CHARACTERISTICS AND DEVELOPMENT OF STRENGTH AND POWER IN RUGBY UNION

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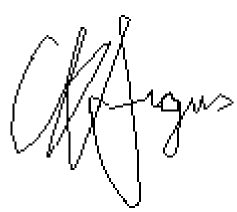
by

Christos Kostas Argus
Primary Supervisor: Dr Nicholas Gill

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.



Christos K. Argus

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Co-Authored Works

The following is a list of publications and presentations that have arisen from work reported in this thesis:

Published Works and Works in Press

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ABSTRACT

Rugby Union is a contact sport where successful performance relies on players possessing a combination of strength, power, speed, aerobic and anaerobic fitness, along with technical skills and tactical knowledge. Resistance training is commonly performed by these players to develop the physical components required for successful performance, in particular strength and power. There is currently limited literature detailing the effects of pre-season and in-season training (and competition) on strength and power in professional Rugby players. Assessing the effects of these different training phases will identify areas of conditioning that may require enhanced programming strategies to ensure performance is optimised.

Study one characterised the difference in strength (bench press, box squat) and power (bench throw, jump squat) across four different levels of competition (professionals, semi-professionals, academy, high school level). Strength and power output were found to discriminate between different levels of competitions, suggesting that younger lower-level players need to improve their strength and power so to prepare for the next level of competition. *Studies two and three* characterised the effects of a pre-season and in-season training phases (consisting of different modes of training being performed concurrently) on strength and power in professional Rugby Union players. Strength was maintained or improved during a concurrent training phase, however small decreases in power occurred. Therefore, it was concluded that methods to improve power need to be developed and assessed. In an attempt to provide potential mechanisms for changes in performance measures, the influence of several covariates were assessed (body composition, salivary hormones testosterone and cortisol, tiredness and soreness). Some small to moderate relationships were observed, however it was concluded that the required change in many of the predictor measure (covariate) to improve a dependent measure (strength or power) was too large to obtain within a single training phase.

Study four assessed the effectiveness of verbal feedback (peak velocity) on acute kinetic performance in a typical resistance training session in professional Rugby players. When

players received feedback following each repetition of a bench throw, peak power and velocity were improved. *Study 5* assessed the load that maximised peak power (Pmax) in the lower body using a spectrum of loads including negative loading. Pmax was obtained using bodyweight loads in 16 of 18 professional players; however statistical analysis revealed discontinuity in the power outputs between bodyweight and all loaded jumps. These findings have implications when attempting to prescribe Pmax intensities for training. *Studies six and seven* assessed the effects of different contrast training methods to improve power throughout an in-season training phase in professional Rugby Union players. Findings from these studies identified different contrast training programs that can improve power and also be easily implemented into a player's existing resistance training program.

In conclusion, this thesis established that power is affected to a greater extent than strength across different training phases involving concurrent training. Furthermore, several methods to improve power throughout an in-season training phase were identified. However, it was regularly noted throughout the thesis that 1) there is no upper limit to performance, and that players should strive for continual improvement in all areas; and 2) although players should continually strive to improve power, training should not focus exclusively on one mode.

PRELUDE

Thesis Organisation

This thesis consists of nine chapters (Figure 1). Chapter one provides a review of the literature and is separated into two main sections: characterisation of strength and power in Rugby Union, and development and assessment of methods to improve strength and power in Rugby Union. Chapter two, three and four are experimental studies which characterise strength and power across different levels of competition, and throughout pre-season and in-season training phases in Rugby Union players. Findings from these initial studies form the basis of the final four experimental studies (chapters five to eight) which developed and assessed methods to improve performance measures identified in the earlier chapters. Finally, chapter nine consists of the primary findings and conclusions, and also discusses practical applications and limitations of the thesis.

Each experimental chapter is presented in paper format with its own introduction, methodology, results and discussion section. Consequently, there is some repetition between the thesis introduction and literature review chapters, and experimental study chapters. Additionally, for the ease of the reader, all references have been placed together at the end of the thesis rather than at the end of each chapter.

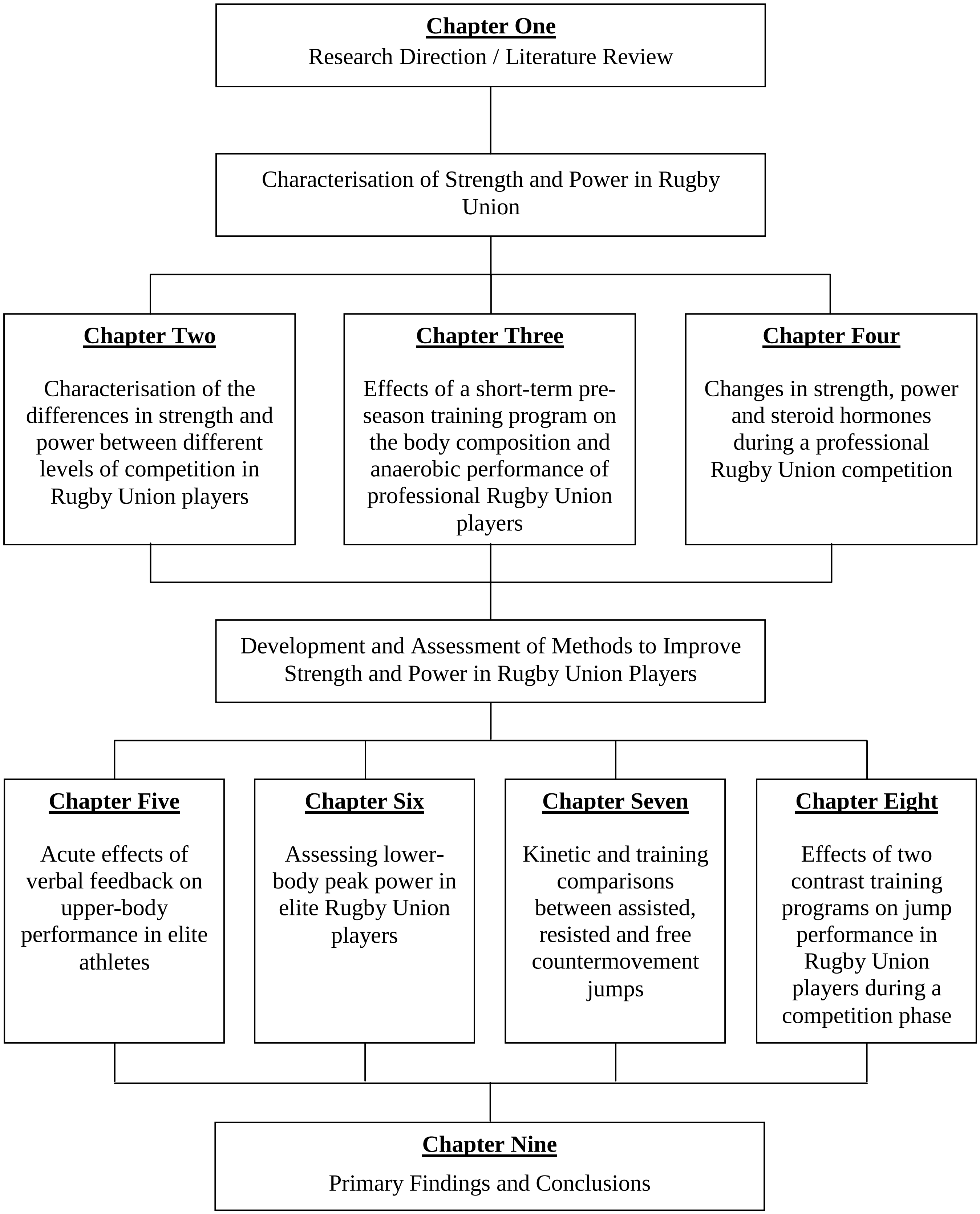

Figure 1. Schematic of the thesis structure.

INTRODUCTION

Possessing high levels of strength and power is critical for successful performance in Rugby Union (159). Bigger, stronger, faster, more powerful athletes are likely to be more effective at the physical components of the game such as dominating the breakdown, winning collisions, or making the gain-line. Stronger more powerful athletes are more likely to be effective in the areas of the game where physical domination of opponents increases the chances of maintaining possession, retrieving (or turning over) the ball, and breaking the defensive line.

Successful Rugby performance, as with many other sports, is multifaceted and involves not only physical but tactical and technical components. As such, the reliability of a test that attempts to incorporate the many aspects of performance is unlikely to be high. Therefore, both coaches and researchers commonly use surrogate measures including gym based strength and power exercises to assess the physical components in isolation. In research examining Rugby Union athletes, a two to three repetition maximum (RM) has typically been selected to assess levels of maximal strength using modifications of the bench press, and squat exercises (50, 59, 100, 120, 121). Researchers have also selected peak or mean power produced during jumping or throwing activities to assess levels of muscular power (50, 59, 100, 101, 120). Although maximum strength and power assessments are not direct measures of sporting ability, they are believed to reflect the physical performance characteristics representative of playing potential (85).

Since the professionalism of Rugby Union in August 1995, Rugby Union athletes have become heavier, and the backs have become taller (169). Additionally in just a four year period between 2004 and 2007, professionals (e.g. provincial and international representatives) had an average increase in strength (estimated 1RM) of 3-5% for upper body and 5-15% for the lower body (185). It has been suggested that the differences observed in size and strength highlights the rate at which the muscularity of Rugby players is increasing (185). These differences may be a result of greater training loads and enhanced nutritional and recovery strategies that has accompanied professionalism (185).

Professionalism has also resulted in players being involved in numerous teams and competitions throughout a calendar year. For example, in New Zealand players may compete in the national provincial championship and the Super Rugby competition; while the very best players may be selected for the national team and compete in several additional competitions (e.g. end of year tour, Tri-Nations, World Cup, etc). Increases in the number of games played, accompanied with the greater physicality of the game due to players being bigger, faster and stronger may potentially lead to shorter playing careers. These factors add to the need for players to be physically prepared from an earlier age. The increased competition and physical demands due to professionalism have resulted in coaches and support staff asking questions such as: What is the best way to physically prepare younger athletes for competition? How do pre-season and in-season training phases affect performance; and, what is the best way to develop athletes throughout such training phases?

To physically prepare younger athletes for competition or progression to a higher level of competition, you must first quantify the current levels of strength and power in each level of competition. Levels of strength and power have been shown to discriminate between levels of completion in a range of different sports (24, 41, 85, 176). However, there is only limited data assessing the differences in strength and power between levels of competition in Rugby Union athletes. Identifying differences in strength and power between different levels of competition will provide conditioning coaches with normative data which can be used to help prepare and transition younger athletes into a higher level of competition. Furthermore, identifying the relationships between strength and power may help to formulate appropriate training methods for athletes from each level of competition.

Currently, the magnitude of performance change that can be made over a pre-season or in-season training phase in professional Rugby Union players is unknown. During these training phases players can train several times a day, and include a variety of training modes which may affect the adaptation to the training stimulus (129). Without appropriate understanding of how different training phases affect measures of performance, conditioning coaches cannot optimally prepare athletes for the rigours of competition. Therefore, assessing the effects of a pre-season and in-season training phase on strength and power in professional Rugby Union players will 1) identify any changes in physical performance; 2) identify the correlates of the potential performance change; and 3) allow for development of more effective strategies to enhance performance. These findings will direct future research so that interventions are designed specifically for the needs of the professional Rugby Union player.

Without a prior understanding of the effects of different training phases on strength and power, identifying and developing methods to enhance these measures of performance is, at best, difficult. Nonetheless, there are several interventions or training methods that have shown to result in acute and chronic improvements in strength and power which could be implemented into a Rugby Union player's current training program. Contrast and complex training are methods where strength and power are trained within the same session. Due to the many aspects of training performed by professional Rugby players (strength, speed, skill, team training, etc), there is only limited time to train each aspect before recovery is compromised. Contrast and complex training methods may reduce the total training time required while still providing sufficient volume and stimulus for adaptation to occur. Contrast and complex training methods have been shown to provide favourable adaptation to strength and power (16, 40, 147). Other potential training strategies which can be programmed as part of contrast or complex training or be a stand-alone training method include augmented feedback and maximal power training. Augmented feedback is a training method where athletes are provided with knowledge of their results either visually or verbally throughout their typical training session in an attempt to improve performance acutely (43, 114). If the acute improvements continue over multiple training sessions and phases it is likely that chronic adaptation will occur. Another possible training method includes training at the load that maximises power output (Pmax). Pmax training has been suggested to provide favourable neural and muscular adaptations and has recently received attention, although it is still relatively unknown if improvements from this type of training are greater than traditional methods (55, 99, 116, 207).

Unfortunately, in an attempt to determine the effectiveness of different training methods, many investigators have recruited untrained, recreationally trained, or club level athletes. For athletes with limited resistance training background, any mode of resistance training is likely to elicit performance benefits due to the novelty of training and their limited training history. Whereas, well trained individuals have less scope for improvement due to their greater training history and current strength and power levels (13). A further limitation of previous literature is that the investigators have instructed the subjects to refrain from any other exercise throughout the duration of the study. Elite contact sport athletes, such as Rugby Union players, perform multiple training sessions within a single training day, each typically using different energy systems. Findings from studies which recruited less trained subjects and/or did not perform additional forms of exercise (concurrent training) may not be transferable to the elite athletic population. To make inferences about the effectiveness of a training method or program, research needs to be performed using the desired population, and should be assessed in conjunction with all other training and stressors that the athlete would normally encounter.

Due to the current deficit in the literature detailing the physical characteristics and physical development of professional Rugby Union athletes, this thesis aims to add to the current body of knowledge by:

1) Characterising strength and power in Rugby Union
    - Assess the difference in strength and power across different level of competition in Rugby Union athletes
    - Identify the relationship of strength and power measures between different level of competition in Rugby Union athletes
    - Characterise the effects of a short-term pre-season training phase on strength and power in Rugby Union athletes

- Characterise the effects of an in-season training phase on strength and power in Rugby Union players
- Determine correlates of change in strength and power throughout a training phase in professional Rugby Union athletes

2) Developing and assessing methods to improve strength and power in professional Rugby Union athletes
    - Assess the effectiveness of augmented feedback throughout a typical resistance session consisting of multiple repetitions and sets
    - Assess the load that maximises peak power in Rugby Union athletes
    - Assess the effects of different contrast or complex training methods, and loading, throughout a concurrent training phase in Rugby Union athletes

CHAPTER ONE

Literature Review

Rugby Union is played in over 100 countries around the world (7) and players require a diverse range of physical attributes including strength, power, speed, agility, endurance, and flexibility, along with technical skill and tactical game knowledge (51). During competition, players complete short bursts of high intensity activities typically lasting from one to fifteen seconds (e.g. sprinting, jumping and tackling), interspersed with longer sub-maximal activities of up to 40 seconds (e.g. jogging, walking and standing) (67, 73). These work to rest ratios place considerable stress on the anaerobic system, while the aerobic system provides energy during sub-maximal periods (73).

Since the professionalism of Rugby Union in 1995, there has been a trend for players to increase body mass and strength (169, 185). Increased strength and power facilitates defensive manoeuvres such as tackling and driving back an opponent, and also increases a player's ability to break tackles when in attack. Additionally, strength and power are highly related to speed and the development of speed, which has been recently shown to be positively correlated with on field performance (185). These factors ultimately increase a team's attacking and defending capabilities; improving the likelihood of success and underpin the theoretical importance of enhancing strength and power in Rugby Union players (24).

Maximal strength refers to the capacity of a muscle to actively develop tension (force), irrespective of the specific conditions under which tension is measured and is required for activities such as scrimmaging or mauling (178). Exercises commonly used to assess strength in Rugby Union players are variations of the bench press and back squat exercise for the upper-and lower-body respectively (50, 59, 100, 101, 120). Muscular power output is defined as the force applied multiplied by velocity of movement (159) and is required for movements requiring high levels of force to be produced rapidly, such as jumping, sprinting or cutting. Researchers have typically selected peak power as the dependent measure to assess levels of muscular power as it has been reported to have the greatest association with athletic performance (72). The exercises commonly performed for assessment of power are weighted and un-weighted countermovement jump, weighted and un-weighted squat jump (static jump), and bench throw (50, 59, 100, 101, 120).

Characteristics of Strength and Power

Differences between Levels of Competition

Levels of strength and power have been shown to clearly distinguish between different levels of athletes within the same sport (12, 14, 15, 24, 41, 85, 86, 118, 157, 176) (Table 1). In American Football, Fry and Kraemer (85) reported that bench press, power clean, sprint and vertical jump performance could differentiate between NCAA Level I, II, and III athletes. Baker (15) reported that elite Rugby League players were stronger and more powerful as indicated by performance in the bench press, jump squat and bench throw than junior high school, senior high school and college aged Rugby League players. Baker (15) went on to conclude that efforts should be made to improve levels of strength and power in players aspiring to achieve elite status. It should be noted that although levels of strength and power can characterise different levels of competition; this does not mean that once a player has obtained such a level that continual improvement is unwarranted. Players should be continually striving to improve, as there is no upper-limit to performance (188).

Table 1. Differences in strength and power measures between athletes of different playing ability within the same sport.

Author	**Sport**	**Exercise**	**Playing level**	**Output (mean ± SD)**
Baker (14)	Rugby League	Bench press (kg)	Professional (n=15)	125 ± 14
			Semi-professional (n=12)	112 ± 15
			College age (n=9)	105 ± 11
		Bench throw (W)	Professional (n=15)	583 ± 72
			Semi-professional (n=12)	565 ± 67
			College age (n=9)	506 ± 64
Baker (12)	Rugby League	Bench press (kg)	Professional (n=22)	135 ± 15
			College age (n=27)	111 ± 15
		Bench throw (W)	Professional (n=22)	610 ± 79
			College age (n=27)	515 ± 78
Baker (14)	Rugby League	Bench press (kg)	Professional (n=19)	140 ± 14
			Semi-professional (n=23)	121 ± 13
			College age (n=17)	109 ± 16
		Bench throw (W)	Professional (n=19)	635 ± 87
			Semi-professional (n=23)	561 ± 57
			College age (n=17)	499 ± 81
Baker (15)	Rugby League	Bench press (kg)	Professional (n=20)	145 ± 15
			College age (n=36)	111 ± 20
			Senior high school (n=15)	98 ± 14
			Junior high school (n=13)	85 ± 10
			Untrained junior high school (n=11)	70 ± 7
		Bench throw (W)	Professional (n=20)	341 ± 24
			College age (n=36)	316 ± 32
			Senior high school (n=15)	283 ± 20
			Junior high school (n=13)	272 ± 19
			Untrained junior high school (n=11)	255 ± 21

		Jump squat (W)	Professional (n=20)	1853 ± 280
			College age (n=36)	1552 ± 203
			Senior high school (n=15)	1394 ± 178
			Junior high school (n=13)	1364 ± 171
			Untrained junior high school (n=11)	1315 ± 135
Baker & Newton (24)	Rugby League	Squat (kg)	Professional (n=20)	175 ± 27
			Semi-professional (n=20)	150 ± 14
		Jump squat (W)	Professional (n=20)	1897 ± 306
			Semi-professional (n=20)	1701 ± 187
Fry & Kraemer (85)	American Football	Bench press (kg)	NCAA division I (n=283)	145 ± 26
			NCAA division II (n=296)	135 ± 26
			NCAA division III (n=197)	129 ± 23
		Back squat (kg)	NCAA division I (n=115)	193 ± 38
			NCAA division II (n=114)	183 ± 35
			NCAA division III (n=68)	177 ± 32
		Power clean (kg)	NCAA division I (n=166)	123 ± 18
			NCAA division II (n=164)	117 ± 17
			NCAA division III (n=109)	113 ± 17
		Vertical jump (cm)	NCAA division I (n=193)	73 ± 9
			NCAA division II (n=181)	69 ± 9
			NCAA division III (n=131)	67 ± 9
Keogh (118)	Australian rules	Bench press (kg)	Under-18 selected (n=29)	64 ± 11
			Under-18 non-selected (n=11)	54 ± 6
		Countermovement jump (cm)	Under-18 selected (n=29)	55 ± 8
			Under-18 non-selected (n=11)	50 ± 5
Mota et al. (157)	Football (soccer)	Isokinetic quadricep strength (N.m)	Under-19 (n=12)	210 ± 47
			Under-17 (n=20)	177 ± 28
			Under-15 (n=39)	155 ± 28
		Isokinetic hamstring strength (N.m)	Under-19 (n=12)	109 ± 25
			Under-17 (n=20)	90 ± 10
			Under-15 (n=39)	78 ± 26

Currently there is paucity of literature examining the differences between strength and power at different levels of competition in Rugby Union players. Understanding the physical differences between different levels of player provides normative data for conditioning coaches, which assists them to set appropriate goals and effectively prepare their players for transition through to the next level of competition. Additionally, by assessing the different performance characteristics, comparisons of correlations between strength and power across the different levels of competition can be made. Although high correlations do not necessarily mean causation, such an analysis approach may highlight whether there is a likely high or low transfer of training between performance measures and help to identify which programming strategies provide the greatest benefits at different levels of competition. Indeed, Baker (14) reported that lower level players relied on maximal strength to increase maximal power and that training should be directed in that regard. In contrast, some players with longer training histories, who can already produce high levels of force, may need to focus more on improving the velocity component of power (14). It was also noted that although training should focus on the strategy that provides the greatest benefit, training should not be directed exclusively on that one mode.

