, 2) the ability to specify lift angle during training to ensure consistency of respective force contributions, whereby the prescription of load can be altered to correspond with guidelines for different foci within the cycles of a periodised plan.

Furthermore it was found that training with horizontal resistance equated for vertical force production is beneficial for improving horizontal performance whilst maintaining vertical performance. Given successful rugby performance relies on force or power to be exerted in both vertical and horizontal directions, the practical application of such findings is that strength and conditioning practitioners should apply a movement-specific approach to the design of resistance training programmes, thereby optimising training transference.

The overriding practical implication from the findings of this PhD thesis is the importance of optimising the training session with respect to how we train (i.e. maximising training stimulus), and what we train (i.e. maximising movement plane specificity), thereby optimising the potential transference of the strength and power adaptations to sport specific performance.

Future directions

This thesis sought to challenge traditional methods and propose alternative strategies with regard to the development of strength, power and speed through resistance training, and the subsequent transference of these variables to on-field performance. In the process, several areas requiring further clarification and/or investigation, that may enable strength and conditioning practitioners to prescribe the use of feedback or horizontal training more effectively, have arisen:

With regard to the use of instantaneous feedback during resistance training, it was reported that a plateau in jump squat velocity occurred after feedback was withdrawn and an increase in velocity was observed when feedback was given. Of practical interest is; 1) do the increases in performance seen with provision of feedback also plateau over time, such that further improvements in performance are not observed; 2) if there is an eventual plateau, when does it occur, that is after how many training sessions; and, 3) if performance does plateau, is the continued use of feedback essential to maintain performance, that is if feedback is removed at this stage does the performance continue to plateau or does it decrease?

With regard to the use of equated horizontal lower body resistance training, it was reported that the use of the equating methodology produced two exercises with equated vertical forces but with differing horizontal forces. Of practical interest is; 1) whether the magnitude of the difference in horizontal force between exercises is of importance, given that at different lift angles different horizontal forces will be present; and, 2) if lift angle is of importance, what is the optimal angle to prescribe during training, provided vertical force production can be practically equated?

Detailed investigations, using similar methodological approaches to those used in this thesis, are required involving other commonly prescribed gym-based resistance exercises, both with respect to the use of feedback and the application of movement specificity. Initially this may be useful in providing alternative training options for strength and conditioning practitioners. In addition, given athletes were shown to improve sport specific performances with single exercise interventions, it would seem intuitive to 'optimise' multiple exercises, which may provide greater potential for adaptation and larger training effects. Furthermore, given athletes were shown to improve sport specific performances over five-six week training programmes, it would seem intuitive to investigate longer or multiple training cycles, which may also provide greater potential for adaptation and larger training effects. Therefore of interest is research examining the effect on adaptations, training effects and transference to sport specific skills of; 1) programmes utilising multiple 'optimised' exercises; and, 2) programmes consisting of multiple training cycles.

The overriding practical implication presented in this thesis is the importance of optimising the potential transference of strength and power adaptations to sport specific performance by either maximising training stimulus through, use of feedback, or maximising movement plane specificity. If each, as separate training techniques, were reported to be beneficial to sport specific performance what is of ultimate interest is the combined benefit of the two. That is, what effect does the provision of instantaneous feedback during horizontal training, have on the transference of strength and power adaptation to sports specific performance?

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APPENDICES

Appendix 1. Ethics approval form (Part 1)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 7 April 2009
Subject: Ethics Application Number 09/33 Strength and power transference in Rugby Union players: implications for training.

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 March 2009 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 11 May 2009.

Your ethics application is approved for a period of three years until 7 April 2012.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/about/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 7 April 2012;

A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/about/ethics>. This report is to be submitted either when the approval expires on 7 April 2012 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the

research does not commence. AUTEK approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEK grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEK and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely



Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Aaron Randell aaron.randell@aut.ac.nz, Justin Keogh, Nicholas Gill

Appendix 2. Consent form (Part 1)



Project title: Strength and power transference in rugby union players: implications for training.