Pre-Season Training

Professional Rugby Union players compete throughout the calendar year and may be involved in up to three separate competitions each year. Consequently there is only a limited time to develop aspects of physical performance required in competition. Short training phases lasting two to twelve weeks prior to the beginning of each competition (pre-season training) normally consist of a high volume, high intensity training regime that incorporates the multi-faceted aspects of physical conditioning including strength, power, speed, aerobic, and anaerobic endurance. Literature examining the effects of a pre-season training phase in the Rugby codes has typically reported three to four resistance training sessions per week, with these sessions having a broad focus (e.g. strength, power and hypertrophy) within the same phase (102, 163, 175). Currently there is limited research investigating the effects of a pre-season training phase in elite Rugby Union players. Tong and Mayes (196) reported that elite international Rugby players significantly improved body composition and grip strength but that small reductions in vertical jump performance were observed during the pre-season. However, this study was performed in 1992 well before the beginning of professionalism. Due to the large changes in training demands and player physical characteristics as a result of professionalism, findings from the study may not necessarily be relevant for players in the modern game.

Improvements in strength during a pre-season training phase in elite Rugby League players have been reported (Table 2). Rogerson and colleagues (175) observed significant improvements in maximal upper-body and lower-body strength in two separate groups (supplement or placebo) performing the same training as measured by bench press and deadlift (27% and 19% respectively) over a five week pre-season training phase. Similarly, in a seven week pre-season with players separated into two resistance training interventions, Harris and colleagues (102) reported significant increases in a concentric only machine squat strength (15% and 11% for the two groups). Additionally, O'Connor and Crowe (163) reported an increase in deadlift strength (approximately 5%) following a six week pre-season phase. Unfortunately, only O'Connor and Crowe (163) reported other training the players completed over the training phase (e.g. aerobic conditioning, skill training). Without consideration for other training performed concurrently within a training phase, drawing conclusions from the data presented is problematic.

Table 2. Studies examining strength and power changes throughout a pre-season in the contact football codes (Rugby Union, Rugby League, American football).

Author	Sport	Duration	Strength Exercise	Power Exercise	Training/Supplement Group	% Change
Harris et al. (102)	Rugby League	7 weeks	Concentric only machine squat		Squat jump training (Pmax; n=9)	11%#
					Squat jump training (80%1RM; n=9)	15%#
				Concentric only machine Jump squat	Squat jump training (Pmax; n=9)	-17%#
					Squat jump training (80%1RM; n=9)	-6%#
O'Connor, & Crowe (163)	Rugby League	6 weeks	Bench press		Control (n=8)	3%*
					HMB + Creatine (n=11)	4%*
					HMB (n=11)	5%*
			Deadlift		Control (n=6)	11%*
					HMB + Creatine (n=6)	11%*
					HMB (n=9)	13%*
				Peak 10 sec cycle power	Control (n=6)	3%*
					HMB + Creatine (n=11)	4%*
					HMB (n=10)	4%*

Rogerson et al. (175)	Rugby League	5 weeks	Bench press	Tribulus terrestris (n=11)	14%*
				Placebo (n=11)	11%*
			Deadlift	Tribulus terrestris (n=11)	21%*
				Placebo (n=11)	17%*

Pmax, load where mechanical power output is maximized. RM, repetition maximum. HMB, β-hydroxy-β-methylbutyrate. #, significance not reported. *, p ≤0.05.

It is unclear whether improvements in power can be made throughout a pre-season training phase. For example, Harris and colleagues (102) reported a decrease in power (-17% and -7%) in two separate training interventions, whereas O'Connor and Crowe (163) reported significant increases in peak power of approximately 3%. Differences in methodology used to assess power may account for much of the discrepancies in findings between these investigations (102, 163). Harris and colleagues (102) selected a concentric only loaded jump squat to assess lower-body power output, whilst O'Connor and Crowe (163) assessed peak power during a ten second maximal cycle ergometer test. Further, the decreases in power observed by Harris and colleagues (102) may have been due to the loading parameters selected. In an attempt to equate training volume between the two training groups, the authors prescribed six sets of 10-12 repetitions of jump squats with only two minutes rest separating each set for one of the training programs. Based on previous research it would seem that 10-12 repetitions of an explosive exercise task would lead to acute fatigue and thus not be the optimal stimulus for power development. Indeed, Baker and Newton (23) reported a significant decline in power output from the sixth to tenth repetition during a set of jump squats or bench throws. While the second training group in the study by Harris and colleagues (102) performed five repetitions each exercise set, which is within the range prescribed by Baker and Newton (23), and a decrease in power was still observed. Therefore, in addition to the sub-optimal repetition range performed; it is likely that other training performed concurrently may have affected power adaptation. However, Harris and colleagues (102) did not detail any other training performed.

It is therefore poorly understood whether strength and power can be improved concurrently throughout a pre-season training phase which incorporates the multiple aspects of conditioning in professional Rugby Union players. More consistency in the methodology of assessing power, along with greater detail of other training performed concurrently, is required to be able gain more insights from the literature.

In-Season Training

Professional Rugby Union players compete in a number of competitions throughout a calendar year and in many instances, it is common for players to compete in 30 to 40 matches within this period. There is limited research on the effects of a competitive season on strength and power in professional Rugby players. In a paper giving resistance training recommendations for an in-season training phase, Baker (11) reported that professional Rugby Union players improved bench press strength by 2% from pre-season levels. However, research on other football codes has produced mixed findings (Table 3).

In Rugby League, Baker (13) examined the ability of professional and college aged players to maintain pre-season levels of strength and power during an in-season of concurrent training. It was concluded that bench press strength in younger college aged players was increased by 3%, and maintained in professional players even though there was a decrease in strength training volume. Additionally, bench throw and jump squat power was maintained in both college age and professional players (13). Similar findings by Gabbett (89) showed that amateur junior Rugby League players were able to maintain the enhancements in vertical jump power developed in the pre-season throughout the competitive season. In contrast, Gabbett (87) found that non-elite senior club level Rugby League players had decreases in vertical jump power during the competitive season when compared to the pre-season (-5%).

Table 3. Studies examining strength and power changes throughout an in-season in the contact football codes (Rugby Union, Rugby League, American football).

Author	Sport	Training Phase Duration	Strength Exercise	Power Exercise	Playing level/Position	% Change
Baker (11)	Rugby Union	Not stated	Bench press		Professional	2%*
Baker (11)	Rugby League	22 weeks	Bench press		Professional	4%*
			Squat		Professional	3%*
Baker (13)	Rugby League	29 weeks	Bench press		Professional (n=14)	-1%
		19 weeks			College age (n=15)	3%*
				Bench throw	Professional (n=14)	0%
					College age (n=15)	2%
				Jump squat	Professional (n=14)	-1%
					College age (n=15)	4%
Gabbett (89)	Rugby League	approximately 22 weeks		Vertical jump	Junior (high school age; n=36)	-1%#
Gabbett (87)	Rugby League	approximately 22 weeks		Vertical jump	Amateur (n=52)	-5%#
Dos Remedios (70)	American football	10 weeks	Bench press		College linemen (n=11)	21%*
					College backs (n=8)	-3%
			Hip-sled (lower-body)		College linemen (n=11)	-4%

					College backs (n=8)	-1%
				Vertical jump	College linemen (n=11)	-4%
					College backs (n=8)	0%
Hoffman and Kang (105)	American football	12 weeks	Bench press Squat		Division III (n=53) Division III (n=53)	-1% 5%*
Schneider (181)	American football	16 week	Bench press		College linemen (n=17) College non-linemen (n=11)	-8%* -8%*
				Vertical jump	College linemen (n=16) College non-linemen (n=12)	-3% -5%*

*, p ≤ 0.05. #, significance not reported.

Differences in findings between investigations are likely due to the differing durations of the in-season phases and also when baseline testing was carried out. A large range of in-season durations spanning from 10 to 29 weeks were observed in the literature reviewed (Table 3). A longer duration in-season will significantly affect the ability to maintain or improve physical performance as players will be exposed to greater competition demands. These increased demands will likely result in greater cumulative fatigue and increased probability of acquiring an injury resulting in some form of reduced or modified training. Indeed, in a recent review on the changes in upper-body strength and power throughout a competitive season in different contact football codes, it was speculated that decreases in performance could be attributed to increased fatigue, increased volume of training, and injury (111).

In attempt to gain better insight into the differences between in-season durations, I have quantified the differences between a longer (>15 weeks) or shorter in-season (<15 weeks). A simple analysis was performed which compared the average performance change reported from each study (Table 3). Due to the limited data detailing change in power, only changes in strength were included. As expected, a longer in-season resulted in only maintenance of strength (0% ± 6%); while strength throughout a shorter in-season improved (3% ± 5%). Although findings are by no means conclusive, they do highlight differences in adaptation (and adaptations that can be expected) between in-seasons of differing durations.

Differences in the assessment period when baseline testing was carried out will also likely contribute to the mixed findings observed. Hoffman and Kang (105) assessed baseline measures at the beginning of the pre-season, whilst Baker (13) assessed baseline at the completion of the pre-season. For accurate assessment of changes in a training phase, baseline testing needs to be assessed as close to the start of the phase as possible; otherwise additional training performed during this time will affect results.

To date only one study has described the changes in upper-body strength in professional Rugby Union players over an in-season (11). However, the training modes, training volumes, and duration of the in-season were not reported. Further research assessing both upper-and lower-body strength and power is required to get a better understanding of the impact of training and competition on these measures. Characterising changes across an in-season will help to identify which areas of conditioning are most affected and subsequently guide future research in developing and assessing appropriate training methods.

Factors Affecting Adaptation and Correlates of Change

There are many programming strategies for developing strength and power; however, many factors can influence adaptation. The chronological age and/or training age of an individual may influence response to a training program. Younger or inexperienced athletes are likely to respond more favourably to most resistance training strategies due to the neuromuscular improvements observed in the early phases of resistance training, such as increased recruitment, firing rate and synchronization of motor units, along with decreased co-contraction of antagonist muscles (30). Additionally, natural maturation responses of younger individuals (especially males) including but not limited to increases in testosterone and muscle mass also play a role in the improvements observed. For older more experienced athletes who have already obtained elite status, there appears to be a plateau in some physical performance parameters. Baker and Newton (22) reported a 6% increase in bench press strength and 5% increase in bench throw power in professional Rugby League players over a four year training period. It was suggested that a diminishing degree of positive adaptation occurs with increased training experience and reduces the scope for strength and power development.

As eluded to in an earlier section; differences in the length of in-season training phase may also influence adaptation to training. Similar to Rugby League, the extensive length of the Rugby Union in-season may also restrict the time available for strength and power training to be conducted. During the in-season, players perform multiple aspects of training including physical conditioning (i.e. strength, power, speed, aerobic and anaerobic fitness) and skill based tasks. A typical in-season week may consist of one to three resistance sessions, one or two high intensity running sessions, three or four skill / tactical team sessions, one to four recovery sessions, and one competitive match. The concurrent training of these aspects of fitness and skill is likely to attenuate training adaptation (129). Furthermore, longer in-season durations also result in shorter off-season or pre-season training phases where strength and power can be prioritized and developed. Therefore, elite players who compete in longer (or multiple) in-seasons may need greater training specificity and enhanced training stimulus for improvements in certain performance measures that have been reported to plateau.

While a range of relationships between strength and power measures have been reported (12, 15, 17, 156, 189), there is limited understanding of how other factors contribute to adaptation. For example, Moss and colleagues (156) reported a correlation of $r = 0.93$ between maximum strength and power at the completion of a nine week resistance training phase; however the relationship between the *change* in maximal strength and power was only $r = 0.13$. Thus, factors other than increased strength played the primary role in improving peak power and vice versa. Improved understanding of factors affecting change in performance is required and may enhance strategies for exercise programming and player management. This understanding may be improved with appropriate methodology and statistical analysis.

Many researchers have monitored performance over a training phase and then have simply presented findings as group means ± standard deviation. Statistical analysis which includes linear modelling of the relationship between the change scores and a covariate can be used to help estimate what effect other variables are having on the change. Briefly, potential covariates that may affect performance adaptation include, but are not limited to, physiological measures such as changes in body composition and steroid hormones, along with psychological measures such as perceptions of fatigue and soreness.

Improving a player's body composition will likely have an impact on performance. Indeed Ahtiainen and colleagues (2) reported that relative changes in isometric force were significantly related to changes in cross sectional area ($r = 0.69$). These findings suggest that the shared variance (r^2 as a %) between the outcome variables indicates that 48% of the change in performance can be explained by the change in cross sectional area. Similarly, steroid hormones may also affect adaptation. Testosterone and cortisol are steroid hormones with the testosterone to cortisol ratio reflecting the balance between anabolic and catabolic environments (81, 82). Higher levels of testosterone have been shown to be significantly and positively related to explosive performance tasks (44), while diminished levels of testosterone and increased levels of cortisol have been linked to overtraining and reduced performance (124, 126, 200). Psychological and psycho-physiological measures such as levels of fatigue or perceived soreness may also be used to help explain change in performance. Increased levels of fatigue and soreness may indicate overtraining which may in turn lead to attenuated adaptation. Indeed Jurimae and colleagues (115) speculated that the significant reductions in power output (3.6%) following an increase in training volume may have been due to an increased state of fatigue. However, more research is required to quantify these effects. Understanding of the effects of covariates, and their causal relationships with change in measures of performance may provide opportunity for enhanced exercise programming and player management strategies.

Summary of Characteristics

Currently there is a limited body of knowledge that assesses physical characteristics and their correlates, along with the effects of different training phases (e.g. pre-season and in-season) on these characteristics, in Rugby Union players. Future research needs to assess and identify these effects. From the existing literature it appears that levels of strength and power are extremely important for successful performance in the Rugby codes. Players should strive to attain greater level of strength and power in attempt to improve playing potential. Based on previous findings in Rugby League players, levels of strength may be maintained or improved throughout the in-season. However, in-season maximal power outputs may decrease, or at best be maintained. If research in Rugby Union players identifies similar trends, then training methods that can improve levels of strength, and maybe more importantly power, need to be identified and developed.

Development and Assessment of Methods to Improve Strength and Power in Rugby Union Players

Resistance training appears to be the method of choice for most athletes and practitioners to develop high levels of strength and power. A plethora of scientific research has investigated different resistance training modalities along with different programming strategies (1, 5, 16, 40, 48, 49). One such method that appears to allow both strength and power gains in well trained athletes, and equally importantly fits in with time constraints, is combination training (contrast and complex training). It has regularly been reported that a combination of strength and power training results in an equal or greater improvement in a single performance measure, or improvement in a greater number of performance measures, than strength or power training in isolation (98, 143). Combined training is a time effective training method that allows both strength and power to be trained within the same session. It has been postulated that combined training provides broader neuromuscular adaptations resulting in greater transfer to a wider variety of performance variables (98). The remainder of this review examines combined training methods (contrast and complex training) and also identifies several training methods that can be included in, or may influence the program design of, the different combination training methods.

Contrast Training

Contrast training is an example of strength and power training which aims to stress both ends of the force-velocity curve within the same session (204). Contrast training consists of performing an exercise with moderate to heavy resistance alternated with a biomechanically similar exercise with low resistance and performed with high velocity (213). For example, heavy back squat followed by body weight countermovement jumps (CMJ). This sequence is then repeated for a prescribed number of sets.

Acute increases in power have been observed using the contrast training method (Table 4), with this effect widely attributed to post-activation potentiation (PAP). PAP refers to the phenomenon by which acute muscle force output is enhanced as a result of a muscle's recent contractile history (173). The improvement in performance has been suggested to be primarily attributed to phosphorylation of specific class myosin light chains (MLC) (83, 154, 172). Briefly, when a muscle is activated (in a previous contraction), there is an increase in Ca^{2+} concentration [Ca^{2+}], resulting in the activation of myosin light chain kinase (MLCK). Phosphyorylation of MLC by MLCK causes increased sensitivity of the actin-myosin interaction to Ca^{2+}, thereby enhancing the force–producing state for the myosin cross-bridges (83, 154, 172). In essence, potentiation increases the force-Ca^{2+} relationship, allowing for a greater amount of force to be produced for a given [Ca^{2+}] (191).

Young and colleagues (213) reported a significant increase (2.8%) in CMJ height when a 5RM back squat was performed prior to the jump. Kilduff and colleagues (120) reported that bench throw and CMJ power could be significantly improved following a 3RM bench press and back squat exercise, respectively (5.3% increase bench throw, 8.0% increase CMJ). Similarly, Matthews and colleagues (147) reported an increase in a basketball chest pass velocity (4%) following a bench press set of five repetitions at 85%1RM; in contrast, no improvements were noted in pass velocity following a set of five repetitions of 2.3kg medicine ball pass. Matthews and colleagues (147) therefore suggested that the degree of augmentation following resistance exercise depends on the magnitude of the resistance used.

While the magnitude of the resistance is important, and it can be acknowledged that there is a minimum intensity required for augmentation to occur; it has been reported that the intent to move a load quickly rather than the actual load itself is more important for performance enhancement. Hansen and colleagues (97) reported no improvement in a CMJ following a set of squats at either 80% or 40% 1RM squat when the subjects were made to perform the squat intervention with a timed lifting cadence using a metronome and preventing the subjects from performing the exercise rapidly. In contrast, Smilios and colleagues (186) reported that when loaded jump squat with only 30% of back squat 1RM was performed as “explosively as possible”, an increase in CMJ height occurred. Additionally, when these same participants performed a back squat exercise (not explosively) with the 30% 1RM load, no improvements were observed (186). As such, it appears that not only load, but the intent to perform the movement as explosively as possible are important factors for PAP to occur.

Table 4. Studies examining the acute effects of contrast loading.

Author	**Subjects**	**Methods**	**Measures**	**Result Summary**
Baker (14)	6 elite males	3 x 6 reps 40kg CMJ performed with (contrast) or without (control) a 3x 60kg CMJ between the 40kg sets	Mean power	↑ 5% contrast* N/C control
Baker (16)	16 elite males	2 x 5 reps 50kg bench throw performed with (contrast) or without (control) a 6 x 65%1RM bench press between the 50kg sets	Single-highest mean power output from each set	↑ 5% contrast* N/C control
Comyns, Harrison, Hennessy & Jensen (49)	12 elite males	3 drop jumps before and after 3 back squats at 65%, 80%, and 93% of 1RM	Flight time, ground contact time, and leg stiffness	↓ 3-5% in flight time following all loads* ↓ 9% ground contact time for 93%1RM* ↑ 11% leg stiffness for 93%1RM*
Duthie, Young & Aitken (75)	11 trained females	3 sets of 3RM half squat followed by 3 sets of SJ (complex); 3 sets of SJ followed by 3 sets of 3RM half squat (traditional), or 3 sets of 3RM half squat alternated with 3 sets of SJ (contrast)	Mean peak power, jump height and peak force for each set of squat jump	N/C between 3 set average for each group. Peak power set 1 of complex lower (3%) than set 1 of control* Set 2 and 3 force lower (1%) than set 1 force in contrast method

French, Kraemer & Cooke (84)	14 trained males	3 x 3 sec or 3 x 5 sec isometric knee extensions or control (no prior loading) prior to drop jumps, CMJ, and knee extension	Drop jump height and force, CMJ height, knee extension torque	↑ 5% drop jump height (3 x 3 sec)* ↑ 5% Drop jump force (3 x 3 sec)* ↑ 6% knee extension torque (3 x 3 sec)* N/C in CMJ height. N/C in any measures following 3 x 5 sec or control
Kilduff et al. (120)	23 elite males	7 CMJ prior to and repeated at 15 sec, 4, 8, 12, 16, and 20 min following a 3RM squat.	Peak power output	↓ 3% following 15s rest* ↑ 8% following 12 min rest*
Kilduff et al. (120)	23 elite males	7 bench throws at 40%1RM bench press prior to and repeated at 15 sec, 4, 8, 12, 16, and 20 min following a 3RM bench press.	Peak power output	↓ 5% following 15s rest* ↑ 5% following 12 min rest*
Mangus et al. (144)	10 trained males	3 CMJ prior to and following 1 x 90%1RM half squat or quarter squat	Jump height	N/C following either condition
Matthews, O'Conchuir & Comfort (147)	12 trained males	Basketball pass prior to and following 5 x 85%1RM bench press, 5 x 2.3kg medicine ball push pass, or rest (control).	Basketball pass velocity	↑ 4% following 5 x 85%1RM bench press* N/C following medicine ball pass or control
Robbins & Docherty	16 trained males	7 sec MVIC in a squat position prior to 5 CMJ and repeated three	CMJ height, force, rate of force development,	↓ in CMJ power in the control group over the three sets (magnitude not reported)*

(174)		times, or control, where the MVIC was omitted and only the CMJ were performed	power, acceleration and velocity	N/C in any other measured variables in either condition
Smilios, Pilianidis, Sotiropoulos , Antonakis & Tokmakdis (186)	10 trained males	2 CMJ or SJ performed prior to, and 1 min following each set (3 sets in total) of 5 reps of half squat and jump squat performed with 30% or 60% 1RM	CMJ and SJ height	↑ 4% (set 1) and 4% (set 2) CMJ height following jump squat 30%* ↑ 3% (set 2) and 4% (set 3) CMJ following jump squat 60%* ↑ 4% (set 1) and 3% (set 2) CMJ following half squat 60%* ↑ 5% (set 1) SJ following half squat 60%*
Walker (204)	10 recreationall y trained males	4 sets of 80%1RM back squat alternated with 4 sets of BWSJ prior to and following 11 weeks of training	Squat Jump height	↑ 5% in jump height following set two compared with pre prior to training* ↑ 4% jump height in set 4 compared to pre prior to training ↓ (unspecified %) in jump height following training *
Weber, Brown, Coburm & Zinder (205)	12 trained males	7 SJ prior to and following 5 back squats at 85%1RM or 5 SJ.	Mean and peak jump height, and mean and peak group reaction force	↑ 6% and 5% mean and peak jump height following 85% back squat* ↑ 5% peak ground reaction force following 85% back squat* ↓ 3 % and 4% in mean in peak jump

				height following JS* ↓ 1% peak ground reaction force following SJ
Young, Jenner & Griffiths (213)	10 recreationally trained males	2 sets of 19kg CMJ prior to, and following 1 set of 5RM half squat	19kg CMJ height	N/C between first two sets of 19kg CMJ ↑ 3% 19kg CMJ height following 5RM half squat*

CMJ, countermovement jump. SJ, static jump. N/C, no change. RM, repetition maximum. MVIC, maximal voluntary isometric contraction. *, $p < 0.05$.

There is only limited literature investigating the chronic response to contrast training (Table 5). Following 11 weeks of contrast training, Walker and colleagues (204) reported significant improvements in leg extensor isometric force (8%), squat jump height (12%), along with significant increases in rate of force development in all time points (0-500ms) during isometric leg extension. Additionally, in a recent investigation Dodd and Alvar (69) reported that following four weeks of either contrast training, or strength and plyometric training in isolation, contrast training tended to result in the greatest improvements in 20, 40 and 60 yard sprint performance, standing broad jump, and an agility test; however all improvements were not significantly different from the other training modalities ($p \leq 0.11$).

While findings by Walker and colleagues (204) and Dodd and Alvar (69) reported performance improvement from contrast training, neither investigation incorporated other modes of training concurrently. In contrast, Maio Alves and colleagues (141) examined the effects of a six week contrast training program during an in-season phase. Programs consisted of either one session per week (C1), two sessions per week (C2) or a control group of young elite soccer players. Both contrast training programs significantly improved 5m and 15m sprint times and resulted in significant increases in squat jump performance. Interestingly, no increases were made in CMJ performance for either training group. These findings by Maio Alves and colleagues (141) suggest that contrast training is effective for improving selected measures of performance during a concurrent phase. However, large differences exists between soccer and the Rugby codes including size of the players, running intensities and distance covered, match durations, and significant differences in body contact. Whether improvements in strength and power measures can be observed after contrast training in athletes in team sports involving frequent high intensity physical collisions, and associated muscle damage and soreness following training and competition, remains unclear.

Table 5. Studies examining the chronic effects of contrast loading.

Author	Subjects	Methods	Measures	Result Summary
Burger (40)	78 division IA American football players	7 weeks of complex or contrast training	Bench press, squat, power clean, medicine ball throw, vertical jump, broad jump	↑ 8% & 5% bench press in complex & contrast* ↑ 15% & 14% squat in complex & contrast* ↑ 7% & 5% power clean in complex & contrast* ↑ 5% & 8% medicine ball throw in complex & contrast* N/C vertical jump in complex ↑ 4% vertical jump in contrast* ↑ 4% & 5% broad jump in complex & contrast*
Dodd (69)	45 trained males	4 weeks of contrast training, heavy resistance training, or plyometric training, performed in randomized order	20, 40 & 60 yard sprint, vertical jump, horizontal jump, agility test.	↑ 2% (small ES) in BJ and agility, for contrast training ↑ 1% (small ES) agility for heavy resistance training ↑ 1% (small ES) 40 yard sprint time for plyometric training.

Maio Alves (141)	23 elite males	Six weeks lower-body contrast training in 3 groups. Gp1, 1x week; Gp 2, 2x week; Gp 3 control	CMJ and SJ height, 5m & 15m speed, agility test	↑ 13% & 10% in SJ in Gp1 & GP2* N/C in CMJ in any group ↓ 9% & 6% in 5m & 15m sprint time Gp1* ↓ 7% & 3% in 5m & 15m sprint time Gp2* N/C in agility test in any group
Walker (204)	10 recreationally trained males	11 weeks of contrast training	Squat jump, squat strength	↑ 12% squat jump height* ↑ 10% squat strength*

ES, effect size. Gp, group. CMJ, countermovement jump. SJ, static jump. N/C, no change. *, $p < 0.05$.

Complex Training

Similar to contrast training, complex training aims to train both high force and high velocity exercises within a single session. The difference being that all the sets of each exercise are performed consecutively before moving on to the next exercise. That is, all sets of heavy resistance training are completed before moving on to plyometric (or ballistic) training. Increases in strength and power measures following acute and short-term complex training programs have been reported (Table 6). Kilduff and colleagues (121) investigated the optimal recovery time for PAP to occur following three sets of three repetitions of back squat (87% 1RM squat). The authors reported that eight minutes after the squat exercise, peak rate of force development, power output and jump height assessed during a CMJ were 32%, 5% and 5% greater than pre squat jump values (baseline). Values at eight minutes were also were significantly greater than at all other time points examined (baseline, 15 sec, 4, 12, 16, 20, & 24 min). However at fifteen seconds post squat, values were significantly lower than baseline. Duthie and colleagues (75) investigated the effects of three sets of squats performed prior to (complex method), following (traditional), or alternating (contrast method) with three sets of jump squat. When the first set of jump squats were compared, mean power was significantly lower in the complex method compared to a traditional method. There was no significant difference in the three set jump squat mean power between each of the methods; however it was noted that there was a trend for complex training to have the lowest power output. The authors suggested that power output may be lower in the complex method due to residual fatigue as a result of the prior three sets of three heavy squats performed.

Table 6. Studies examining the acute and chronic effects of complex training.

Author	Subjects	Methods	Measures	Results
		Acute Adaptations		
Bevan, Owen, Cunningham, Kingsley & Kilduff (31)	26 professional Rugby players	3 sets of 3 bench press (87%1RM), followed by a bench throw at 15 sec & 4, 8, 12, 16, 20, & 24 min post bench press	Throw height, peak power	↓ 10% throw height at 15 sec* ↑ 5% throw height at 8 min* N/C in throw height at other time points ↓ 7% (estimated) peak power at 15 sec* ↑ 5% (estimated) peak power at 8 min* N/C in peak power at other time points
Duthie, Young & Aitken (75)	11 trained females	3 sets of 3RM half squat followed by 3 sets of SJ (complex); 3 sets of SJ followed by 3 sets of 3RM half squat (traditional), or c3 sets of 3RM half squat alternated with 3 sets of SJ (contrast)	Mean peak power, jump height and peak force for each set of squat jump	N/C between 3 set average for each group. Peak power set 1 of complex lower (2.7%) than set 1 of control* Set 2 and 3 force lower (0.9%) than set 1 force in contrast method
Kilduff, Owen, Bevan, Bennett, Kingsley & Cunningham (121)	20 professional Rugby players	CMJ prior too, and 15 sec, 4, 8, 12, 16, 20, & 24 min following 3x3reps 87%1RM squat	Peak rate of force development, peak power, jump height	↓ in all measures at 15 sec* ↑ 32%, 5% & 5% in peak rate of force development peak power and jump height at 8 min* N/C in measures at 4, 12,16,20 & 24 min compared to baseline

Chronic Adaptation

Adams, O'Shea, O'Shea & Climstein (1)	48 males	6 weeks of complex, plyometric or strength training or control	Vertical jump	No pre-values reported ↑ 10.7 cm complex training* ↑ 3.8 cm plyometric training* ↑ 3.3 cm strength training* N/C control
Burger (40)	78 division IA American football players	7 weeks of complex or contrast training	Bench press, squat, power clean, medicine ball throw, vertical jump, broad jump	↑ 8% & 5% bench press in complex & contrast* ↑ 15% & 14% squat in complex & contrast* ↑ 7% & 5% power clean in complex & contrast* ↑ 5% & 8% medicine ball throw in complex & contrast* N/C vertical jump in complex ↑ 4% vertical jump in contrast* ↑ 4% & 5% broad jump in complex & contrast*
Ingle, Sleap & Tolfrey (112)	54 pubertal boys	12 weeks complex training or control	Vertical jump, 40 m sprint, basketball chest pass, squat, bench press	↑ 4% vertical jump in complex training* ↑ 3% 40m sprint in complex training* ↑ 3% basketball chest pass complex training* ↑ 49% squat strength in complex training* ↑ 35% bench press strength in complex training* N/C in measures in the control group
Mihalik, Libby, Battaglini & McMurray (155)	11 male & 20 female volleyball players	4 weeks of complex or compound training (strength day, plyometric day)	Vertical jump height, mean power	↑ 5% & 9% in vertical jump height in complex and compound training* ↑ 5% & 8% in mean power in complex and compound training*

Rahimi, Arshadi, Behpur, Boroujerdi & Rahimi (170)	48 male college students	6 weeks of complex, plyometric, or resistance training or control	Angular velocity during 15 sec and 60 sec cycle ergometer	↑ 66% & 50% angular velocity in 15 & 60 sec cycle in complex training* ↑ 38% & 24% angular velocity in 15 & 60 sec cycle in plyometric training* ↑ 16% & 25% angular velocity in 15 & 60 sec cycle in resistance training* ↓ 3% angular velocity in 15 sec cycle in control ↑ 3% angular velocity in 60 sec cycle in control
Santos & Janeira (177)	25 adolescent male basketball players	10 weeks complex training or control	SJ, CMJ, medicine ball throw	↑ 13% SJ in complex* ↑ 11% CMJ in complex* ↑ 20% medicine ball throw in complex* ↓ 9% SJ in control ↓ 8% CMJ in control* ↑ 5% medicine ball throw in control*
Toumi, Best, Martin & Poumarat (197)	22 male handball players	6 weeks complex or strength training or control	Isometric force, CMJ height, SJ height	↑ 16% & 16% in isometric force in complex and strength training* ↑ 13% CMJ height in complex training* ↑ 11% & 9% in SJ height in complex and strength training* N/C in control

CMJ, countermovement jump. SJ, static jump. N/C, no change. *, $p < 0.05$.

Increases in strength and power have been reported following short-term complex training programs (Table 6). Adams and colleagues (1) reported significantly greater increases in CMJ height following six weeks of complex training (10.7 cm) when compared to plyometric training only (3.8 cm), strength training only (3.3 cm) or a control group (no change reported). In a similar study, Tuomi and colleagues (197) reported that increases in maximal isometric strength were observed after three weeks of complex training while no increases were observed in a resistance training only group. It was not until six weeks that increases in isometric strength were observed in the resistance only group, and were similar to the magnitude of improvement in the complex training group. Tuomi and colleagues (197) suggested that initial performance adaptations during complex training had a greater effect on muscular strength rather than maximal explosive strength. In addition, only the complex training groups showed increases in CMJ height following six weeks of training and these increases were associated with increased EMG activity (197).

In an investigation comparing the training effects of complex and contrast training methods, Burger (40) recruited 78 male division I American football (Gridiron) players. Each player performed a battery of test prior to, and following, a seven week training phase. It was reported that both training programs significantly increased bench press, squat and power clean strength along with medicine ball throws, broad jump and an agility test. Two measures were identified that indicated a significant difference between the groups. Improvements in the bench press were significantly greater in the complex training group, whilst the increase in CMJ height approached significance ($p = 0.057$) in favour of the contrast training program (40). Interestingly, although not statistically different, improvements in the strength tests tended to be greater in the complex training group, while contrast training resulted in greater improvements in the field based power tests. The author went on to speculate that these findings may have reached significance had the length of the training phase been greater.

While combination training has been shown to be more effective than strength or power training in isolation, it appears that contrast and complex training programs may produce different performance adaptations. Contrast training may lead to enhanced adaption of explosive power movements, but at the detriment of maximising force output, whereas complex training may result in a more favourable force output response, but a reduced improvement in power output. These findings may have implications for the appropriate program design choice for athletic goals. Indeed, if changes in strength and power throughout a Rugby Union training phase are similar to findings in Rugby League players (i.e. reductions or maintenance in power) then contrast training may be a more beneficial training method. Furthermore, it is relatively unknown whether improvements in strength and power can still be achieved with combined training methods within a training phase where other training modes are performed concurrently, such as in the Rugby codes. Future research needs to assess performance changes under these conditions.

Several other training methods can be used to supplement complex and contrast training methods. The following sections discuss methods that can be included in, or may influence the program design of, different combination training methods.

Loading Parameters

The external load selected for ballistic or plyometric training can influence performance adaptation and needs to be considered carefully when programming. Many researchers have attempted to determine the load that maximizes peak power output (Pmax) (14, 18, 19, 53, 55, 99, 102, 116). This optimal loading strategy has been suggested to enhance performance in explosive exercise by providing favourable neural and muscular adaptations (14, 18, 19, 53, 55, 99, 102, 116, 158, 159, 207). Pmax is typically expressed at loads ranging from 30% to 70% of maximum strength (18, 19, 102). However more recently some studies have reported that 0% maximum lower-body strength (i.e. bodyweight) is the load that maximises power output (53, 55). The large variation in Pmax loads reported within the literature appears to be due to the differences in exercise performed, methods used to assess and calculate power, and the participants recruited (64).

Although there has been a large amount of literature examining Pmax loads, there is minimal literature investigating the chronic effects of Pmax training (102, 207). Wilson and colleagues (207) compared the training effects of ten weeks of either traditional weight, plyometric (depth jump), Pmax training, or a control group. Following the training phase all training groups increased CMJ performance, however, the Pmax group improved significantly more than the traditional weight training group. Additionally, peak knee extension torque significantly increased only in the Pmax group. There were no significant improvements in any of the training groups in 30m sprint, however the authors did note that sprint time improvement in the Pmax group was approaching significance ($p = 0.08$). Finally, although isometric strength was only reported pre to mid training (5 weeks), it was reported that only the traditional weight training group significantly increased strength over this five week period. The authors concluded that several training strategies can be used to increase dynamic performance in at least some performance measures, however, performance gains in a greater number of measures was optimized by training at the Pmax load (207). One major limitation of the study by Wilson and colleagues (207) was that the Pmax training load was not calculated for each individual. Instead the authors selected a standard load of 30% 1RM as recommended by previous work. Unfortunately, this assumes that each individual's Pmax load is the same, when in reality there are likely to be individual differences. Indeed, Baker (14) reported that stronger players attain maximal power with a significantly lower percent of 1RM strength than less strong players. As such, to effectively assess the training effects of Pmax loading, each individual's Pmax load should be determined prior to the training program.

Harris and colleagues (102) investigated the effects of seven weeks of either Pmax jump squat (where each subject trained at their individual Pmax load) or heavy (80% 1RM) jump squat training in elite Rugby League players. It was reported that training at Pmax or heavy jump squat loads was equally effective, resulting in similar improvements in 10m and 30m sprint performance, and 1RM strength. However, decreases in jump squat peak power, velocity and force were observed in both groups following the training phase. These decreases may be due to the study being conducted as part of a pre-season training phase where other training was being performed concurrently. As such, the other training modes performed may have affected adaptation. Based on the scarce literature available, the effectiveness of using Pmax loading as a training intervention is unclear and requires further investigation. However, from the current literature it does appear that Pmax training is at least equally effective as other training methods for improving measures of strength and power performance.

Psychological Strategies

Psychological strategies can be separated into either intrinsic or extrinsic methods. Intrinsic methods include self-talk, imagery, and ‘psyching up’ along with task-intrinsic feedback. Task-intrinsic feedback refers to sensory feedback that is naturally available while performing a task and includes auditory, proprioceptive, visual and tactile feedback (139). Extrinsic methods refer to receiving information pertaining to performance of a skill which is additional to sensory feedback and comes from a source external to the person performing the skill or task (139). These include augmented feedback and non-specific encouragement such as a crowd cheering.

Augmented feedback can be separated into two categories, knowledge of performance (KP) and knowledge of results (KR). Knowledge of performance is information about the movement characteristics that led to the performance outcome. For example following a golf swing, a coach may instruct an athlete the he or she lifted their head and took their eye of the ball during the movement. Knowledge of results is information about the outcome of performing the skill, e.g. “you jumped 3 cm further in that attempt”. While KR and KP may be effective for skill acquisition; for elite athletes who have already acquired appropriate techniques, KR may be more effective for enhancing performance compared to KP. Indeed, Magill and Wood (140) suggested that once an individual has acquired a skill, receiving quantitative feedback (such as in KR) may lead to enhanced performance as it enables the individual to refine characteristics of the skill.

Nonetheless, both intrinsic and extrinsic methods have been shown to enhance performance acutely (Table 7). McNair and colleagues (151) investigated the effect of verbal encouragement during isometric elbow contractions. Specifically, the researcher spoke the words “come on, you can do it” and repeated this phrase until the conclusion of the test. The authors reported a 5% increase in peak torque when verbal encouragement was received compared to a non-encouragement condition. During a skill based task, Hatzigeogiadis and colleagues (103) reported that a greater distance could be achieved in an overhead water-polo ball throw when participants used self-talk consisting of saying the words “I can” prior to the throw. Assessing the effects of augmented feedback, Kim and Kramer (123) assessed the use of KR (visual feedback) on leg extensor torque and reported a 14-19% improvement when KR was provided compared to a no-KR condition on three separate occasions. Moreover, when the test was completed four weeks later without KR, the initial KR group produced significantly greater torque than the no-KR group. These findings may suggest that the augmented feedback helped develop the ability to use the task-intrinsic feedback in the initial sessions, so when augmented feedback was removed later on, the task-intrinsic feedback was better utilised. Indeed, the authors suggested that receiving KR produced more effective learning, leading to greater retention of the knee extension skill (123).

Table 7. Studies examining the acute effects and chronic adaptations of psychological strategies to enhance performance

Author	Subjects	Method	Measures	Result Summary
		Acute Adaptation		
Campenella, Mattacola & Kimura (43)	15 males & 15 females; untrained	Visual FB, Verbal encouragement, combined (visual FB and verbal encouragement) or control during isokinetic extension and flexion	Peak quadricep and hamstring torque	↑ 7% quadricep & 5% hamstring torque with visual FB* ↑ 8% hamstring torque with combined* N/C verbal encouragement
Figoni & Morris (79)	20 untrained males	Visual FB or no-FB during Isokinetic leg extension and flexion set at $15°.s^{-1}$ and $300°.s^{-1}$	Mean peak torque	↑ 12%* extension torque with FB compared to no-FB at $15°.s^{-1}$ ↑ 13%* flexion torque with FB compared to no-FB at $15°.s^{-1}$ N/C at $300°.s^{-1}$
Hatzigeorgiadis, Theodorakis & Zourbanos (103)	30 male & 30 females; untrained	Instructional self-talk, motivational self-talk, or control prior to throwing water polo ball for distance	Throwing distance	↑ 7% with motivational self-talk* ↑ 2% with instructional self-talk N/C control
Hopper (110)	16 elite females	Visual FB or control during an explosive leg press task	Watts	↑ 2% with visual FB*
Jung & Hallbeck (114)	21 untrained males	Verbal FB, visual FB, or no-FB during a handgrip strength task	Static handgrip strength, peak handgrip strength	↑ 10% static grip strength, and 6% peak hand grip strength with verbal FB* ↑ 8% static grip strength, and 5% peak hand grip strength with visual FB*

Kellis & Baltzopoulos (117)	25 untrained males	Visual FB or no-FB provided during isokinetic leg extension and flexion at $30°.s^{-1}$ and $150°.s^{-1}$	Extension and flexion torque	↑ 7% extension torque and 9% flexion torque at $30°.s^{-1}$ * ↑ 6% extension torque and 9% flexion torque at $150°.s^{-1}$ *
Kim & Kramer (123)	10 males & 10 females; untrained	Visual FB or no-FB provided during isokinetic knee extension and flexion on 3 occasions	Extension and flexion torque	↑ 14-19% in torque in the FB group compared to no-FB*
McNair (151)	10 males & 10 females; untrained	Verbal encouragement or no-encouragement during isometric elbow flexion	Isometric force	↑ 5% force increased with verbal encouragement*
Tod et al. (195)	12 males & 12 females; recreationally trained	Motivational self-talk, instructional self-talk, neutral ST (control), and no instruction on vertical jump performance	Vertical jump height, impulse, angular rotation about the knee	↑ 3% & 3% jump height in instructional motivational self-talk compared to control* ↑ 2% & 1% jump height in instructional motivational self-talk compared to no instruction* ↑ 4% & 3% impulse in instructional motivational self-talk compared to control* ↑ 1% & 3% angular rotation in instructional motivational self-talk compared to control* ↑ 3% & 5% angular rotation in instructional motivational self-talk compared to no instruction#

Tod et al. (194)	12 males & 8 females; recreationally trained	Psyching up, neutral distraction or attention placebo during an isokinetic bench press	Peak force	↑ 12% following psyching up compared to neutral distraction* ↑ 8% following psyching up compared to attention placebo*
van Herp & Shah (199)	27 untrained males	Combined visual FB and verbal encouragement or no-FB peak torque during isokinetic knee extensors at $60°.s^{-1}$ or $450°.s^{-1}$	Total work	↑ 15% & 17% with FB at $60°.s^{-1}$ & $450°.s^{-1}$ compared to no-FB*
Wulf et al. (212)	1 male & 9 females; untrained	External focus, internal focus or control during a vertical jump	Vertical jump height	↑ (not stated) in jump height with external focus compared to internal focus or control*
Wulf et al. (210)	3 males & 5 females; untrained	Vertical jump with external or internal focus	Vertical jump height, EMG	↑ 10% in jump height with external focus compared to internal focus* ↓ EMG with external focus
Wulf & Dufek (209)	4 males & 6 females; untrained	Vertical jump with external or internal focus	Vertical jump height, impulse, joint movements	↑ 5% jump height with external focus compared to internal focus* ↑ 13% impulse with external focus compared to internal focus* Significant ↑ in ankle, knee & hip joint movements*

Chronic Adaptations

Brown, Daniel & Gorman (39)	24 untrained men	30 sec isometric squat once a day, 5 days a week for 5 weeks, performed with (Gp1) or without visual FB (Gp2), or a no training (control)	Isometric squat force	↑ 99% force in Gp1*^ ↑ 29% force Gp2* N/C in control
Randell et al. (171)	13 elite males	6 weeks of 40 kg jump squats performed with (Feedback) or without (control) instantaneous feedback	Vertical jump height, horizontal jump distance, sprint time (10m, 20m, 30m)	↑ 5% vertical jump, 3% horizontal jump in feedback group (small ES) ↑ 3% vertical jump in control group (small ES) ↓ 1% in 10m, 20m, & 30m sprint time in feedback (small to moderate ES) N/C in horizontal jump or sprint times in control

Gp, group. CMJ, countermovement jump. SJ, static jump. N/C, no change. ES, effect size. *, $p < 0.05$. [#] significance not reported. ^ significantly greater ($p < 0.05$) than Gp2.