Project Supervisor: **Prof John Cronin**

Researcher: Aaron Randell

- I have read and understood the information provided about this research project in the Information Sheet dated 7th April 2009.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.
- I agree to take part in this research.
- I understand that the Bay Plenty Rugby Football Union Head Strength and Conditioning Coach will be given the data and results.
- I wish to receive a copy of the report from the research (please tick one):
Yes No

Participant's signature:.....

Participant's name:.....

Participant's Contact Details (if appropriate):

.....
.....
.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 7th April 2009 AUTEK Reference number 09/33.

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

Appendix 3. Subject information sheet (Part 1)



Date Information Sheet Produced:

7/04/2009

Project Title:

Strength and Power Transference in Rugby Union Players: Implications for Training

An Invitation:

I, Aaron Randell, am a PhD candidate in strength and conditioning at AUT University in Auckland, working in conjunction with Professor John Cronin. You are invited to participate in a study that is expected to assist in the development and transference of power in rugby players. Please understand that your participation is voluntary and you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

This study aims to investigate the influence of immediate performance feedback on power output during a resistance training session and on the transference to rugby performance tests. The results of this study will be used to prescribe monitoring methods that enable rugby players to optimise resistance training sessions. Various presentations and publications will also be developed from the results of this research.

How were you chosen for this invitation?

You are being invited to participate in this study as a result of your current selection in the Bay of Plenty Rugby Union (BOPRU) training squad. BOPRU is not formally involved with this research project. Although you may be contracted to BOPRU your participation in this project is voluntary. Your decision whether to participate or not in this study will not affect any contract you may have with BOPRU.

What will happen in this research?

If you decide to participate in this research, you will be asked to complete a consent form prior to any data collection. You will be asked to complete a familiarisation session and six testing sessions. Your age, height and weight will be recorded first. You will then be asked to perform a warm-up specific to the exercises you will complete. The testing sessions will require you to perform four sets of eight squat jumps in a Smith machine with an absolute load of 40 kg. You will be instructed to perform the movement as fast / explosively as possible. Your movements will be recorded with a position transducer and where appropriate you will be given feedback. Following the completion of the testing session you will be asked to undergo an eight week periodised pre-season rugby training programme, including pre and post NZRU performance tests. The programme will be similar to one you would normally be required to complete as part of your training, as are the performance tests. Your movements during the jump squat and split squat jumps will be recorded with a position transducer and where appropriate you will be given feedback. Please feel free to communicate any questions you have at any time during the session.

What are the discomforts and risks?

You are being asked to complete exercises that are part of your normal resistance training programme. There is a possibility of injuring yourself, however the probability of this occurring is no more likely than you injuring yourself during normal training. If at any time you do not feel that you are able to complete the exercises requested, please notify the researcher immediately. Additionally, please notify the researcher at this time if you have a current injury that might affect your performance of these movements, or that might be worsened or aggravated by the required tasks. There will not be any adverse consequences if you need to withdraw for any reason, at any time.

How will these discomforts and risks be alleviated?

You have been asked to physically prepare yourself prior to the testing in addition to being given a warm up that has been specifically designed for the exercise you will complete. Please notify the researcher if you feel that you need more time to prepare or recover as we are interested in measuring your best performance.

What are the benefits?

By participating in this study, you are providing us with information about the possible benefits of within session performance feedback for the development and transference of power for rugby players. While the outcome of this research may not produce any immediate benefits to you, the intention is to gain a better understanding of monitoring strategies during resistance training for rugby. Your participation will also assist in the development of monitoring strategies aimed at optimizing the training emphasis.

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 your privacy be protected?

The results of each participant will be kept confidential. However, in addition to the student researcher (Aaron Randell) and the primary supervisor (Prof. John Cronin), results will be viewed by the Head strength and conditioning coach at BOPRU. In the event that a still photograph is used in a presentation or publication, the head of the individual will be blurred in an attempt to avoid identification. The summarised results from the study will be available to you upon completion of the study. These results will also be submitted for publication in peer reviewed journals as a means of developing the ensuing training prescriptions.

What are the costs of participating in this research?

We acknowledge and respect the fact that you are quite busy. We have attempted to keep the training and testing sessions as brief as possible. We estimate that your complete time commitment will be no more than 60-75 minutes for each of the sessions.

What opportunity do you have to consider this invitation?

After you have read through this form, you will have the opportunity to ask any questions you would like about the study. After your concerns have been satisfied, you will be given an opportunity to decide whether or not you would like to participate. Please feel free to take as much time as you feel is necessary to make this decision. If you would like to return at a later date or time, please notify the researcher and accommodations will be made without any adverse consequences.

How do you agree to participate in this research?

If you would like to participate in this study, please complete the attached consent form. If you would rather not participate, you are free to leave.

Will you receive feedback on the results of this research?

Yes, if you are interested in receiving the summarised results, please check the appropriate bubble on the consent form. We also ask that you provide your contact information so we can communicate the results with you. Your personal information will not be disclosed to anyone beyond the primary supervisor (Prof. John Cronin) and the PhD student (Aaron Randell).

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. John Cronin, john.cronin@aut.ac.nz, 09 921 9999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTECH, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Who do you contact for further information about this research?

Researcher Contact Details:

Aaron Randell, aaron.randell@aut.ac.nz

Project Supervisor Contact Details:

Prof. John Cronin, john.cronin@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 7th April 2009, AUTECH Reference number 09/33.

Appendix 4. Ethics approval form (Part 2)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 25 May 2010
Subject: Ethics Application Number 10/42 Strength and power transference in Rugby Union players: implications for training.

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 12 April 2010 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 14 June 2010.

Your ethics application is approved for a period of three years until 24 May 2013.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 24 May 2013;

A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics>. This report is to be submitted either when the approval expires on 24 May 2013 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to

the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEK grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEK and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely



Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Aaron Randell aaron.randell@aut.ac.nz, Justin Keogh, Nicholas Gill

Appendix 5. Consent form (Part 2)



Project title: Strength and power transference in rugby union players: implications for training.

Project Supervisor: **Prof John Cronin**

Researcher: Aaron Randell

- I have read and understood the information provided about this research project in the Information Sheet dated 25/05/2010.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant information will be destroyed.
- I permit the researchers to obtain photographic and/or video images during training that may be required as part of this project.
- I understand that the photographs and video images will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- I understand that any copyright material created by the photographic/video sessions is deemed to be owned by the researcher and that I do not own copyright of any of the photographs.
- 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 any infection.
- I understand that the North Harbour Rugby Union Head Strength and Conditioning Coach will be given the data and results.
- I wish to receive a copy of the report from the research (please tick one): Yes No
- I agree to take part in this research.

Participant's signature:.....

Participant's name:.....

Participant's Contact Details (if appropriate):

.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 25/05/2010
AUTEK Reference number 10/42.

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

Appendix 6. Subject information sheet (Part 2)



Date Information Sheet Produced:

25/05/2010

Project Title

Strength and Power Transference in Rugby Union Players: Implications for Training
An Invitation

I, Aaron Randell, am a PhD candidate in strength and conditioning at AUT University in Auckland, working in conjunction with Professor John Cronin. You are invited to participate in a study that is expected to assist in the development and transference of power in rugby players. Please understand that your participation is voluntary and you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

This study aims to investigate the influence of using exercises with a horizontal component during resistance training on the transference to rugby performance tests. The results of this study will be used to prescribe training methods that enable rugby players to optimise resistance training sessions. Various presentations and publications will also be developed from the results of this research.

How were you chosen for this invitation?