There are many psychological strategies that can be performed in attempt to elicit performance improvement. As such, the mechanisms that may lead to performance improvements are likely to differ between strategies. Within the current literature, clear mechanisms in which psychological strategies may affect performance are somewhat lacking. It is thought that performance improvements may be due to a combination of enhanced neuromuscular activation, intent, focus of attention, levels of arousal, and improved skill performance and learning (114, 123, 138, 151, 194, 211). Indeed, in some individuals, the ability to perform a maximal voluntary contraction (MVC) of muscle fibres is inhibited by supraspinal drive acting on the motor units (151, 190). This inhibition is highlighted through the use of the interpolated twitch technique (ITT) in which an electrical stimulus is imposed on a contracted muscle to evoke increases in strength greater than what can be produced voluntarily (190). Thus, it may be speculated that psychological strategies may enhance motor unit activation through increased supraspinal drive from the increased intent and concentration on the task and that this leads to greater strength and power performance.

Currently, devices which enable KR to be provided are being more widely used within many athletic populations. This increased use is likely due to favourable reports from recent research along with an increase in commercially available portable and user friendly devices, such as linear transducers, jump mats, and timing lights which allow instantaneous feedback to be provided. However, although acute improvements in strength and power have been reported as a result of psychological strategies; the protocols used to assess these improvements have consisted of a single repetition or set. Resistance training performed by athletes typically involves multiple sets and repetitions performed consecutively in attempt to elicit favourable adaptation (167). Differences in volumes of work performed, (e.g. single repetitions vs. multiple sets and repetitions) may affect the response to such psychological strategies. Therefore, the acute effect of these strategies on a resistance training session commonly performed by athletes still requires investigation.

There is limited literature investigating the chronic training effect of psychological strategies (Table 7). In 1984, Brown and colleagues (39) reported that five weeks of a 30 second isometric squat protocol performed five days per week with visual feedback (maximal force production) lead to greater increases in strength than observed in a second group performing the same training intervention without feedback. More recently, Randall and colleagues (171) provided instantaneous feedback (peak velocity) following each repetition of a 40 kg squat jump over a six week training phase in elite Rugby players. It was reported that players who received feedback improved vertical jump, horizontal jump and sprint performance more so that the control group (small to moderate effect sizes).

Based on the current literature it appears that psychological strategies such as receiving verbal feedback, may be beneficial for improving performance in selected strength and power measures. Additionally, the use of such strategies may be easily implemented as part of an athlete's existing program or as part of a combined training method program.

Conclusions and Recommendations

Professional Rugby Union players perform a variety of different training modes concurrently within a training phase which is likely to affect the training response or adaptation to a training program (129). However, much of the current strength and conditioning literature does not address the issue of how concurrent training performed by Rugby Union players may influence strength and power adaptation. Therefore, investigations need to firstly characterise the effect of different training phases on strength and power in Rugby Union players; and secondly, examine different training methods within a typical concurrent training phase to validate and consolidate previous findings.

CHAPTER TWO

Study One: Characterisation of the Differences in Strength and Power between Different Levels of Competition in Rugby Union Players

Introduction

The ability to produce high levels of muscular power is critical for successful performance in most contact sports such as American Football and Rugby League (13, 98). Furthermore, it has been suggested that possessing high levels of maximal strength is the most important factor influencing power production (17, 180, 189). Although maximum strength and power tests are not measures of sporting ability, they are believed to represent performance characteristics of playing potential in many sports (3).

Since the introduction of professionalism in Rugby Union in 1995, Rugby players have become bigger and stronger (169, 185). Indeed, in just a short period from 2004-2007 players had an average increase in strength of 3-5% for upper body and 5-15% for the lower body (185). Additionally, the southern hemisphere super Rugby competition, which consisted of ten teams in 1995, has now expanded to a 15 team competition. As a consequence players are competing in a greater number of games throughout the calendar year. Due to the greater number of teams and increased competition demands, a greater pool of players is therefore required. Recently, it has been suggested that younger players are being selected to fill the void (185).

Levels of strength and power have been used to effectively discriminate between different levels of competition in a range of sports including, American Football (85), Rugby League (12, 15, 24), Volleyball (176), Kayaking (86), and Ice Hockey (41). Fry and Kraemer (85) have evaluated physical performance characteristics of 19 American Football collegiate programs (981 participants) across three different levels of competition (NCAA division I, II, and III). It was reported that bench press performance was significantly different between all levels of play; identifying that division I athletes were 6% and 11% stronger than division II and III athletes, respectively. Additionally, vertical jump performance was significantly greater in division I than in division II and III athletes. Interestingly, back squat performance did not clearly differentiate between levels of competition. These findings are supported by Baker (12, 14, 15), who reported significant differences in bench press strength, and upper and lower body power between different levels of competition in Rugby League athletes in Australia. However, in contrast to findings by Fry and Kraemer (85), Baker and Newton (24) also reported significantly greater lower body strength in higher level athletes.

Correlations between the change in strength and the change in power have been reported to reduce as players become more elite. For example, Baker (13) reported that the relationship between the change in relationship between strength and power was $r = 0.73$ and $r = 0.39$ in state level and national level Rugby League players, respectively. These findings suggest that as players become more highly trained, improving one aspect of performance may not transfer to improvements in the other performance measure. Determining the relationships between strength and power between different levels of competition may provide insight into what training methods may be more effective for different level of players. Indeed, if relationships between strength and power are weak in professional players, then more specific power-orientated training methods may be of greater benefit. If the opposite is true, and there is a large transfer of training (large correlations), traditional strength training methods may be equally beneficial for developing power.

There is currently limited literature reporting differences in physical performance between separate levels of competition in Rugby Union players. If indeed younger players are being selected as a result of greater competition requirements, a better understanding of strength and power across different levels of competition in Rugby Union is required. These findings will provide normative data for coaches and conditioners who are responsible for developing younger players. Normative data may provide clearer direction when allocating training time to focus on individual needs, allowing them to effectively prepare players for transition through to the next level of performance. Additionally, a better understanding of the relationship between strength and power may provide a guideline as to which training methods may be more beneficial for improving performance on an individual basis. Therefore, the aim of this investigation was to characterise differences and determine the relationship between strength and power in players across different levels of competition in Rugby Union.

Methods

Experimental Approach to the Problem.

In order to characterise strength and power across different levels of play in Rugby Union players, participants from four distinct levels of competition (professional, semi-professional, academy, and high school 1st XV) volunteered to participate in this investigation. All players were tested on two separate occasions to determine individual strength and power measures. On the first occasion players were tested for upper- and lower-body strength (bench press and box squat, respectively) and on the second occasion players were tested for upper- and lower-body power (bench throw and jump squat, respectively). Players had been performing these exercises in their regular resistance training sessions. Verbal encouragement was given throughout all strength and power assessments. All players completed testing during their in-season phase of competition.

Subjects

A total of 112 Rugby Union players including 43 professionals competing in an international and provincial competition full time; 19 semi-professionals competing in the provincial competition (and who have not played in the professional level) for six months of the year; 32 academy level players competing in either age group provincial level or B-level provincial competition; and 18 high school (secondary school) level players competing in a regional high school competition were involved. Subject characteristics are presented in Table 8. Players were informed of the experimental risks and signed an informed consent document prior to the investigation. This investigation was approved by an Institutional Review Board for the use of human subjects. Due to injury from training or competition prior to assessment eight professional and ten academy players did not take part in any of the lower body testing. Additionally, due to their limited training history no high school players performed the jump squat.

Table 8. Characteristics of Rugby Union players from four distinct playing levels during the in-season training phase.

	Age (years)	Height (cm)	Body weight (kg)	Training age* (years)
Professional (n=43)	24.4 ± 2.7	184.7 ± 6.2	103.4 ± 11.2	5.6 ± 2.3
Semi-professional (n=19)	20.9 ± 2.9	187.2 ± 7.6	100.7 ± 11.5	2.9 ±1.9
Academy (n=32)	19.6 ± 1.8	186.9 ± 6.5	95.6 ± 11.0	1.5 ± 1.1
High school (n=19)	16.6 ± 0.8	180.9 ± 8.4	86.5 ± 13.7	0.7 ± 0.5

* Training age refers to the time spent within a supervised and monitored program.

Procedures

Bench Press and Box Squat

Maximal strength was assessed using the bench press and box squat exercises using methods previously described (10). Briefly, players were required to perform three sets (50, 70, 90%) of sub-maximal (four-six repetitions) bench press or box squat followed by one maximal set (100%) of one-four repetitions. For the bench press players used a self-selected hand position, and were required to lower the bar to approximately 90° angle at the elbows and then pressed the bar in a vertical movement so that the arms were fully extended. During the box squat, players used a self-selected foot position and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each player to allow the top of the thighs to be parallel to the floor while in the seated position. A three minute rest period separated all sets. Each maximal set was used to predict each player's one repetition maximum (RM) bench press (r = 0.993) and box squat (r = 0.969) using the following equation (132, 136):

$$1RM \quad = \quad (100*weight)/(101.3-(2.67123*reps))$$

Bench Throw

Upper-body peak power was assessed using a bench throw exercise performed in a Smith Machine. Players warmed up with two sets of four repetitions of bench press at 50% of their 1RM. Players then completed two sets of four repetitions of bench throw at 50% and

60% of 1RM (10, 18). Players used a self-selected hand position and lowered the bar to a self-selected depth. Players were then required to propel (throw) the bar vertically as explosively as possible. A three minute rest period separated all sets.

Jump Squat

Lower-body peak power was assessed using a countermovement jump squat exercise performed in a Smith Machine. Players warmed up with two sets of four repetitions of 90° squat at 55% of their 1RM. Players then completed two sets of four repetitions of jump squat at 55% and 60% of 1RM (10, 19). Players used a self-selected foot position and lowered the bar to a self-selected depth. Players were then required to jump as explosively as possible. A three minute rest period separated all sets.

Power Data Collection

A GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) was used to collect peak power for each repetition of bench throw and jump squat using the methods described elsewhere (71). Briefly, GymAware® consists of a spring-powered retractable cord that passes around a pulley which is mechanically coupled to an optical encoder. The retractable cord is then attached to the barbell and velocity and distance are calculated from the spinning movement of the pulley upon movement of the barbell. The encoder gives one pulse approximately every three millimetres of load displacement, with each displacement value time stamped with a one-millisecond resolution. The mass of the bar (as entered into a personal digital assistant), the entire displacement (mm) of the barbell, and time (ms) for the movement are used to calculate peak values for power (71).

Statistical Analyses

All data were log-transformed to reduce non-uniformity of error, with effects derived by back transformation as percent changes (108). Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-subject standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, 1.2, and >2.0 for small, moderate, large and very large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial (187). To make inferences about the true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects (25).

To help explain any differences in performance, all performance data were also normalized to body mass using allometric scaling with a derived power exponent (59, 60). The equation for normalizing performance to body weight was: *normalised performance* = Y/X^b, where Y is the performance, X is the body mass, and b is the power exponent. The derived power exponent was determined by plotting performance and body mass on a log-log scale. The slope of the linear regression line was then used as the derived power exponent. Allometric scaling is generally superior to ratio scaling (performance/body mass) as ratio scaling penalises heavier athletes.

Interclass correlation (r) and coefficient of variation (%) for all measures have previously been assessed in our laboratory on professional Rugby players were 0.900 and 5.0% (bench throw), 0.904 and 4.8% (jump squat), 0.915 and 4.3% (bench press), and 0.915 and 4.6% (box squat), respectively. Additionally, interclass correlation and coefficient of variation were also assessed on the high school level players and were 0.860 and 6.3% (bench throw), 0.950 and 2.2% (bench press), and 0.790 and 7.0% (box squat), respectively. Validity of the GymAware® optical encoder has been previously reported elsewhere (71).

Results

Magnitudes of the difference between the characteristics of the players are presented in Table 9. With the exception of height, magnitudes ranged from small to very large in favour of the players in competing at a higher level of competition. Raw data (mean ± SD) for each level of competition is presented in Table 10. Correlations between strength and power are presented in Table 11.

Table 9. Magnitudes of the difference in player characteristics between Rugby Union players from four distinct competition levels during the in-season training phase.

		Professional	Semi-professional	Academy
Semi-professional	Age	Moderate	-	-
Academy		Very large	Large	-
High School		Very large	Very large	Very large
Semi-professional	Height	(negative)Small	-	-
Academy		(negative) Small	Trivial	-
High School		Trivial	Moderate	Small
Semi-professional	Weight	Small	-	-
Academy		Moderate	Small	-
High School		Large	Moderate	Moderate
Semi-professional	Training age	Moderate	-	-
Academy		Very large	Very large	-
High School		Very large	Very large	Moderate

Table 10. Maximal strength and power (mean ± SD) between Rugby Union players from four distinct competition levels during the in-season.

	Professional	Semi-professional	Academy	High School
Bench Press (kg)	141 ± 21	134 ± 13	115 ± 16	85 ± 13
Bench Throw (W)	1140 ± 220	880 ± 90	800 ± 110	560 ± 140
Box Squat (kg)	184 ± 32	182 ± 28	151 ± 30	100 ± 19
Jump Squat (W)	5240 ± 670	4880 ± 660	4430 ± 950	N/A

Table 11. Correlations of upper and lower body strength and power in Rugby Union players from four distinct competition levels during the in-season.

	Professional	Semi-Professional	Academy	High School
Bench-Bench Throw	0.40	0.58	0.53	0.92
Box Squat-Jump Squat	-0.13	0.30	0.13	N/A

The derived power exponents calculated for scaling to body weight were 1.073 ±0.193 (±90% confidence limits), 1.379 ±0.272, 1.089 ±0.302, and 0.910 ± 0.242 for bench press, bench throw, box squat and jump squat, respectively. The percent difference in absolute and allometrically scaled relative data between levels of competition is presented in Table 12.

Table 12. Percent difference (mean ± 90% confidence limits) in absolute and allometrically scaled relative strength (bench press, box squat) and power output (bench throw, jump squat) from four separate levels of competition in Rugby Union players.

		Professional		Semi-Professional		Academy	
		Absolute (%)	Relative (%)	Absolute (%)	Relative (%)	Absolute (%)	Relative (%)
Semi-professional	Bench Press	4.5 ±6.1 Moderate	0.7 ±7.8 Unclear	-	-	-	-
Academy	Bench Press	18.9 ±5.9 Large	11.5 ±4.9 Moderate	14.7 ±6.5 Large	10.9 ±7.7 Moderate	-	-
High School	Bench Press	39.4 ±7.4 Very large	26.1 ±6.3 Very large	36.6 ±7.9 Very large	26.6 ±8.6 Very large	25.7 ±7.8 Large	16.5 ±6.2 Large
Semi-professional	Bench Throw	21.2 ±6.9 Large	17.2 ±8.9 Moderate	-	-	-	-
Academy	Bench Throw	29.0 ±6.5 Very large	21.1 ±6.4 Large	9.9 ±6.5 Moderate	4.8 ±7.9 Small	-	-
High School	Bench Throw	51.3 ±11.7 Very large	37.3 ±9.9 Very large	38.3 ±11.7 Very large	24.3 ±10.8 Large	31.5 ±11.5 Large	20.5 ±8.9 Large
Semi-professional	Box Squat	0.8 ±8.3 Unclear-trivial	-2.8 ±8.8 Unclear-trivial	-	-	-	-
Academy	Box Squat	18.3 ±9.2 Moderate	11.6 ±9.3 Moderate	17.7 ±10.3 Moderate	14.0 ±10.3 Moderate	-	-
High School	Box Squat	46.0 ±10.4 Very large	31.7 ±12.4 Large	45.6 ±11.3 Large	33.5 ±13.2 Large	33.9 ±12.0 Large	22.7 ±13.5 Large
Semi-professional	Jump Squat	7.0 ±6.7 Small	4.3 ±5.8 Small	-	-	-	-
Academy	Jump Squat	16.6 ±9.0 Moderate	10.9 ±7.2 Moderate	10.3 ±9.9 Small	6.9 ±7.9 Small	-	-
High School	Jump Squat	N/A	N/A	N/A	N/A	N/A	N/A

Discussion

The aim of this investigation was to characterise differences in strength and power in players across different levels of competition in Rugby Union. As expected, greater absolute strength and power outputs were observed in players that participated in a higher level of Rugby Union competition. The only measure that did not discriminate between levels of competition was box squat strength between professional and semi-professional players. When performance was normalized for weight, the magnitudes of the difference were reduced for all measures and both bench press and box squat strength could not discriminate between professional and semi-professional levels of competition.

Differences in strength and power between the players in different levels of competition are likely due to maturation and body mass. As the level of competition increased, the chronological age and training age of the players also became larger (moderate to very large effect sizes). Maturation and training age plays a large role in the ability to produce high levels of force and power. Older players, or players with greater training ages will likely have developed more efficient movement patterns in the strength and power tasks assessed, have enhanced ability to activate musculature (e.g. increased synchronisation of motor units, decreased antagonist co-activation), and reduced inhibitory feedback from force regulators (e.g. Golgi tendon organs) allowing for greater production of force and power (24, 30, 93, 161).

Findings from the current study imply that by the time players are competing at a higher level there is less scope for improvement. Indeed, the greatest improvement in strength and power from one level of competition to the next was in the period from high school into an academy system. Based on the findings, by the time players are training in an academy system and have a training age of only 1.5 years, approximately 81% of strength and 71% of power has already been developed. Therefore, the majority of physical development appears to be attained throughout the first 1-2 years of training within a structured environment. This observation is particularly important as it highlights the importance of having appropriate development pathways set in place. If players are indeed being selected from a younger age, then attention needs to be given throughout this level of development to ensure the maximal gains are achieved.

Higher level players had a greater body mass than their lower level counterparts. Although body composition was not assessed, it could be assumed that the heavier higher level players had a greater muscle mass than that of the lower level players (88, 91). Increased muscle mass is an important determinate of muscle strength. Indeed, Stone and colleagues (189) suggested that possessing greater levels of maximal strength may affect peak power output in that "(a) A given weight would represent a smaller percentage of maximal strength for a stronger person; thus, this weight would be easier to accelerate. (b) A person with greater maximum strength may have larger or greater percentage of type II muscle fibres" (189). As such, assuming skill level is equal; a larger player with greater muscle mass or a player with a greater type II muscle fibre percentage may be more effective in some aspects of Rugby where physical domination of an opponent or maximal speed and acceleration are critical for successful performance e.g. tackling or breaking through the defensive line.

Normalising performance to body mass reduced the magnitude of the difference between the levels of competition. These finding are in agreement with the contention that body mass contributes to performance during functional performance tests (59, 60). When performance was normalised for body mass, semi-professionals had no difference in squat strength than the professionals. However, professional players still possessed greater power output than the semi-professionals. These findings suggest that while body mass and strength are important in producing power, there are other significant factors that contribute to power production. This is further highlighted by the negative correlation between lower-body strength and power in the professionals.

As players become more elite, increases in strength may not reflect increases in power output (12). Consequently, conditioning coaches may place more emphasis on other training methods more likely to enhance power once an 'adequate' strength base has been obtained (12). For example, professional athletes may complete a greater volume of modified Olympic lifts, intensified plyometrics, and advanced lifting programs such as complex and contrast training. As Rugby players have only a limited training time available, a change in emphasis would result in less training volume dedicated to improving strength, and likely result in strength maintenance rather than improvement. This change in training emphasis may help explain why the professionals, although not stronger, had a greater power output than the semi-professional players.

Similar to findings by Fry and Kremer (85), lower body strength values in the current investigation were not substantially different between the top two levels of competition. Fry and Kremer (85) speculated that methodological issues (scores obtained by different researchers, discrepancies in squat depth, use of knee wraps) may have been a reason for the similar scores of each competition group. However, in the current investigation all testing sessions were conducted by the same researcher to ensure standardized lifting technique was performed by all players. As such, lifting technique or use of lifting aids can be ruled out. It may be possible that the lack of difference in lower body strength is due to differences in training mode and volume. Professionals typically perform a lower amount of resistance training volume throughout the year compared to semi-professionals due to longer in-season training phases. The greater length of the in-season phase in the professional players substantially decreases the time available for off-season training phases where strength and power can be developed (8, 10). Additionally, due to longer in-seasons, professionals typically perform a greater volume of non-resistance training (e.g. team training) throughout the year. This greater non-resistance training volume may attenuate improvements in strength and power due to the inability of the body to simultaneously adapt to contrasting training stress (137). Furthermore, with longer in-season phases and greater competition demands, there is an increased likelihood of injury occurring or need for increased player management; which from an applied perspective, typically results in an unloading of lower-body training intensity and volume. All these factors are likely to limit physical development, especially in the lower body.

Upper body correlations between strength and power ranged from 0.40 in the professionals to 0.92 in the high school players. The shared variance of these measures (r^2 as a %)

suggest that up to 85% of bench throw power in high school players can be explained by bench press strength, while only 16% of bench throw power in professionals can be explain by bench performance. These findings show that to improve power in professionals, other training methods distinct from increasing maximal strength, need to be identified and implemented. In contrast, to improve bench throw power in lower level players, maximal strength training may have the greatest transfer to power.

Lower body correlations between strength and power were lower than that previously reported in other Rugby codes (17). The professional players in the current investigation actually had a negative correlation between box squat and jump squat. The difference in movement patterns of the lower body exercises selected may have influenced the relationships observed. Indeed, the box squat exercise is designed to minimise any contribution of the stretch shortening cycle; whereas, the jump squat is performed with a countermovement which utilises the stretch shortening cycle.