You are being invited to participate in this study as a result of your current selection in the North Harbour Rugby Union (NHRU) training squad. NHRU is not formally involved with this research project. Although you may be contracted to NHRU your participation in this project is voluntary. Your decision whether to participate or not in this study will not affect any contract you may have with NHRU.

What will happen in this research?

If you decide to participate in this research, you will be asked to complete a consent form prior to any data collection. You will be asked to complete a familiarisation session and an initial testing session. Your age, height and weight will be recorded first. You will then be asked to perform a warm-up specific to the exercises you will complete. The testing session will require you to perform one set of six different exercises. Your movements will be recorded with a force platform. Following the completion of the testing session you will be asked to undergo an eight week periodised pre-season rugby training programme, including pre and post NZRU performance tests. The programme will be similar to one you would normally be required to complete as part of your training, as are the performance tests. During the study you may be photographed and/or videoed with any images captured used for academic purposes only. Please feel free to communicate any questions you have at any time during the session.

What are the discomforts and risks?

You are being asked to complete exercises that are part of your normal resistance training programme. There is a possibility of injuring yourself, however the probability of this occurring is no more likely than you injuring yourself during normal training. If at any time you do not feel that you are able to complete the exercises requested, please notify the researcher immediately. Additionally, please notify the researcher at this time if you have a current injury that might affect your performance of these movements, or that might be worsened or aggravated by the required tasks. There will not be any adverse consequences if you need to withdraw for any reason, at any time.

How will these discomforts and risks be alleviated?

You have been asked to physically prepare yourself prior to the testing in addition to being given a warm up that has been specifically designed for the exercise you will complete. Please notify the researcher if you feel that you need more time to prepare or recover as we are interested in measuring your best performance.

What are the benefits?

By participating in this study, you are providing us with information about the possible benefits of using resistance exercises with a horizontal component for the development and transference of power for rugby players. While the outcome of this research may not produce any immediate benefits to you, the intention is to gain a better understanding of movement specific training during resistance training for rugby. Your participation will also assist in the development of training strategies aimed at optimizing the training emphasis.

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 your privacy be protected?

The results of each participant will be kept confidential. However, in addition to the student researcher (Aaron Randell) and the primary supervisor (Prof. John Cronin), results will be viewed by the Head strength and conditioning coach at NHRU. In the event that a still photograph is used in a presentation or publication, the head of the individual will be blurred in an attempt to avoid identification. The summarised results from the study will be available to you upon completion of the study. These results will also be submitted for publication in peer reviewed journals as a means of developing the ensuing training prescriptions.

What are the costs of participating in this research?

We acknowledge and respect the fact that you are quite busy. We have attempted to keep the training and testing sessions as brief as possible. We estimate that your complete time commitment will be no more than 60-75 minutes for each of the sessions.

What opportunity do you have to consider this invitation?

After you have read through this form, you will have the opportunity to ask any questions you would like about the study. After your concerns have been satisfied, you will be given an opportunity to decide whether or not you would like to participate. Please feel free to take as much time as you feel is necessary to make this decision. If you would like to return at a later date or time, please notify the researcher and

accommodations will be made without any adverse consequences.

How do you agree to participate in this research?

If you would like to participate in this study, please complete the attached consent form. If you would rather not participate, you are free to leave.

Will you receive feedback on the results of this research?

Yes, if you are interested in receiving the summarised results, please check the appropriate bubble on the consent form. We also ask that you provide your contact information so we can communicate the results with you. Your personal information will not be disclosed to anyone beyond the primary supervisor (Prof. John Cronin) and the PhD student (Aaron Randell).

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. John Cronin, john.cronin@aut.ac.nz, 09 921 9999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEK, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Who do you contact for further information about this research?

Researcher Contact Details:

Aaron Randell, aaron.randell@aut.ac.nz

Project Supervisor Contact Details:

Prof. John Cronin, john.cronin@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 25/05/2010, AUTEK Reference number 10/42.

Appendix 7. Abstracts of experimental chapters

Chapter Three

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (in press). Reliability of performance velocity for jump squats under feedback and non-feedback conditions. *Journal of Strength and Conditioning Research*.

Advancements in the monitoring of kinematic and kinetic variables during resistance training have resulted in the ability to continuously monitor performance and provide feedback during training. If equipment and software can provide reliable instantaneous feedback related to the variable of interest during training it is thought that this may result in goal-oriented movement tasks that increase the likelihood of transference to on-field performance or at the very least improves the mechanical variable of interest. The purpose of this study was to determine the reliability of performance velocity for jump squats under feedback and non-feedback conditions over three consecutive training sessions. Twenty subjects were randomly allocated to a feedback or non-feedback group and each group performed a total of three “jump squat” training sessions with the velocity of each repetition measured using a linear position transducer. There was less change in mean velocities between Sessions 1-2 and Sessions 2-3 (0.07 and $0.02 \text{ m}\cdot\text{s}^{-1}$ vs. 0.13 and $-0.04 \text{ m}\cdot\text{s}^{-1}$), less random variation ($\text{TE} = 0.06$ and $0.06 \text{ m}\cdot\text{s}^{-1}$ vs. 0.10 and $0.07 \text{ m}\cdot\text{s}^{-1}$) and greater consistency ($\text{ICC} = 0.83$ and 0.87 vs. 0.53 and 0.74) between sessions for the feedback condition as compared to the non-feedback condition. It was concluded that there is approximately a 50-50 probability that the provision of feedback was beneficial to the performance in the squat jump over multiple sessions. It is suggested that this has the potential for increasing transference to on-field performance or at the very least improving the mechanical variable of interest.

Chapter Four

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2010). Effect of performance feedback during velocity based resistance training. Submitted to *Sports Biomechanics* (second review).

This study quantified the effect of performance feedback on jump squat velocity over six consecutive training sessions in twenty semi-professional rugby players. Players were randomly assigned to a feedback (n=10) or non-feedback group (n=10) and completed three separate testing sessions (four sets of eight concentric squat jumps with an absolute load of 40 kg) with the feedback group receiving real-time feedback on peak velocity of the jump squat at the completion of each. Groups then crossed over for a further three sessions with the feedback group receiving no feedback and the non-feedback group receiving feedback. A plateau in velocity after feedback was withdrawn and an increase in when feedback was given was observed. In addition it was found that there was an average 2.1% increase in the mean velocity with feedback. The chance that this change was practically beneficial was 78% with a 22% chance that the benefits of feedback were trivial. The improvement in performance observed during the provision of feedback suggests that the athlete may be better able to optimise the training session goal (e.g. movement velocity, power output, etc.), that is, they are able to produce performances that are consistently better than those achieved without feedback.

Chapter Five

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Pedersen M. C. (2011). Effect of instantaneous performance feedback during six weeks of velocity based resistance training on sport specific performance tests. *Journal of Strength and Conditioning Research*, 25(1), 87-93.

The purpose of this study was to investigate the effect of instantaneous performance feedback (peak velocity) provided after each repetition of squat jump exercises over a six week training block on sport specific performance tests. Thirteen professional rugby players were randomly assigned to one of two groups, feedback (n = 7) and non feedback (n = 6). Both groups completed a 6 week training programme (3 sessions/week) comprising exercises typical of their normal pre-season conditioning programme. Squat jumps were performed in two of the three sessions each week during which both groups performed three sets of three concentric squat jumps using a barbell with an absolute load of 40 kg. Participants in group one were given real-time feedback on peak velocity of the squat jump at the completion of each repetition using a linear position transducer and customised software, whilst those in group two did not receive any feedback. Pre and post testing consisted of vertical jump, horizontal jump and 10 m/20 m/30 m timed sprints. The relative magnitude (effect size) of the training effects for all performance tests were found to be small (0.18 to 0.28), except for the 30 m sprint performance which was moderate (0.46). The probabilities that the use of feedback during squat jump training for six weeks was beneficial to increasing performance of sport specific tests was 45% for vertical jump, 65% for 10 m sprints, 49% for 20 m sprints, 83% for horizontal jump, and 99% for 30 m sprints. In addition to improvements in the performance of sport specific tests, suggesting the potential for greater adaptation and larger training effects, the provision of feedback may also be utilised in applications around performance targets and thresholds during training.