Findings from the current study suggest that both strength and power can discriminate between the higher two (professional and semi-professional) and lower two (academy and high school) levels of competition. Notwithstanding this, the ability to produce high levels of power, rather than strength, may be a better determinate of playing ability between professional and semi-professional players. Therefore, Rugby players wanting to enhance playing potential should focus on methods to improve power. However, it must be noted that our findings do not suggest that once a certain threshold of strength has been reached that it is no longer important to keep developing it. Our findings simply show that as players become more elite it becomes more difficult to improve some aspects of performance (which is likely due to increased competition demands) and that other mechanisms for improving power, rather than simply increasing in strength, are required.

Practical Applications

As strength and power output can discriminate between different levels of competitions, younger players should strive to attain greater levels of strength and power in an attempt to reach, or to be physically prepared for, progressing to the next level of competition. These findings also suggest that appropriate pathways that nurture physical development, such as academies or development squads, are a critical component within a professional structure to ensure player succession. Nonetheless, practitioners must be cautioned to not attempt to accelerate these physical attributes too quickly in the young untrained players and each individual should be viewed and approached differently based on individual training history, playing position, injury history and physical maturity.

CHAPTER THREE

Study Two: Effects of a Short-Term Pre-Season Training Program on the Body Composition and Anaerobic Performance of Professional Rugby Union Players

Introduction

Elite Rugby Union players compete in matches throughout a calendar year. As a consequence, it is common for the player to have a limited time to prepare for the physical aspects of the game between each separate competition e.g. international test matches, Super Rugby and provincial representation. Short training phases prior to the beginning of each separate competition (pre-season) provide conditioning coaches and players with short opportunities to significantly enhance aspects of physical conditioning. In most instances this time period ranges from two to six weeks before the players are required to compete on a weekly basis again. Once competition commences, the volume of conditioning training is reduced while the volume of specific Rugby training sessions (e.g. tactical and skill sessions) is increased. Improvements in specific areas of physical conditioning during these competitive phases will be limited by the brevity of these pre-season training blocks (163). It is therefore imperative that the programming during the pre-season phase is as effective as possible.

For elite Rugby Union players, pre-season training normally consists of a high volume, high intensity training regime that incorporates the multi-faceted aspects of physical conditioning. The goals of the pre-season training phase are to increase aerobic and anaerobic fitness, speed, strength and power, and improve body composition (increase lean mass, decrease fat mass). To achieve these goals, players typically train multiple aspects of performance concurrently, which has been reported to compromise physical adaptation (129). To date there is limited literature examining the effects of a pre-season training phase in professional Rugby Union players, and therefore the magnitude of improvement that can be expected during short phases of high volume, high intensity training is unknown. Currently programming for a pre-season training phase for elite Rugby Union players is based primarily on personal experience and/or anecdotal evidence (including non-specific literature, e.g. novice or strength trained athletes). Knowledge from investigating such short term training phases will provide strength and conditioning practitioners with data regarding magnitude of change and the rate of change in specific performance measures, potentially enhancing programming strategies for players across a complete calendar year.

Very little literature has examined the magnitude of improvement achievable over a pre-season in elite players in similar football codes. In elite Rugby League players, significant increases in strength (bench press ~14%, deadlift ~21%) have been reported in pre-season training phases of up to six weeks (163, 175). Contrasting findings have been reported in power development during a pre-season in elite Rugby League players. O'Connor and Crowe (163) reported significant increases in peak power (3%) during a 10s cycle ergometer test over the six week training phase. In contrast, Harris and colleagues (102) reported a significant decrease in peak power (~17%) as assessed by machine jump squats following a seven week pre-season. Unfortunately, Harris and colleagues (102) did not detail any additional training that players were performing during the training phase, making comparisons between the investigations difficult. It may be likely that increased levels fatigue caused by high volume and intensity training throughout the seven week phase may have led to the observed reductions in power (115). Limited findings have also been reported in changes in body composition over a pre-season. O'Connor and Crowe (163) reported a significant decrease in sum of eight skinfolds (approximately 6%), while Rogerson and colleagues (175) reported significant increases in fat free mass over similar length pre-seasons in elite Rugby League players. Although there are similarities between Rugby Union and Rugby League, there are also many differences including duration of work periods, type of work (dynamic or static), work : rest ratios, differences in the time spent at maximal and sub-maximal intensities, and distances covered (m) throughout the game (67, 73, 74, 90, 152). Due to such differences, applying research findings from one Rugby code to the other code may not always lead to the appropriate training recommendations.

By monitoring and assessing changes in anthropometric and performance measures over a pre-season training phase, conditioning coaches may be better able to determine the quality and effectiveness of training. A detailed analysis of the effects of a short term training phase on the players' body composition, strength and power may provide value by improving our understanding of the magnitude of the potential adaptation in such measures. Therefore the aim of this investigation was to determine the effects of a four week pre-season on strength, power, body composition and fatigue in elite Rugby players.

Methods

Experimental Approach to the Problem

Following a six week reduced volume maintenance phase (off-season), players began an intense four week training phase (pre-season) with the goal to increase strength, power, and muscle mass, while decreasing fat mass and improving aerobic and anaerobic fitness. During the first day of the training phase an anthropometric profile of the players was compiled. Players were then tested for upper-body and lower-body strength (bench press and box squat). On the second day players were tested for upper-body and lower-body power (bench throw and jump squat). Players were reassessed on these same measures on the second to last day (Thursday; strength assessment) and last day of training (Friday; body composition and power assessment) in week four. Additionally players completed the recovery-stress-questionnaire (RESTQ) on the first and last day of the training phase to determine changes in self-reported fatigue. Due to time constraints and additional commitments of the professional player, seven players did not complete the RESTQ.

Subjects

Thirty three elite Rugby Union players from a Super Rugby professional team volunteered to take part in this study (mean ± SD; age, 24.8 ± 2.4 years; height, 186.2 ± 6.1 cm; mass, 102.3 ± 10.3 kg). Each player had undergone at least two years of intensive and regular resistance training exercise, and must have been competing in a prior national or international competition to be included in this study. Each player was informed of the risks and benefits of the study and signed consent forms. This study was approved by the Auckland University of Technology Ethics Committee.

Procedures

Body Composition

International Society for the Advancement of Kinanthropometry (ISAK) protocols were used to determine the anthropometric profile of the Rugby players (162). Measurement included body mass, stretch stature, eight skinfolds (triceps, subscapular, biceps, iliac crest, supra iliac, abdominal, thigh, calf), and three limb/body girths (flexed upper-arm, chest, mid-thigh). Fat mass was estimated using the prediction equation by Withers and colleagues (208). Fat-free mass was calculated by subtracting fat mass from body mass. Girth measurements reported were adjusted for skinfold thickness and were calculated by assuming the body segment to be a cylinder and multiplying the skinfold thickness (in cm) by π and subtracting this value from the measured girth (134). The technical error of measurement (TEM) for each skinfold site and girth measurement was: triceps, 3.4%; subscapular, 3.5%, biceps, 3.1%, iliac crest, 2.1%, supraspinale, 3.3%, abdominal 1.8%, front thigh, 1.9%, medial calf, 2.5%, arm girth (flexed and tensed), 0.3%, chest girth, 0.7%, and mid-thigh girth, 0.6%. All TEM's were below upper limits recommended (166).

Bench Press and Box Squat

Strength was assessed using the bench press and box squat exercises using methods previously outlined (10). Briefly, each player was required to perform three sub-maximal sets (two-six repetitions; 50%, 70%, 90% of perceived maximum strength) prior to one maximal set (100% effort) of two-four repetitions. Each set was separated by a two minute rest period. For the bench press players used a self-selected hand grip and lowered the bar to a 90° angle at the elbow. During the box squat players used a self-selected foot position and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each player to allow the top of the thighs to be parallel to the floor while in the seated position. Each maximal set was used to predict the player's one repetition maximum (1RM). The coefficient of variation (CV %) for bench press and box squat was assessed in ten professional Rugby players assessed one week apart and were 4.3% and 4.6%, respectively. The following equation with a reported correlation of 0.993 for bench press and 0.969 for box squat was used to predict each player's 1RM (132, 136):

$$1RM = (100 \times weight)/(101.3-(2.67123 \times reps))$$

Bench Throw

Upper-body power was assessed using a bench throw exercise performed in a Smith machine (CV=5.0%). The warm-up consisted of two sets of four repetitions bench press at 50% of 1RM bench press. Players then completed one set of four repetitions of bench throws at 50% and 60% 1RM bench press (10) as maximum muscular power in the bench press throw appears to be produced at these loads in elite strength trained Rugby League players (18). Players used a self-selected hand position and depth throughout the movement. Players were required to press the bar as explosively as possible trying to propel the bar for maximum height. Three minutes rest was allowed between each set.

Jump Squat

Lower-body power was assessed using a jump squat exercise performed in a Smith machine (CV=4.8%). The warm-up consisted of two sets of four repetitions squat (i.e. lowering the bar to a 90° knee angle) using a load of 55% of 1RM box squat. Players then completed one set of four repetitions jump squat at 55% and 60% 1RM box squat (10) as maximum muscular power in the jump squat appears to be produced at these loads in elite strength trained Rugby League players (19). Players used a self-selected foot position and lowered the bar to a self-selected depth throughout the movement. Players were required to jump as explosively as possible aiming for maximum height. Three minutes rest was allowed between each set.

Power produced during each bench throw and jump squat repetition was quantified with a GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) (71). Validity of the GymAware® optical encoder has been previously reported elsewhere (71). System mass (weight of the bar plus bodyweight) was used for the calculation of power in the jump squat only (72).

Fatigue Assessment

Players completed the recovery-stress questionnaire (RESTQ) on the first and last day of the training phase so that (subjective) levels of fatigue could be assessed (113). Briefly, the RESTQ consists of 77 items and allows analysis of 19 scales such as general stress, emotional stress, and fatigue. Players answered all 77 items, however for the purpose of this investigation only responses relating to fatigue were analysed as it has been suggested that levels of fatigue may have an effect on physiological adaptation (102).

Training

Players performed the training phase (pre-season) over a period of four weeks. Training was performed on three days (Wednesday-Friday) in week one; four days (Monday-Thursday) in week two; and five days (Monday-Friday) for weeks three and four.

Training consisted of resistance training sessions (45-60 min; Hypertrophy, 4 sets of 8-12 RM, 90 s rest for 5 exercises; Strength, 3-7 sets of 2-6 RM, 3 min rest for 4-6 exercises; Power, 3 sets of 4-6 reps at 50-70% 1RM, 2 min rest for 4-6 exercises; and Circuit Training, 6-12 reps, 30 s rest for 10 exercises), aerobic conditioning sessions (20-60 min; efforts of >2 min; swimming, cycling, rowing, conditioning games, orienteering), anaerobic conditioning sessions (45-60 min; repeated efforts of 5-45s duration, 1:1-2 work to rest; boxing, hill sprints, repeated speed), and Rugby specific training (45-60 min; defensive patterns, team plays) (Table 13). Following each session, all players rated their ratings of perceived exertion (RPE) using the ten point Borg scale (37).

Table 13. Outline of the final training week during the pre-season training phase in professional Rugby Union players.

	Monday	Tuesday	Wednesday	Thursday	Friday
AM	Speed + Resistance Training	Resistance Training + Aerobic/Anaerobic Conditioning	Aerobic / Anaerobic Conditioning	Resistance Training	Resistance Training + Team Training
PM	Boxing + Team Training	Resistance Training	Aerobic / Anaerobic Conditioning	Team Training + Aerobic / Anaerobic Conditioning	Boxing + Recovery

Resistance Training: Typical exercises were squat variation, vertical push, vertical pull, horizontal press.

Team Training: Defense, attack, game plan and general skills.

Anaerobic Conditioning: Repeated high intensity running efforts e.g. 10 x 20 m @ 20 s, 10 x 50 m @ 40 s.

Aerobic Conditioning: Low-moderate running/cycling/swimming/rowing efforts of 20-40 min.

Speed: Agility drills for 5-10 min, resisted sprints 10-20 m x 4-8 reps, over-speed bungees 20 m x 2-3 reps, 20-50 m sprints x 2-3 reps.

Recovery: 20 min light cycling, 10 min Contrast Baths and 30 min massage.

Boxing: Repeated high intensity punching, 1:1 work : rest ratio, 10x10 s, 10x20 s 8x30 s, 5x1 min, 3x2 min.

Throughout the four week training phase players performed 53 sessions in total (3.1 sessions per training day) at an average RPE of 7.4. Resistance training accounted for 38% of the total number of training sessions (Table 14).

Table 14. Training mode, training frequency, and ratings of perceived exertion in elite Rugby Union players over a four week pre-season training phase.

Training Mode	Week 1	Week 2	Week 3	Week 4	Total Sessions	Mean RPE
Resistance Training	3	5	7	5	20	7.1
Hill Sprints	2	1	1	0	4	9
Boxing training	2	2	1	2	7	8.4
Aerobic and anaerobic conditioning	2	5	5	4	16	7.4
Speed	0	0	2	1	3	6.9
Rugby Specific Training	0	0	0	3	3	5.6
Total Sessions	**9**	**13**	**16**	**15**	**53 (Total)**	**7.4 (Mean)**

RPE, ratings of perceived exertion.

Statistical Analyses

Strength, power and anthropometric characteristics were log-transformed to reduce non-uniformity of error, and the effects of the training phase were derived by back transformation as percent changes (108). Due to the uniformity of the fatigue data, it was analysed without transformation.

Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-player standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate and large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial (187). To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects (25).

Relationships between the changes in measures were determined by fitting a simple linear model to the relationship between the change scores and the covariate. The resultant change in the measure is based on a two standard deviation increase in the covariate (108).

Results

Increases of 13.6 kg (90% Confidence limits ±2.9 kg) and 17.6 kg (±8.0 kg) were observed in bench press and box squat strength respectively over the four week pre-season training phase indicating a positive training effect (2.7% and 2.8% on average per week, respectively). However, a decrease of 70.6 W (±53.5 W) and 280.1 W (±232.4 W) occurred in bench throw and jump squat power, respectively. Magnitudes and the average weekly change for all variables are reported in Table 15.

Over the four week training phase there were small reductions in the sum of eight skinfolds (11.0 ±2.7 mm) and fat mass (1.4 ±0.4 kg). Small increases were observed in fat-free mass (2.0 ±0.6 kg) and flexed upper-arm girth (0.6 ±0.2 cm). A moderate increase in mid-thigh girth (1.9 ±0.5 cm) and a trivial increase in chest girth (0.5 ±0.9 cm) were also observed over the four week pre-season. Fat-free mass, flexed upper-arm girth, chest girth and mid-thigh girth increased by 0.7%, 0.4%, 0.1%, and 0.9% on average per week, respectively. Fatigue levels increased moderately from the start to the end of the training phase (0.6 ±0.4 units).

Table 15. Baseline values and change in strength, power and body composition, and fatigue in elite Rugby Union players over a four week pre-season training phase.

Measure	Pre Value (± SD)	Post Value (± SD)	Change (±90 % CL)	Meaning-fulness	Weekly Change
Bench Press (kg)	124.3 (± 19.1)	137.9 (± 20.0)	11.1% (±2.3%)	Moderate	2.7%
Box Squat (kg)	154.8 (± 25.7)	172.4 (± 30.7)	11.3% (±4.7%)	Moderate	2.8%
Bench Throw (W)	1158.2 (± 210.8)	1087.6 (± 177.0)	-5.6% (±5.1%)	Small	-1.5%
Jump Squat (W)	5359.8 (± 626.9)	5079.6 (± 547.4)	-5.2% (±4.6%)	Small	-1.3%
Sum of 8 Skinfolds (mm)	93.4 (± 26.7)	82.4 (± 22.5)	-11.5% (±2.6%)	Small	-3.0%
Fat Mass (kg)	13.7 (± 4.8)	12.3 (± 4.1)	-9.5% (±2.8%)	Small	-3.3%
Fat Free Mass (kg)	86.8 (± 7.2)	91.1 (± 7.8)	2.2% (±0.6%)	Small	0.7%
Upper-arm Girth (cm)	39.0 (± 2.0)	39.6 (± 1.9)	1.6% (±0.5%)	Small	0.4%
Chest Girth (cm)	109.4 (± 6.5)	109.9 (± 5.7)	0.5% (±0.9%)	Trivial	0.1%
Mid-thigh Girth (cm)	55.5 (± 2.7)	57.4 (± 3.0)	3.5% (±0.9%)	Moderate	0.9%
Fatigue (units)	1.8 (± 0.9)	2.4 (± 0.8)	0.6 (±0.4)	Moderate	0.2

CL, confidence limits.

Relationships between the change in performance and change in anthropometric measures were mostly unclear (Table 16); however some small to moderate relationships were observed between the changes. For example, a small relationship between the change in flexed upper-arm girth and the change in bench press strength occurred over the pre-season. This relationship represents a 4.1 kg (±4.7 kg) increase in bench press strength for a two standard deviation (2SD) increase in the change in flexed upper-arm girth (Table 16).

Table 16. Relationship between the change in performance and change in body composition and fatigue measures in elite Rugby Union players over a four week pre-season training phase.

Predictor Measure (± 2SD of change; %)	Dependent Measure (% Change [± 90%CL])			
	Bench Press	Box Squat	Bench Throw	Jump Squat
Fat Free Mass (± 3.5)	4.8 (±4.6) Small	-0.5 (±10.1) Unclear	0.7 (±11.1) Unclear	3.6 (±12.0) Unclear
Flexed Upper-arm Girth (± 3.3)	4.1 (±4.7) Small	-	-1.4 (±11.0) Unclear	-
Chest Girth (± 4.3)	1.2 (±4.9) Unclear	-	-1.2 (±11.3) Unclear	-
Mid-thigh Girth (± 6.9)	-	0.3 (±10.1) Unclear	-	-9.2 (±6.3) Moderate

CL, confidence limits. Table details the performance change in a dependent measure if you were to increase the predictor measure by 2SD of the change that occurred in that measure over the training phase.

Discussion

The primary purpose of this investigation was to determine the effects of a pre-season training phase on strength, power and body composition in professional Rugby Union players. Findings indicate that strength in both the upper- and lower-body can be improved over a four week pre-season training phase of high volume concurrent training. In contrast, levels of upper- and lower-body power may be negatively affected by the same training regime. Over the four week training period, small decreases in fat mass were observed in conjunction with a small increase in fat free mass, and flexed upper-arm girth and moderate increases in mid-thigh girth.

An increase in bench press 1RM (13.6 kg) and box squat 1RM (17.6 kg) were observed over the training phase. Players 1RM strength in the current study (baseline bench press

124 kg, baseline box squat 155 kg) was similar to or greater than previously reported in elite Rugby Union players, confirming their well-trained status (131 kg bench press and 150 kg box squat) (27, 28).

Previous literature has reported enhanced strength improvements with increased frequency of training. Hoffman and colleagues (106) reported that five sessions per week produced superior performance enhancements than three, four, or six sessions per week. It is likely that five sessions per week provided optimal loading for adaptation to occur, while six sessions may have compromised adaptation due to inadequate recovery and increased residual fatigue (102, 115). The current investigation utilised on average five sessions per week and produced larger increases in strength than those that have conducted a similar length pre-season training phase utilising up to four sessions per week (163, 175). Therefore, there appears to be a dose response relationship to performance improvements. However, there may be a limit to the frequency of training that produces positive adaptation.

Increases in strength may also be due to hypertrophy of the musculature. A small increase in lean muscle mass, flexed upper-arm girth and a moderate increase in mid-thigh girth were observed over the training phase. Increased muscle cross-sectional area has been previously shown to be an important determinate of increased muscle strength and may be due to changes in muscle fibre composition (increased percent Type II fibres), muscle fibre area (% area Type II), and pennation angle (34, 35, 146). In an investigation examining the effects of different supplementation (combinations of protein, carbohydrate and creatine) in three separate groups performing a ten week resistance training regime; Cribb, Williams and Hayes (61) reported that the group with the largest increase in lean body mass and muscle fibre cross sectional area also experienced the greatest gains in 1RM strength. The authors went on to conclude that at least 40% of the increases in strength could be attributed to hypertrophy of the muscle (61).

Prior to the pre-season training phase, players had performed approximately six weeks of off-season training. The off-season training phase consisted of a reduced volume of high intensity training in which players complete unsupervised low intensity training in non-specific modalities. Fifteen out of the 33 players in the current investigation were assessed for bench press strength in a separate investigation (unpublished findings) at the conclusion of their previous competitive season, immediately prior to the off-season training phase. The investigation used the same methodology for assessing bench press performance. Analysis of the data identified that bench press strength decayed during the off-season at an average rate of 2.2% per week (13.4% over 6 weeks). Previous investigations have also reported detraining effects in elite athletes during an off-season (42, 94). Hãkkinen and Komi (94) reported a similar decrease in squat strength of 2.5% per week (10% over 4 weeks) for Olympic weight lifters in their off-season. Additionally, Caldwell and Peters (42) reported similar detraining findings in semi-professional soccer players. Although no strength measures were assessed, Caldwell and Peters (42) reported significant decreases in lower-body power (approximately 5.2%) following an off-season training phase. It appears that the increases in strength that occurred in the four week pre-season in the current investigation may essentially be the return to competition levels, which recovered at a slightly quicker rate of approximately 2.7% per week. Therefore, much of the initial increases in strength observed may be due to a reconditioning from the off-season phase. These findings also suggest that a short term phase of high volume training provides adequate stimulus to recondition previously well trained players to competition level.

A small decrease in both upper-body (-5.6%) and lower-body power (-5.2%) occurred over the pre-season. Similarly, Harris and colleagues (102) reported a decrease in peak power following a seven week pre-season in two separate groups of elite Rugby League players training at either 80% 1RM or the load where peak power was maximised (-17% and -7%, respectively). Harris and colleagues (102) speculated that decreases in power may have been due to fatigue or decreased effort in the post-training testing occasion. According to the fitness-fatigue model, following a period of stressful training the magnitude of specific fitness and fatigue after-effects are high. It is not until the fatigue after-effects have been removed that the training effects can be observed (46). As such, positive training adaptation may have occurred, but was masked by fatigue due to the large volume of training completed accompanied by inadequate recovery prior to testing. The decrease in power observed in the current investigation may be due to several factors including large training volumes and the resultant increase in overall fatigue.