Chapter Eight

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and McMaster, T. (2011). Does exercising involving horizontal component movement affect vertical plane adaptation? Submitted to *Journal of Strength and Conditioning Research*.

Advancements in the monitoring of kinematic and kinetic variables during resistance training have resulted in the ability to continuously monitor performance and provide feedback during training. If equipment and software can provide reliable instantaneous feedback related to the variable of interest during training it is thought that this may result in goal-oriented movement tasks that increase the likelihood of transference to on-field performance or at the very least improves the mechanical variable of interest. The purpose of this study was to determine the reliability of performance velocity for jump squats under feedback and non-feedback conditions over three consecutive training sessions. Twenty subjects were randomly allocated to a feedback or non-feedback group and each group performed a total of three “jump squat” training sessions with the velocity of each repetition measured using a linear position transducer. There was less change in mean velocities between Sessions 1-2 and Sessions 2-3 (0.07 and 0.02 m.s⁻¹ vs. 0.13 and -0.04 m.s⁻¹), less random variation (TE = 0.06 and 0.06 m.s⁻¹ vs. 0.10 and 0.07 m.s⁻¹) and greater consistency (ICC = 0.83 and 0.87 vs. 0.53 and 0.74) between sessions for the feedback condition as compared to the non-feedback condition. It was concluded that there is approximately a 50-50 probability that the provision of feedback was beneficial to the performance in the squat jump over multiple sessions. It is suggested that this has the potential for increasing transference to on-field performance or at the very least improving the mechanical variable of interest.

Chapter Nine

Randell, A. D., Cronin, J. B., Keogh, J. W. L., Gill, N. D, and Claxton, J. E. (2011). The effect of five weeks training using horizontal component resistance exercise equated for vertical force production on sport specific speed, strength and power. Submitted to *Journal of Strength and Conditioning Research*.

The purpose of this study was to investigate the effect of training using equated vertical component exercises on sprint times and measures of strength and power. Seventeen professional rugby players were randomly assigned to one of two groups, vertical (n = 9) and horizontal (n = 8). Both groups completed a 5 week training programme comprising exercises typical of their normal pre-season conditioning programme. Subjects performed either a traditional squat movement (vertical) or an angled squat movement (horizontal) with vertical GRFs equated during two of the three weekly resistance sessions. Pre and post testing consisted of 10 m / 20 m / 30 m timed sprints, 1RM squat, vertical jump (VJ) and horizontal jump (HJ). No statistically significant differences were found ($p = 0.11$ to 0.99) for the post training 10 / 20 / 30 m timed sprints, 1RM squat, VJ and HJ measures for either of the groups. The training effects for both groups for all performance tests were found to be small (Effect Size = -0.35 to 0.39), except for the horizontal group 20-30 m sprint time which was large (0.81). The probabilities that there was actually a practical difference between the groups, in terms of the variable of interest (sprint times), whereby five weeks of horizontal component training had superior adaptive potential were 44% for 10 m, 14% for 20 m, and 74% for 30 m, whereas the probabilities vertical training had superior adaptive potential were 24%, 64% and 8% for 30 respectively. It is suggested that the use of horizontal component lower body training results in practical improvements in short distance sprinting performance as compared to traditional vertical based training. This knowledge may allow strength and conditioning practitioners to explore other possible training benefits that this training specificity may have.