Performing multiple aspects of conditioning during the same phase, as seen in many team sports, may lead to an excess volume of training. Indeed, a large volume of concurrent training was completed over the four weeks of training in the present study (53 sessions) and may have affected power production. It has been previously suggested that high training volume compromises power development (13, 129). In contrast to the findings in the present investigation and that of Harris and colleagues (102); O'Connor and Crowe (163) reported a significant increase in lower-body power over a six week pre-season in elite athletes. Notably, these athletes performed a total of only eight sessions each week. The lower volume of total training volume may have minimised fatigue, allowing for appropriate power adaptation to occur (163).

Players in the present investigation reported a moderate increase in fatigue from the start to the end of the training phase. It has previously suggested that power training should be performed with minimal influence from fatigue (66). Jurimae and colleagues (115) reported significant reductions in power output (3.6%) following an increase in training volume and concluded that reductions may have been due to an increased state of fatigue. It therefore appears possible that Rugby Union players, who train with significant loading, may experience some overall fatigue which can result in no improvement and even a small decline in power output.

A small increase in fat-free mass (2.2 kg) was observed over the training phase in conjunction with a small increase in flexed upper-arm girth (0.6 cm) and a moderate increase in mid-thigh girth (1.9 cm). Additionally, a small decrease in the sum of skinfolds was observed (-11.0 mm). Previous literature has reported significant decreases in sum of skinfolds and increases in fat free mass over a pre-season (163, 175). It appears that the large volume of training performed in this phase was adequate to elicit positive adaptations in body composition.

Our results showed mostly unclear relationships between the change in body composition measures and performance measures (Table 16), although some small relationships were observed e.g. between bench press and flexed upper-arm girth. This relationship suggests players may increase bench press strength by 4.1% by improving upper-arm girth by two standard deviations (2SD; 3.3%). Additionally, a small relationship between bench press strength and fat-free mass was observed. These findings agree with the philosophy, at least for the upper-body, that increases in muscle mass result in increased strength. However, caution should be taken when interpreting these findings and note the moderate sized 2SD of each predictor measure needed to increase strength. The lack of relationships between the changes in box squat strength and the changes in either fat-free mass or mid-thigh girth suggest that increases in lower-body strength may be largely accounted for by other mechanisms such as neural, fibre, or other morphological adaptations rather than increased muscle mass (22).

The average weekly rate of change for upper-body and lower-body strength was an increase in 1RM of 3.4 kg and 4.4 kg, respectively. This rate of change is larger than previously reported in similar level athletes over a pre-season training regime of concurrent training. O'Connor and Crowe (163) and Rogerson et al. (175) reported an average rate of change of 0.8 kg and 2.7 kg a week for bench press strength, respectively. Interestingly, the rate of change was also higher than reported in participants performing single mode training only (resistance training; 1.4 kg and 2.8 kg per week for bench press and squat, respectively) (61). The weekly rate of change for fat-free mass was 0.5 kg. This is similar to previously reported changes (0.53 kg weekly increase) in a ten week single mode training regime aimed at increasing muscle strength and size in resistance trained participants (61).

The rate of change findings from the current investigation provide insight for strength and conditioning practitioners who need to know the degree of adaptation that can be made in a short term training phase. These findings show that moderate improvements can be made in strength, fat mass and fat-free mass during a short term training phase by performing a high volume of concurrent high intensity aerobic, anaerobic, and resistance training. For team sport athletes such as Rugby Union players who perform concurrent training and have regular breaks between campaigns or shorter breaks as seen during a bye week or rest week, positive gains can be made quickly to allow players to further develop or to allow for reconditioning to occur.

Practical Applications

Increases in strength and fat free mass can be achieved in a relatively short time during a high volume short term training phase consisting of concurrent training in elite, professional Rugby players. Although a single resistance training session per week may maintain or improve these variables; performing a greater volume of resistance training sessions per week may elicit greater performance benefits. However, as some loss of power production may occur with such high training volumes, specific training phases involving a lower volume work and less cumulative fatigue may be required closer to competition if improvements in power are to occur. Such improvements can potentially be achieved during pre-competition phases when the content of training becomes more focused on skill and game plans rather than overall conditioning.

CHAPTER FOUR

Study Three: Changes in Strength, Power and Steroid Hormones during a Professional Rugby Union Competition

Introduction

Rugby Union is a high contact, dynamic sport in which players require a combination of strength, power, speed, agility, endurance and sport-specific attributes. As such, Rugby Union players perform concurrent training in an attempt to elicit gains in the many physical attributes required. Traditionally, concurrent training has been discussed as performing training modes with contrasting physical adaptations during the same training phase, typically strength and endurance (129). However the term concurrent does not necessarily denote contrasting modes of training, rather concurrent is simply defined as existing or happening at the same time. Therefore, concurrent training may be more accurately discussed as numerous aspects of physical preparation targeted simultaneously during a training phase. Indeed, team sport athletes predominately perform concurrent training to maximise adaptation in the many physical aspects they are required to perform. Similar to other athletes, physical conditioning plays a large role in the preparation and subsequent performance of Rugby players.

Pre-season conditioning is considered crucial for players to develop the physical characteristics required for successful competitive performance (e.g. strength, power, speed, aerobic and anaerobic endurance) (181). Elite Rugby players may train as many as four times per day during this phase of a season. During the competitive Rugby season, the main emphasis of a conditioning program is to maintain or improve on the gains made in the pre-season training (13). This emphasis can be complicated however, due to the reduction in conditioning volume during the competitive season as additional training goals are introduced alongside previous training goals (i.e. additional training sessions such as position-specific drills).

It is unclear whether it is possible to maintain or improve upon pre-season levels of physical performance throughout a competitive season that involves predominantly concurrent training. Indeed, research on other football codes has produced mixed findings (13, 70, 87, 89, 181). For example, Baker (13) found that bench press strength in college aged Rugby League players increased by 3.4%, whereas professional players maintained bench press strength (-1.2%) during a competitive season. Additionally, both upper-body and lower-body power was maintained in both of these playing groups (13). Gabbett (89) reported similar findings in that amateur junior Rugby League players were able to maintain lower-body muscular power (-0.7%) throughout a competitive season. In contrast, Gabbett (87) found that non-elite senior club level Rugby League players had decreases in muscular lower-body power (-5.3%); while Schneider and colleagues (181) reported significant decreases in maximal upper-body strength (~8%) and lower-body power (~4.6%) in college aged American football players across a competitive season.

Although there are similarities between these football codes (Rugby Union, Rugby League and American football), there are also many differences. These differences include the duration of work periods, type of work (dynamic or static), work : rest ratios, differences in the time spent at maximal and sub-maximal intensities, distances covered throughout the game, and different rules and regulations (67, 73, 90, 152). Such differences between codes, and therefore training priorities, may be partly responsible for the contrasting findings relating to the maintenance of strength and power previously reported in these football codes.

Another limitation of this literature is that there appears to be little research into the possible mechanisms contributing to the changes in strength and power across a competitive season of football. One such mediator might be the hormonal system. Testosterone and cortisol are steroid hormones with the testosterone to cortisol ratio (T : C ratio) reflecting the balance between anabolic and catabolic environments (81, 82). Higher levels of testosterone have been previously linked to performance in strength and power tasks (44); while diminished levels of testosterone and increased levels of cortisol have been linked to overtraining and reduced performance (124, 126, 200). A better understanding of the effects of a competitive season on these steroid hormones, and their relationship with strength and power may provide opportunity for enhanced programming strategies at an individual level.

While some evidence exists for the effect of the competitive season on the physical fitness characteristics of high-level Rugby League and American football players, there is currently no such literature for elite Rugby Union players. Therefore, the primary purpose of this study was to investigate changes in strength, power and levels of testosterone and cortisol over a 13 week competitive season of Rugby Union. It was hypothesized that strength and power would show little change over the course of the season. The secondary purpose was to identify the relationship between changes in strength and power and hormonal concentrations.

Methods

Experimental Approach to the Problem

Following an intensive seven week training phase (pre-season); players were monitored for levels of strength, power, and salivary hormones throughout a 13 week competitive season of Rugby Union. Specifically, maximal upper-body strength (bench press, n=32), lower-body strength (box squat n=20), upper-body power (bench throw, n=29) and lower-body power (jump squat, n=17) were assessed on separate occasions throughout the competitive season. On testing occasions when power was assessed, players also reported their perceptions of soreness and tiredness, and provided saliva samples for testosterone and cortisol analyses (n=32). Players were assessed on a minimum of two and up to five occasions during a 13 week international competition (weeks 1-2, 4-5, 6-7, 9-10, and 12-13) for each measure. The irregularity in time between testing occasions was due to national and international travel associated with the Super 14 competition. The discrepancy in number of testing occasions throughout the season was due to minor injuries that prevented an individual from performing the desired movements. Importantly, evenly spaced testing and/or equal numbers of tests per player are not requirements of the mixed modelling analytical procedure used in this investigation.

Although many physical attributes are required for successful performance in Rugby Union, only selected measures were monitored. The current investigation was conducted using elite players in a professional environment, and therefore the researchers were limited in their ability to test players and could not assess on-field attributes such as endurance, agility, speed and sport specific skills.

Subjects

Thirty two professional Rugby Union players from a Super 14 professional Rugby team (age, 24.4 ± 2.7 years; height, 184.7 ± 6.2 cm; mass, 104.0 ± 11.2 kg) volunteered to take part in this study. The Super 14 competition is the premier provincial Rugby competition in the southern hemisphere involving 14 full-time professional teams from three countries competing from February to May and involves national and international travel. Players had at least two years of resistance training experience and were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for use of human subjects (Auckland University of Technology ethics committee).

Procedures

All strength (bench press or box squat) and power assessments (bench throw or jump squat) were performed at the beginning of the player's regular training session, and were performed on separate days. All sessions were performed in the morning between 0800 and 1000 h and players were given verbal encouragement throughout all assessments. The 1RM measures derived from these exercises were selected due to their ability to accurately reflect levels of strength and power in both the upper-body and lower-body. Additionally, the exercises were regularly used as part of the players training programme and therefore the players were aptly familiarised.

Bench Press and Box Squat

Maximal strength was assessed using the bench press and box squat exercises. Each player was required to perform three sets (50%, 70%, 90% effort, two-six repetitions) of sub-maximal bench press and box squat followed by one set to failure of one to four repetitions. Three minutes rest was allowed between each set. Each set to failure was used to predict the players' one repetition maximum (1RM) (132). For the bench press, players used a self-selected hand position, and were required to lower the bar to a 90° angle at the elbows and then pressed the bar in a vertical movement so that the arms were fully extended. The depth and hand position were kept consistent throughout all testing occasions. During the box squat, players used a self-selected foot position, and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each player to allow the top of the thighs to be parallel to the floor while in the seated position. The foot position selected was kept consistent throughout all testing occasions. Each repetition was performed irrespective of time.

The following equation was used to predict bench press and box squat 1RM (132) and has been shown to have a correlation between actual and predicted 1RM of $r = 0.993$ and $r = 0.969$ for bench press and box squat, respectively (136):

$$1RM = (100 \times weight)/(101.3-(2.67123 \times reps))$$

Soreness and Tiredness

On arrival at the training facility on the days which power was assessed, players rated their perceptions of soreness and tiredness on a ten point scale ranging from 0 = normal to 10 = extremely sore (soreness scale), or 0 = normal to 10 = extremely tired (tiredness scale) (47).

Salivary Hormones

Resting saliva samples were also obtained from each player prior to each power assessment. Salivary samples were obtained in this study as they are stress-free and non-invasive (202). Salivary samples also reflect the free (non-protein-bound) plasma fraction which has been reported to be more physiologically relevant than total blood levels (164, 203). Players provided a ~2 mL sample by passive drool into polyethylene tubes which were stored at -20°C until assayed for testosterone and cortisol. Sugar-free gum was used to stimulate saliva flow before collection.

Bench Throw

Upper-body power was monitored over the competitive season using a bench throw exercise performed in a Smith machine. Players warmed up with two sets of four repetitions of bench press at 50% of their most recently predicted 1RM bench press. Players then completed two sets of four repetitions of the bench throw at 50% and 60% 1RM bench press as these loads have been previously shown to produce maximal upper-body power in well trained players (13). Players used a self-selected hand position and lowered the bar to a self-selected depth which was kept constant throughout all testing occasions. Players were then asked to throw the bar vertically and explosively as possible, trying to propel the bar to a maximal height (161). Three minutes rest was allowed between each set.

Jump Squat

Lower-body power was monitored over the competitive season using a jump squat exercise performed in a Smith machine. Players warmed up with two sets of four repetitions lowering the bar to a 90° knee angle using a load of 55% of their most recently predicted 1RM box squat. Players then completed two sets of four repetitions of jump squat at 55% and 60% 1RM box squat as these loads have been previously shown to produce maximal lower-body power in well trained players (13). Players used a self-selected foot position and lowered the bar to a self-selected depth which was kept constant throughout all testing occasions. Players were then asked to jump as explosively as possible, to propel themselves and the bar off the ground. Three minutes rest was allowed between each set.

The power produced during each bench throw and jump squat repetition was quantified with a GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) using the methods described elsewhere (71). Quantification of the power produced during the jump squat exercise included bodyweight and bar mass (system mass) in the calculation, whereas only the bar mass was included for bench throw (72).

Training Loads

Training loads for each session were recorded and calculated by randomly selecting five players to give the training session a rating of perceived exertion (RPE) using the Borg scale (37) (Table 18). This intensity was then averaged and multiplied by the duration of the training (minutes) to calculate a training load for the session.

Prior to the beginning of the competitive season, players had completed seven weeks of concurrent strength and conditioning. This entailed three to seven resistance training sessions per week that differed between individuals (45-60 min; Hypertrophy, 4 sets x 12 RM, 90 s rest for 5 exercises; Strength, 3-7 sets x 2-6 RM, 3 min rest for 4-6 exercises; Power, 3 sets x 4-6 reps at 50-70% 1RM, 2 min rest for 4-6 exercises; and Circuit Training, 6-12 reps, 30 s rest for 10 exercises). Conditioning consisted of two to three high intensity running sessions each week (45-60 min; repeated efforts of 5-45 s duration, 1:2 work to rest). Additionally, one or two recovery sessions were completed each week (30 min; swimming, cycling, games). More than 50% of the players achieved or equalled personal bests in the box squat and/or bench press exercises during the pre-season. Of the remaining players, many were nearing previous personal bests in the same exercises, suggesting that the majority of the players were close to their own personal peak condition at the outset of this study.

During the 13 week in-season, training was reduced to one to three resistance sessions (Strength, 3-7 sets x 2-6 RM, 3 min rest for 4-6 exercises; Power, 3 sets x 4-6 reps at 50-70% 1RM, 2 min rest for 4-6 exercises), one or two high intensity running sessions (20-30 min; repeated efforts of 5-20 s duration, 1:2 work to rest), three or four skill / tactical team sessions, one or two recovery sessions, and one competitive match (played either internationally in South Africa or Australia, or nationally in New Zealand; Table 17).

Table 17. An example training week during a competition training phase in professional Rugby Union players.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	Full Body Resistance Training 45-60 min 4-6 Sets 2-6RM	Team Training (Units) 30-45 min	Recovery Day *Optional Extras	Team Training (Units) + Speed Or Power 30-45 min 3-4 Sets 4-6 Reps 30-80% 1RM 25-40 min	*Optional Extras		Recovery 60 min
PM	Team Conditioning / Recovery 30-45 min	Team Training + Anaerobic Conditioning 60-75 min + 15-20 min		Team Training 45-60 min	Final Team Rehearsal 15-25 min	GAME	

Resistance Training: Typical exercises were squat variation, vertical push, vertical pull, horizontal press.

Team Conditioning / Recovery: Pattern work and games.

Team Training (Units): Positional groups focus on specific unit skills.

Team Training: Defense, attack, game plan and general skills.

Anaerobic Conditioning: Repeated high intensity running efforts e.g. 10 x 20 m @ 20s, 10 x 50 m @ 40 s.

* Optional Extras: Skill, conditioning, and massage options based on individual needs.

Speed: Agility drills for 5-10 min, resisted sprints 10-20 m x 4-8 reps, over-speed bungees 20 m x 2-3 reps, 20-50 m sprints x 2-3 reps.
Power: Jump squat, power clean, push press, bench throw
Recovery: 20 min light cycling, 10 min Contrast Baths and 30 min massage.

Specifically, during the pre-season, backs performed approximately 3.4 ± 1.3 resistance training sessions per week in comparison to 1.3 ± 0.6 resistance sessions per week during the in-season. Forwards performed approximately 5.0 ± 1.7 resistance sessions per week in the pre-season in comparison to 2.2 ± 0.7 resistance sessions during the in-season. Resistance training loads and duration are presented in Table 18.

Table 18. Average weekly training load and training duration (mean ± SD) of elite Rugby Union players during the pre-season and in-season competitive phases.

	Forwards (mean ± SD)		Backs (mean ± SD)	
	Pre-season	In-season	Pre-season	In-season
Total training duration (min)	737 ± 150	411 ± 107	709 ± 146	377 ± 91
Total load (duration x RPE)	4322 ± 766	1857 ± 579	4048 ± 673	1693 ± 476
Resistance training duration (min)	228 ± 90	93 ± 31	164 ± 62	62 ± 33
Resistance training load (duration x RPE)	1404 ± 491	521 ± 177	1008 ± 344	358 ± 193

RPE, rating of perceived exertion (0-10 scale); Forwards, n=19; Backs, n=13.

Saliva Analysis

Saliva samples were analysed in triplicate for testosterone and cortisol using radioimmunoassay (RIA) methods (29). Briefly, standards from serum diagnostic kits (Diagnostic Systems Laboratories, USA) were diluted in phosphate buffer saline (Sigma P4417) to cover the expected ranges of 0-18.56 and 0-1.73 $nmol \cdot L^{-1}$, for cortisol and testosterone respectively. Saliva sample sizes of 50 and 100µl were used for cortisol and testosterone respectively. Antibodies were diluted with a phosphate buffered saline solution containing 0.05% bovine serum albumin. Kit standards were diluted so that ~50% binding was achieved with respect to the total counts. Detection limits for the assays were 0.4 and 0.004 $nmol \cdot L^{-1}$ for cortisol and testosterone respectively.

Statistical Analyses

The analysis was performed in three stages. First, the values of all measures were characterised via a straightforward reliability model, which consisted of a fixed effect for the mean value at each assessment and random effects to characterize typical variation within a player from assessment to assessment and between players in any one assessment (Table 19). Secondly, to show changes in mean values, a straight line was fitted to each player's values with assessment date as the predictor measure; the model provided the predicted change between the first and last assessment dates averaged over all players (Table 20). Finally, to investigate the ability of each measure to predict changes in performance, a similar model was used with each measure as the predictor measure (Table 21). All analyses were performed using the mixed procedure (Proc Mixed) in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC).

Strength, power and hormone concentrations were log transformed before all analyses to account for non-uniformity of errors; for these measures the means shown are the back-transformed means of the log transformed data, while the standard deviations and effects (changes in means) are shown as percents. Soreness and tiredness were analysed without transformation.

Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-player standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate and large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial. To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

The interclass correlation (ICC) and coefficient of variation (CV) for bench throw and jump squat activities were 0.900 and 5.0%, and 0.904 and 4.8% respectively. Validity of the GymAware® optical encoder has been previously reported elsewhere (71). The intra- and inter-assay CV were 1.58 and 16.48 % for cortisol, and 1.61 and 12.75 % for testosterone.

Results

The overall mean weights for bench press and box squat 1RM strength across the season were 141 kg and 194 kg respectively (Table 19). A trivial decrease was observed in bench press strength (-1.7 kg), while a small increase in box squat strength (16.0 kg) was observed from the start to the end of the 13 week competitive season (Table 20). Overall mean scores for bench throw and jump squat were 1150 watts (W) and 5190 W respectively (Table 19). A trivial decrease was observed in bench throw power (-40 W), while a small decrease in jump squat power (-175 W) occurred over the competitive season (Table 20).

The overall means for resting testosterone, cortisol and the testosterone to cortisol ratio (T : C ratio) for the competitive season were 99 $pg \cdot mL^{-1}$, 2.0 $ng \cdot mL^{-1}$, and 50 (units) respectively (Table 19). Moderate increases in testosterone and cortisol were observed over the 13 weeks, while a small decrease occurred in the T : C ratio (Table 20). Trivial changes in ratings of perceived soreness and tiredness were also observed from the start to the end of the competition (Table 20). Individual differences over the competitive season were mostly trivial or inestimable and therefore not reported in Table 20.

The analysis of the relationship between predictor and dependent measures revealed mostly trivial but unclear findings (Table 21). However, some small to moderate relationships were observed. When examining relationships one must note the (two) large within standard deviations necessary to allow for the performance enhancement in the dependent measure e.g. to improve jump squat strength by 2.3% an player would need to increase T : C ratio by 320%.

Table 19. Values of performance, hormonal, and psychological measures for all testing sessions over a 13 week competitive season of concurrent training in elite level Rugby Union players.

Measure	Overall Mean	Between-subject SD	Within-subject SD
1RM Bench press	141 kg	16%	5%
1RM Box squat	194 kg	17%	9%
Bench throw PP	1150 W	23%	12%
Jump squat PP	5190 W	15%	7%
Testosterone	99 $pg \cdot mL^{-1}$	50%	37%
Cortisol	2.0 $ng \cdot mL^{-1}$	100%	90%
T : C ratio	50	110%	97%
Soreness (0-10)	3.0	2.2	2.0
Tiredness (0-10)	3.1	2.2	2.0

RM, repetition maximum; PP, peak power; T : C , testosterone : cortisol; Bench press, n=32; Box squat, n=20; Bench throw, n=29; Jump squat, n=17; Soreness, tiredness, testosterone and cortisol, n=32.

Table 20. Linearised changes in performance, hormonal, and psychological measures over a competitive season of concurrent training in elite level Rugby Union players.

Measure	Effect (±90%CL)	Magnitude
1RM Bench press	-1.2% (±2.7%)	Trivial
1RM Box squat	8.5% (±7.2%)	Small
Bench throw PP	-3.4% (±4.9%)	Trivial
Jump squat PP	-3.3% (±5.5%)	Small
Testosterone	54% (±27%)	Moderate
Cortisol	97% (±51%)	Moderate
T : C ratio	-22% (±25%)	Small
Soreness (0-10)	0.2 (±0.8)	Unclear
Tiredness (0-10)	-0.2 (±0.9)	Unclear

RM, repetition maximum; PP, peak power; CL, confidence limits; T : C , Testosterone : Cortisol; Bench press, n=32; Box squat, n=20; Bench throw, n=29; Jump squat, n=17; Soreness, tiredness, testosterone and cortisol, n=32.

Table 21. Change in a dependent measure associated on average with two within-subject SD of change in a predictor measure in well trained elite Rugby Union players over a competitive season.

Predictor measures	Two within-subject SD	Change in dependent measures (±90%CL)			
		Bench throw	Jump squat	Bench press	Box squat
1RM Bench press	11%	10.0% (±4.1%) Small	_	_	_
1RM Box squat	18%	_	2.6% (±3.8%) Trivial	_	_
Bench throw PP	27%	_	_	11.0% (±5.1%) Moderate	_
Jump squat PP	12%	_	_	_	4.4% (±7.0%) Small
Testosterone	105%	-0.7% (±4.4%) Unclear	0.8% (±3.9%) Unclear	-2% (±17%) Unclear	3% (±13%) Unclear
Cortisol	322%	-0.3% (±4.3%) Unclear	-2.4% (±4.2%) Trivial	0.2% (±4.2%) Unclear	6.7% (±7.4%) Small
T : C ratio	320%	1.2% (±4.9%) Trivial	2.3% (±4.9%) Trivial	-2.2% (±6.2%) Unclear	-3.0% (±6.8%) Unclear
Soreness	2.1	1.4 (±4.7) Trivial	-0.7 (±4.4) Unclear	5.7 (±4.1) Small	0.4 (±5.4) Unclear
Tiredness	2.1	-2.9 (±5.0) Trivial	-4.5 (±3.8) Small	4.8 (±5.5) Small	1.7 (±4.5) Trivial

CL, confidence limits; RM, repetition maximum; PP, peak power; T : C , testosterone : cortisol.

Discussion

The primary purpose of this study was to investigate changes in strength, power and levels of testosterone and cortisol over a 13 week competitive season in Rugby Union players. The present findings suggest that upper-body maximal strength and power of elite Rugby players can be maintained throughout a competitive season. Interestingly, specific changes in the lower-body were evident, with a small increase in maximal strength, but a small decrease in power. Moderate increases in both testosterone and cortisol were observed throughout the competitive season, with a larger increase in cortisol levels producing a small reduction in the T : C ratio. The secondary purpose was to identify what relationships, if any, existed between the changes in strength, power and hormonal concentrations. Statistical analysis revealed some positive small to moderate relationships between strength and power. However, these relationships appear to be unobtainable throughout a competitive season due to the large increases in performance (in the predictor variables) needed to elicit change.

Similar to previous studies, strength was maintained (-1.7 kg; -1.2%) in the upper-body, and improved (16.0 kg; 8.5%) in the lower-body throughout the competitive season even with a reduction of resistance training volume (13, 70, 181). Numerous factors are reported to influence strength adaptations to resistance training (13, 129, 167). Baker (13) reported that upper-body strength in college aged players could be increased (3.4%), but only maintained in professional players during a competitive season. It has been suggested that lack of strength gains in professional players is likely due to their greater strength training background, which may reduce the scope for further strength improvements (13, 22). It is also likely that the variation in training modality that occurs in football codes influences adaptation. Specifically, the players in this study performed combinations of skill, tactical, strength, power, speed and aerobic training sessions. As a result of this wide variety of different training stimuli performed and the need for recovery, some of these physical qualities may only be trained once a week during some points of the in-season phase. Such combinations of training stimuli may also produce numerous challenges to the body's adaptive processes (129).

In the present study the lack of improvement in upper-body strength (-1.2%) throughout the competitive season may have been due to a decreased resistance training volume (1.3 and 2.2 sessions per week, for backs and forwards respectively). Indeed, a meta-analytic review of strength training protocols (167) concluded that trained players require eight sets per muscle group two times per week to improve strength. This supports findings from the current study as although the forwards did perform on average 2.2 resistance sessions per week in the competitive season, only one of these sessions had a specific upper-body strength focus, thus preventing players from achieving the possible training volume required to increase upper-body strength.

In contrast to the upper-body results, there was a small 8.5% increase in lower-body strength throughout the competitive season. This increase suggests that training status and performing combination training may not significantly affect gains in strength; rather increases in strength may more likely due to the frequency and volume of training. Indeed, heavy lower-body resistance exercise was performed twice a week for the forwards (one strength session, one power session), and once for backs (one power session). Additionally, the forwards typically performed scrum training once a week which consisted of maximal isometric contractions of the lower-body (in a position that is similar to a horizontal hack squat) while the backs completed resisted sled sprinting once a week. It is possible that this combination of gym- and field-based lower-body resistance training provided adequate stimulus to increase lower-body strength across the entire group. One may speculate that the reduced gym-based resistance training during the competitive season provided adequate stimulus to maintain upper-body and lower-body strength, but it was the additional non-gym based lower-body activities (e.g. scrum and resisted sled training) that could have contributed to the increase in lower-body strength. Therefore changes in strength over a competitive season appear to be related to the frequency / volume of the adaptive stimulus rather than effects of concurrent training or training status.

The results of the present study are consistent with previous literature in that a small decrease in lower-body power (-175 W; -3.3%) was observed throughout a competitive season, while power in the upper-body was maintained (-40 W; -3.4%) (13, 87, 89, 181). Unfortunately, limited data exists that quantify changes in power in elite players over the course of a training or competition phase. Similar to the data reported earlier on strength, the changes observed for power may be due to numerous factors including training volume and stimulus, inadequate recovery, and training status (13, 22, 87, 129).

As with strength adaptations, positive adaptations in power are likely to require an adequate training stimulus. The reduction of training load throughout the competitive season may have led to insufficient stimulus provided to promote positive adaptation in power. Indeed, the players only completed one gym based power session each week on average throughout the competitive season. Furthermore, the introduction of additional training goals (e.g. skills) throughout the competitive season further reduced the potential training volume that could be performed in each of the numerous aspects of conditioning throughout each week.

Decreases in power may also be due to a compromised physical development caused by residual fatigue induced by limited recovery time between successive matches and training sessions (87). Repeated residual fatigue caused by weekly competition and training stress without adequate recovery, may have led to the players being in an 'over-reached' state resulting in a short-term decrement in performance (95).

It has been previously shown that performance gains are reduced in elite athletes with a high training status (13, 22). For example, Baker and Newton (22) assessed power in sub-elite Rugby League players over a four year period and reported that initial increases in power diminished as players became stronger (and progressed to an elite level). This increase was eventually followed by a cessation of power improvements by the end of the second year. The lack of improvement may suggest that elite level athletes need a greater volume of training and/or perhaps a more specific stimulus to enhance power production. Therefore the lack of improvement in upper-body and lower-body power may have been due to a combined effect of 1) inadequate recovery between matches, 2) insufficient training stimulus (intensity and frequency) and, 3) athlete training status.

There was large within-subject variation in hormonal data over the competitive season (Table 19). However moderate increases in testosterone (54%) and cortisol (94%) were observed throughout the season. A small reduction (22%) in the testosterone to cortisol ratio also occurred due to the larger increase in cortisol over the competitive season. There is a limited body of knowledge regarding hormonal changes in athletes over competitive seasons. Nonetheless, potential mechanisms for the increase in testosterone and cortisol observed may include such factors as deflated pre-test values, training volume, recovery, and psychological variables (77, 78, 126, 150, 200).

Increases in testosterone observed throughout the season may have been due to a diminished resting level of testosterone on the first testing occasion. During periods of heavy or high volume training, levels of testosterone can be significantly reduced (126, 200). It may be possible in the current study that during the initial testing session players may have been experiencing a reduced testosterone level as a result of the prior intense seven week pre-season training phase.

The increase in testosterone throughout the 13 week season may also be due to a 'recovery' of the endocrine system caused by the reduction of training load throughout the season (for training loads see Table 18). Increases in testosterone have previously been reported following an 11 week competitive soccer season (126). Kraemer and colleagues (126) suggested that the recovery / increase in testosterone reflected the dramatic reduction of training stress throughout the season. Increases observed in testosterone may also be in part due to psycho-physiological mechanisms. The players in the current study lost their first five games of the season, but then went on to win seven of their final eight games. Etias (78) reported that humans undergo specific endocrine changes in response to victory or defeat and that the victor responds with a greater increase in testosterone than the loser.

Periods of intense training have previously been reported to increase levels of cortisol (124, 126). In contrast to testosterone, one may speculate that the large volume of training performed in the pre-season in the current study may have lead to an increased cortisol level at the initial testing session. Interestingly, there was a continual increase in cortisol throughout the competitive season even though there was a reduction in training volume. Although somewhat speculative, this may have been caused by the difference in training intensity between the pre-season and competitive season phases. By reducing the training volume throughout the competitive season, players may be less effected by fatigue and are able to train at a higher intensities (for shorter periods). The greater intensities of training during the competitive season may place additional physical stress on the player in comparison to the high volume, moderate intensity pre-season training. Furthermore, when comparing pre-season and competitive season phases, there was a greater amount of physical impact and contact throughout the competitive season in comparison to the pre-season training. This higher intensity of training coupled with the added volume of physical impact may have added to the increase in cortisol observed.

Increases in cortisol following a single game of Rugby Union have been previously reported (77). The authors concluded that a minimum of five days rest (or light training) was needed to adequately recover from the demands of the game (77, 92). The players in the current study were generally performing intense and physically demanding training by the second or third day following the game. Therefore, based on the findings from Elloumi and colleagues (77), the players may not have recovered fully. Inadequate recovery following games in addition to the training demands and successive weekly competition may have caused a gradual increase in cortisol levels over the competitive season.

Psychological factors may also add to the increased level of cortisol. Previous investigations have reported a statistically larger increase in cortisol following competition than in simulated competition or training (96, 165) Additionally, increased cortisol levels have been reported prior to competition in instances where the perceived importance of the outcome is greater (150). Due to the professional nature of the sport the perceived importance of the outcome is regularly high. Players also have additional pressure to perform, as poor performance can lead to non-selection, which can ultimately lead to a loss of employment. This additional pressure to perform can increase the level of stress. Stressful situations have been reported to be one of the best known triggers for an increase in cortisol levels (6).

The statistical analysis used in the current investigation allowed for a better understanding not of cause and effect, but rather *change* and effect between measures. It should be noted that strength and power measures were not measured at the same time (24-48 hours apart) due to structure of the training week. The results from the present investigation indicated that upper-body power may be improved by increasing upper-body strength. The relationship supports the contention that increases in power can be attained through increased strength (21). However, starkly contrasting findings were observed in the lower-body measures in which a trivial relationship between changes in box squat and jump squat was observed. The differences between the relationships of the upper-body and lower-body may be due to the differences in the kinematics of the movements. The bench press and bench throw both employ the stretch shortening cycle (SSC); only the jump squat exercise uses the SSC in the lower-body exercises assessed. The box squat differs in that at the end of the eccentric phase there is a pause (sitting on the box) before the commencement of the concentric phase, minimising the SSC. These differences potentially explain the disparity in the relationships observed between the upper-body and lower-body. Findings from the present study also suggest that increases in strength can be obtained through increasing power output, albeit to a much lesser extent. Caution should be taken when interpreting these findings, as although some small to moderate relationships were observed, the actual observed change in performance measures over the competitive season were much smaller than the within standard deviations needed to obtain the predicted changes in performance. Therefore many of the relationships would be near unobtainable in elite players over a competitive season. For example, to increase jump squat power by 2.6% you would need to increase box squat strength by 18%, whereas the observed change in box squat over the competitive season was only 8.5%.

The results also revealed mostly trivial but unclear findings for hormonal relationships with the exception of a small relationship between cortisol and box squat. However, as with the performance measures the large within standard deviation of cortisol needed to increase box squat strength is very large and would be virtually unobtainable and may have a negative effect on other adaptation processes.

The findings from the current study revealed that maximal upper-body strength can be maintained while lower-body strength may be improved throughout a competitive Rugby Union in-season despite a decreased volume of resistance training. In contrast, power was negatively affected by the competitive season, especially in the lower-body. Although many factors may contribute to changes in strength and power over a competitive season, it seems these measures may be primarily affected by training load (intensity and volume). Additionally, it appears there may be some crossover effect between performance measures; however the required change in many of the predictor measures to improve a dependent measure may be too large to obtain throughout a competitive season. Therefore, it may be suggested that for improvement in individual performance measures players need to train specifically for that measure to maximise potential adaptation, at least in elite Rugby Union players over a competitive season.

Practical Applications

Findings from this investigation suggest that volume and intensity of training are the primary factor in enhancing performance measures in elite Rugby Union players over a competitive season. We suggest that players of a high training status and long training history may need to train more specifically to enhance performance in individual performance measures. In addition to training specificity, an increase in resistance training volume may be needed to improve levels of strength and power within a competitive season of concurrent training. We suggest that two resistance sessions per week for each major muscle group may be sufficient to maintain strength and power; but greater than two resistance sessions (or two plus additional supplemental non-gym based resistance training i.e. weighted sled sprinting) may be needed to improve strength and power in elite Rugby Union players during a competitive season. Whether such training can be performed while still allowing the players to recover from the game and training loads remains unknown.

CHAPTER FIVE

Study Four: Acute Effects of Verbal Feedback on Upper-Body Performance in Elite Athletes

Introduction

To be successful in a chosen sport, athletes need to develop a variety of specific skills and physical attributes. In many sports, such as Rugby Union, athletes have limited time to train and develop each physical attribute before optimal recovery is compromised or injury risk is increased. It has been suggested that athletes may sometimes train with insufficient motivation or intensity to maximise their training time (192), and their training quality may suffer. Therefore, improving the quality of each training session (without extending the duration or increasing the volume) is a common goal for many athletes and practitioners Quality of training is vital to the success of the conditioning programme and relates to the exercise stimulus required to make specific improvement (127). For example, attempting to maximise jump height or velocity during vertical jump training may lead to greater training quality and adaptation when compared to performing the same quantity of jumps performed with sub-maximal intent.

Psychological strategies may be a method for improving training quality and have been previously reported to improve performance of strength, power and skill based tasks (114, 123, 151, 194). Psychological techniques can be classified as either intrinsic (e.g. self-talk, ‘psyching up’, task intrinsic feedback) or extrinsic where visual and verbal feedback provides knowledge of results or performance. Although the exact mechanisms for improvement are unclear, improvements may be due to a combination of enhanced neuromuscular activation, intent, focus of attention, levels of arousal, and improved skill performance and learning (114, 123, 138, 151, 194, 211).

‘Psyching up’ has been shown to increase isokinetic bench press strength by 11.8% when compared to a mental distraction control (194). Additionally, Jung and Hallbeck (114) reported an increase in peak handgrip strength of approximately 5% when visual feedback or verbal encouragement were given. It should be noted that the strength improvements in the aforementioned investigations were assessed in testing sessions consisting of a single repetition or set, an approach that is atypical in resistance training where multiple sets and repetitions are performed consecutively (excluding one repetition maximum lifting) (167). Therefore, the effect of psychological strategies on resistance training performance still requires investigation.

Training quality can be affected by accumulated fatigue that occurs throughout a training session and may cause a reduction in exercise movement velocity (135). As such, the rate of work done (i.e. power) in the final sets may not be as high as the initial sets, resulting in reduced training quality. Using psychological techniques, Tod and colleagues (195) reported a significant increase (~4.7%) in knee angular velocity during a vertical jump when athletes performed self-talk such as “I can jump high” prior to jumping. Verbal feedback is a type of augmented feedback that may influence movement velocity when delivered to athletes throughout training sessions, although to date such a possibility has not been investigated. A finding that verbal feedback increases movement velocity during resistance training, thus allowing training quality to be maintained or improved, may have practical implications for coaches and athletes.

While strength is important and often assessed in practice, research indicates that power may be a better predictor of athletic performance (159). Numerous authors have reported increased lower-body power when psychological strategies were implemented (195, 199, 206). To date, only one study has investigated the acute effects of psychological methods on upper-body power (103). It was reported that the use of self-talk (labelled motivational self-talk) increased distance of an over-head throw of a water polo ball in untrained swim class students compared to a no-talk (control) condition (103). It is currently unknown whether augmented feedback can improve performance in upper-body power exercises in well trained athletes. Therefore, the purpose of this investigation was to determine the effects of verbal feedback on upper-body power in a resistance training session consisting of multiple sets and repetitions in well trained Rugby Union players. We hypothesised that receiving augmented feedback throughout a training session would improve training quality, observed as enhanced power output and velocity within each exercise set.

Methods

Experimental Approach to the Problem

To assess the effects of verbal feedback on mean peak power and mean peak velocity; nine elite Rugby Union players were assessed using the bench throw exercise on four separate occasions each separated by seven days. All testing sessions were conducted at 0930 hours on the same day of the week. Players had been instructed to maintain a high level of hydration in the 24 hours leading up to each testing occasion. All players were provided a standardised breakfast on all testing days, approximately two hours prior to training. Players were instructed to abstain from caffeine during the 12 hours prior to each testing session. Each player completed two sessions consisting of three sets of four repetitions of the bench throw with feedback provided following each repetition; and two identical sessions where no-feedback was provided after each repetition. Each set was separated by two minutes rest. Players were randomly split into two groups which differed in the order they received feedback or no-feedback over the four testing occasions (Figure 2). Power and velocity were assessed using the bench throw exercise due to their common usage in power training programs and research studies, and as a representation of upper-body explosive performance (10, 18). Multiple repetitions and sets were performed to be more representative of a typical training session. Peak power and velocity were selected as the dependent measures as they have been reported to have the greatest association with athletic performance (72).

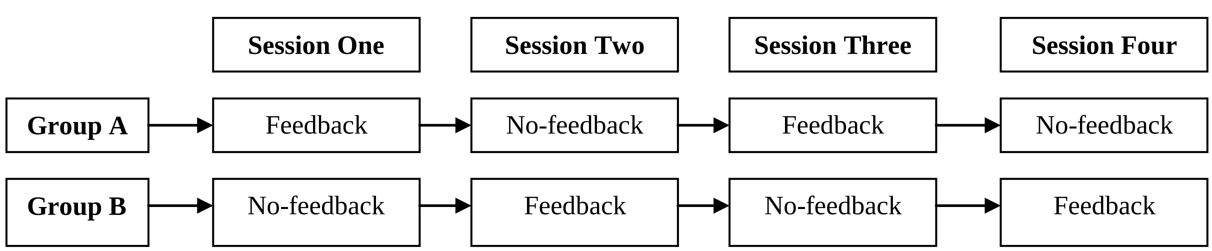

Figure 2. Outline of testing order to assess difference in bench throw performance when feedback or no-feedback is recieved. Group A, n=4; Group B, n=5.

Subjects

Nine elite Rugby Union players from a Super Rugby professional team volunteered to take part in this study during the start of the competitive phase of their season (mean ± SD; age, 22.1 ± 2.1 years; height, 184.2 ± 7.7 cm; mass, 107.3 ± 13.2 kg; maximal bench press strength, 135.9 ± 22.6 kg). Each player had at least two years of intensive and regular resistance training experience. All players were informed of the experimental risks and benefits of the study and signed a consent document prior to the study commencing. The investigation was approved by an Institutional Review Board for use of human participants.

Procedures

Feedback

Peak velocity ($m \cdot s^{-1}$) was obtained by a GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) and the numerical value (e.g. 2.38 $m \cdot s^{-1}$) was verbally provided to each player following the completion of each repetition. Verbal feedback was provided at a volume slightly greater than normal conversation volume due to the additional noise created within the gymnasium. No other feedback or motivation (e.g. "come on" or "you can do it") was provided. The no-feedback condition had only the repetitions counted aloud (i.e. "1, 2, 3, 4") at the same volume as the feedback condition. The same encoder was also used to record the peak velocity and peak power of each repetition for later analysis (71). Briefly, GymAware® consists of a spring-powered retractable cord that passes around a pulley mechanically coupled to an optical encoder. The retractable cord is then attached to the barbell and velocity and distance are calculated from the spinning movement of the pulley upon movement of the barbell. The encoder gave one pulse approximately every three millimetres of load displacement, with each displacement value time stamped with a one-millisecond resolution. The mass of the bar (as entered into a personal digital assistant), the entire displacement (mm) of the barbell, and time (ms) for the movement are used to calculate mean values for power (71).

Bench Throw

A standardised warm up consisting of two sets of ten body-weight press ups followed by one set of five explosive press ups with a clap was completed. Players then completed three sets of four repetitions of bench throw at a load of 40-kg within a Smith machine that was equivalent to 30% (± 5%) of the group's mean maximal bench press. Players used a self-selected hand position and lowered the bar to a self-selected depth (10). Players then threw the bar vertically and explosively as possible, trying to propel the bar to attain maximal velocity (161). Each repetition began with an eccentric phase followed immediately by a concentric phase with no pause between the two phases. In both conditions a one second pause occurred following the completion of each repetition (at the end of the concentric phase) so that verbal feedback or no-feedback could be provided (obtained via GymAware®). Players rested for two minutes between all warm up and training sets. Players were asked to rate their effort after each set; all reported maximal effort.

Statistical Analyses

The first repetition from each set was excluded from analysis, as feedback could not be provided until after the completion of the first repetition. The repetitions for each set from the two feedback sessions were combined and averaged prior to analysis, as were the no-feedback repetitions. Mean peak power and mean peak velocity data of all nine repetitions, as well as the mean for each set of three repetitions (set one, two or three), were used for analysis.

All data were log-transformed to reduce non-uniformity of error, and the effects were derived by back transformation as percent changes (108). Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-participant standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate and large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial (107). An effect size of 0.2 was interpreted as the smallest worthwhile change. To make inferences about the true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects (25). Intra-class correlations (r) and coefficient of variation (CV%) for the bench throw was assessed on 11 recreationally trained males and were $r = 0.949$ and 5.2%, and $r = 0.957$ and 3.1% for peak power and peak velocity, respectively.

Results

A small increase of 1.8% (90% confidence limits; ±2.7%) in mean peak power of all repetitions was observed when feedback was received. When each set was compared individually there was no difference in mean peak power between the first set in either condition. The mean peak power in the second set was 2.4% (±4.7%) greater when feedback was received when compared to the second set of the no-feedback condition which represented a small effect. There was also a small increase of 3.1% (±3.3%) in mean peak power of the third set in the feedback condition compared with no-feedback (Figure 3).

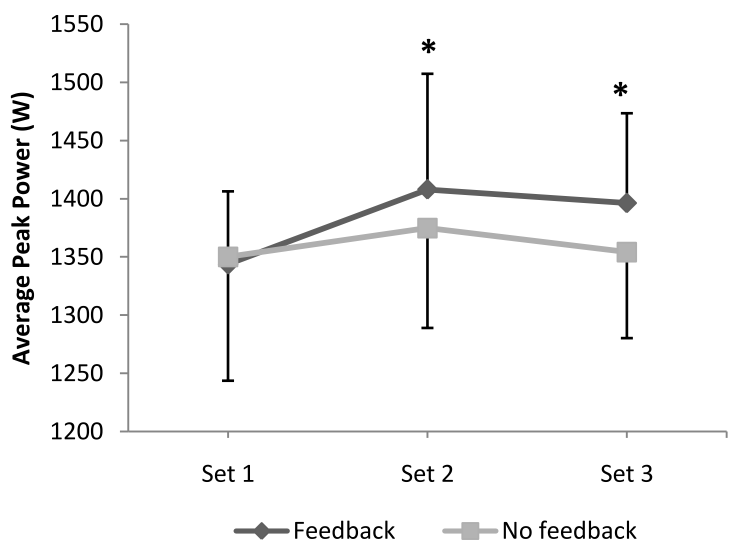

Figure 3. Mean peak power and standard deviations (error bars) obtained during three sets of three repetitions of 40-kg bench throw. Peak velocity feedback was provided in a verbal manner at the completion of each repetition for the feedback condition. * denotes a small difference between conditions.

Mean peak velocity of all repetitions was 1.3% (±0.7%) greater when feedback was provided and this represented a small effect. When each set was compared, a small improvement in mean peak velocity was observed in all three sets in the feedback condition compared to no-feedback. Increases in mean peak velocity were 1.3% (±1.1%), 1.1% (±1.1%) and 1.6% (±1.0%) for set one, two and three, respectively (Figure 4).

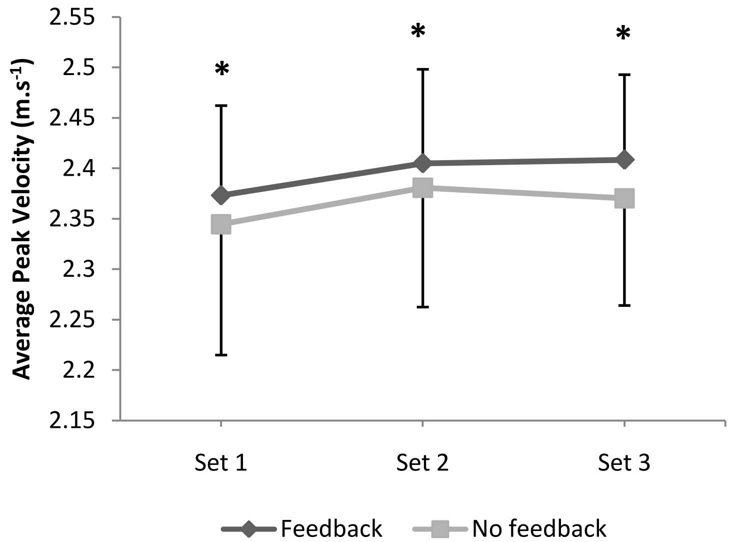

Figure 4. Mean peak velocity and standard deviations (error bars) obtained during three sets of three repetitions of 40-kg bench throw. Peak velocity feedback was provided in a verbal manner at the completion of each repetition for the feedback condition. * denotes a small difference between conditions.

There were no clear differences between the change in peak power or velocity from set to set between either of the conditions. However, the change in mean peak power from set one to set two in the feedback condition was nearing a clear difference compared to the no-feedback condition (2.5 ±5.6%; effect size, 0.37 ±0.83). Figure 5 illustrates the individual response in mean peak velocity and power to feedback and no-feedback conditions.

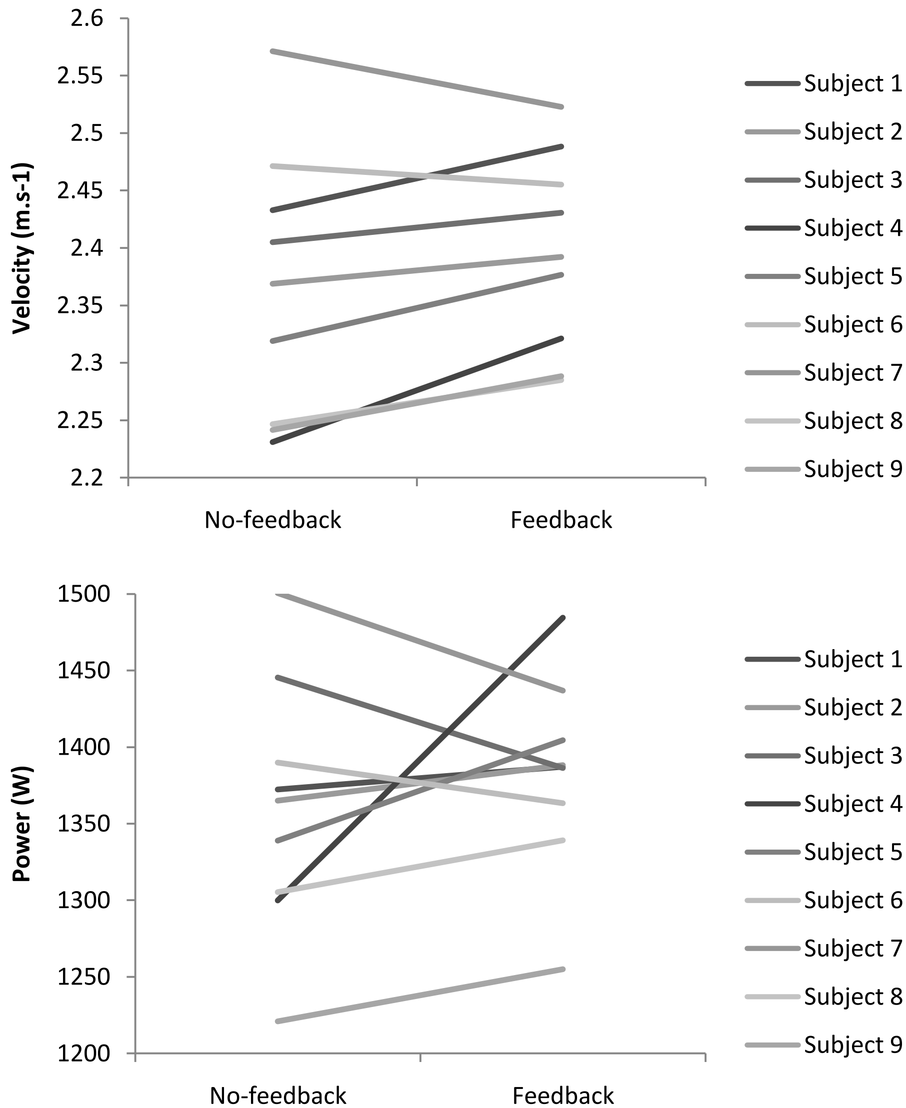

Figure 5. Subject variation mean peak velocity and mean peak power in three sets of three repetitions of 40-kg bench throw performed with or without verbal feedback.

Discussion

The purpose of this investigation was to determine the acute effects of verbal feedback on upper-body power in a resistance training session consisting of multiple sets and repetitions in well trained athletes. Small improvements in bench throw mean peak power and mean peak velocity were observed when verbal feedback was received immediately after each repetition. These results contribute to the current body of knowledge in several ways. Firstly, to our knowledge, only one other investigation has examined the effects of psychological strategies on upper-body power (103). Indeed, the previous investigation examined the effects of feedback on a relatively complex skill based task (overhead water polo throw), whereas the current investigation examined the effects on a simpler task (bench throw). Secondly, this was the first investigation to examine the effects of feedback in well-trained athletes using assessment procedures typical of a traditional resistance training session i.e. consisting of multiple sets and repetitions. As such, the current investigation addresses a deficit in the strength and conditioning literature.

Receiving verbal feedback improved mean peak power and velocity of the training session by 1.8% and 1.3%, respectively. The greatest benefit when receiving feedback appears to be in the latter sets of training. Indeed, when each set was analysed separately, improvements were greatest in the final set (3.1% mean peak power; 1.6% mean peak velocity). These findings suggest that receiving feedback improved the rate of work done and the therefore the overall quality of the training session, especially as the training session progresses. If these improvements can be made during one training session, the long-term effects of repeating these 'higher quality' sessions may result in enhanced training adaptations and potentially better performance (116, 159, 207). Although the benefits gained may appear small, it should be noted that previous literature has reported 5% improvements in upper-body power in elite Rugby League players over a four year period (22). As such, improvements of ~3.1% in a single session are a positive and worthwhile finding.

Performance improvements were smaller than previously reported in studies investigating the effects of psychological strategies in muscular force (114, 123, 151, 194, 195, 199). Differences may be due to the level of participants and musculature recruited. It is commonly accepted that well trained individuals routinely recruit a greater percentage of their muscles than their untrained counterparts (125, 168, 198). Therefore in untrained individuals, there may be a greater potential for feedback and other psychological strategies to enhance muscular activation and subsequent performance improvements. The smaller improvements in the current study may also be due to the muscle group involved (i.e. upper-vs. lower-body, with the larger muscle mass of the lower-body possibly having a greater scope for improvement.

The mechanisms for improvements as a result of feedback were not assessed in the current investigation. Previously, authors have speculated that improvements from psychological interventions such as feedback may be due to a combination of enhanced neuromuscular activation, intent, focus of attention, levels of arousal, and improved skill performance and learning (114, 123, 138, 151, 194, 211). Further research should attempt to identify the mechanisms that lead to performance improvements with specific feedback as this may allow the nature of the feedback to be altered to further augment the acute response.

Interestingly, there appeared to be a small increase in mean peak power and velocity from set one to set two in both conditions (Figure 3; Figure 4). It is possible that either the warm-up prior to the first set was not adequate to prepare the players for maximal effort, or although not measured in the current investigation, there may have been potentiating effects provided from the first training set. Post-activation potentiation is a phenomenon in which acute muscle force output is enhanced as a result of contractile history and typically is evident following maximal or near maximal lifting (173). However it is possible that the lighter load performed with maximal intent may have provided some potentiating effects. Indeed, Thompsen and colleagues (193) reported increased standing long jump distance after performing a dynamic warm up wearing a weighted vest of only 10% bodyweight when compared to performing the same warm up without the additional weight. Although in the current study both groups tended to produce greater mean peak power on set two than set one, we observed a small but unclear difference (effect size = 0.37 ±0.83) in mean peak power between the conditions, suggesting the possibility that the increase in mean peak power across the first two sets was greater in the feedback than no-feedback condition (Figure 3). It may therefore be suggested that in addition to post-activation potentiation, the greater improvements in power for the feedback group may have been in part due to a potentiating effect of receiving feedback.

The use of verbal feedback resulted in acute increases in upper-body mean peak power and velocity. However it is unknown whether providing acute feedback to players across multiple training sessions will provide continuous acute adaptations in performance over a longer training phase, or if adaptation will diminish with repeated use. Future research should investigate the chronic training effects of receiving feedback to determine any long term use benefits.

Practical Applications

Providing augmented feedback during the performance of a typical power training exercise improves the rate of work done (i.e. power output) and hence the quality of training of well-trained athletes, in which even a small improvement~~s~~ in power is difficult to achieve. Based on our findings, conditioning coaches and athletes should consider the use of specific feedback (i.e. velocity) during a resistance training session to improve performance and maximise training quality.

CHAPTER SIX

Study Five: Assessing Lower-Body Peak Power in Elite Rugby Union Players

Introduction

Rugby Union is a competitive sport which requires high levels of muscular power. As such, training methods that enhance muscular power are of extreme importance for the physical preparation in these athletes. The load that maximizes peak power (Pmax) has been discussed for more than 20 years and has been suggested to enhance power and performance in explosive exercise (19, 116, 159). It has been proposed that training at the load that maximizes power may provide favourable neural and muscular adaptations (116, 159, 207).

To accurately determine the effects of training at Pmax, Pmax must first be identified at an individual level. However, large variations in the load that produces Pmax have been reported (14, 19, 53, 55, 99, 102, 116). Traditionally, findings suggest that Pmax is typically expressed at loads ranging from 30% to 70% of maximum strength (19, 102). More recently, some studies have reported that Pmax occurs at loads less than 30% of maximal strength (53, 55). The large between-study variation in Pmax appears to be due to differences in the exercises performed, the methods used to assess power, and the participants recruited (64). As such, using a Pmax load from the literature may be ill-advised as it seems necessary to identify individual and specific Pmax loads in order to maximise training responses.

To accurately quantify Pmax, power outputs across multiple loads need to be investigated. Recently, researchers have reported that vertical jump Pmax occurred when using bodyweight only (53, 55). However, power was not assessed at loads less than bodyweight. As such, whether Pmax can be increased further with negative loading is unclear. A novel approach to assess bodyweight at negative loads is with the use of elastic bands that may be attached in a manner which provides upward tension, thereby reducing the effective bodyweight of the subject.

Another methodological issue is that many investigations have assessed Pmax using single efforts (repetitions) at each load (53, 54, 62, 99, 102), whereas power training typically consists of performing sets of three to five consecutive repetitions (21). Furthermore, recent literature has revealed that power is not maximised until the second or third repetition of a set (23). If the overall aim is to train at Pmax (using consecutive repetitions); then Pmax should be assessed in the same manner. To date only Baker and colleagues (14, 19) have assessed Pmax in a training environment performing multiple consecutive repetitions and reported that Pmax occurred between 40-70% of maximum strength. Finally, the experience level (or training history) of subjects assessed may produce variation in the findings. Baker (14) reported that stronger athletes may produce Pmax at lower intensities than weaker athletes. Therefore, to make accurate comparison between investigations, subjects need to be of similar strength levels.

Elite Rugby Union players typically have high levels of strength and regularly perform resistance training with multiple sets and consecutive repetitions. If methodology issues have an effect on the load that maximises peak power, then specific population assessment needs to occur to accurately identify Pmax. Determining Pmax in this population will provide players with specific training intensities that allow maximal peak power to be achieved during training, which in turn may lead to enhanced performance gains (116, 159, 207). Therefore, the purpose of this investigation was to determine lower-body Pmax in elite Rugby Union players.

Methods

Experimental Approach to the Problem

In order to more accurately quantify Pmax in terms of how it is commonly applied to training programs, elite Rugby Union players were assessed for lower-body maximal strength and power across a spectrum of loads including negative loading. Four separate sessions were assessed, with each session separated by 24 hours (Table 22). Multiple repetitions were performed in each set (one set of four repetitions at each load) to be more representative of a typical training session. Peak power was selected as the dependent measure as it has been reported to have the greatest association with athletic performance (72). Power was assessed using the jump squat exercise due to its common usage in power training programs and research studies and its ability to represent lower-body power (10, 19).

Table 22. Order and outline of strength and power assessments.

	Mode	Exercise	Load
Session One	Lower-body strength	Box squat	Maximal
Session Two	Lower-body power	Jump squat	-28%, -15% 1RM box squat
Session Three	Lower-body power	Jump squat	0%, 20%, 30% 1RM box squat
Session Four	Lower-body power	Jump Squat	40%, 50%, 60% 1RM box squat

RM, Repetition maximum. Twenty four hours separated each session.

Subjects

Eighteen elite Rugby Union players from a Super Rugby professional team during the pre-season phase of their campaign volunteered to take part in this study (mean ± SD; age, 23.8 ± 2.2 years; height, 185.8 ± 6 cm; mass, 103.8 ± 10.6 kg). Each player had undergone at least two years of intensive and regular resistance training exercise, and must have been competing in a prior national or international Rugby competition to be included in this study. Players were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for use of human subjects. Four players were unable to attend session two due to unforeseen circumstances.

Procedures

Strength

Maximal strength was assessed using the box squat exercise using methods previously outlined (10). Briefly, following three sub-maximal sets of box squat, each player then performed one set to failure of one to four repetitions. Players used a self-selected foot position and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each player to allow the top of the thighs to be parallel to the floor while in the seated position. The box squat was performed using free weights. Three minutes rest was allowed between each set. Each set to failure was used to predict the players' one repetition maximum (1RM).

The following equation was used to predict box squat 1RM (132). This equation is a valid measure of 1RM strength as it has been shown to have a correlation between actual and predicted 1RM of r = 0.969 (136):

$$1RM = (100 \times weight)/(101.3-(2.67123 \times reps))$$

Jump Squat

Lower-body power was assessed using a jump squat exercise performed in a Smith machine. Players warmed up with two sets of four repetitions lowering the bar to a 90° knee angle using a load of 50% of their 1RM box squat. Players then completed one set of four repetitions of jump squats at -28% (± 5%), -15% (± 3%), 0% (bodyweight), 20%, 30%, 40%, 50% or 60% 1RM box squat. Players used a self-selected foot position and lowered the bar to a self-selected depth during these performance tests. Players were then required to jump as explosively as possible trying to jump as high as they could (10). Three minutes rest was allowed between each set. The bodyweight jump was assessed using a broomstick which was placed behind the neck and on the top of the shoulders. The -28% (± 5%) and -15% (± 3%) jump squats were an assisted jump, performed in a squat cage wearing a climber's harness with an elastic band (Iron Woody LLC, Olney MT, USA) attached to either side of the harness (at the hip level), with the other end attached above the player to the top of the squat cage. Two thicknesses of elastic bands were used. The elastic bands provided vertical tension which reduced the body weight of each player when the player was in a standing position with hip and knee fully extended. The reduction in weight was assessed by having players stand on scales with and without the attachment of the elastic bands.

The power and displacement produced during each repetition was quantified with a GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) using the methods described elsewhere (9, 71). Quantification of the power produced included bodyweight and bar mass (system mass) in the calculation (72).

Statistical Analyses

To estimate the load that maximized mechanical power output, a quadratic was fitted to each player's power output (in Watts) and load (% of 1RM). However, in all but two players, power at bodyweight was clearly above any quadratic curve fitted to the points (Figure 6). Additionally, for the four players that did not complete the assisted jumps, the quadratic curves all had positive curvature where theory predicts negative curvature. Therefore, for all players we used the value observed at bodyweight for Pmax. Findings were discussed as means and standard deviations.

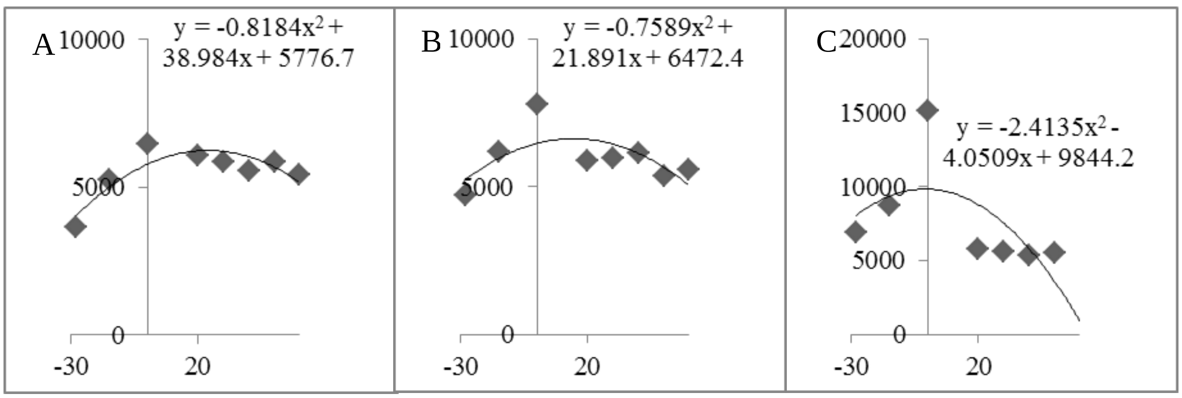

Figure 6. Examples from three different subjects of quadratics fitted to power outputs at different intensities. The data point on the vertical axis represents bodyweight. A, example of best fit. B, example of typical fit. C, example of worst fit.

In addition to fitting a quadratic, standardised differences of the mean were used to assess magnitudes of effects between each individual load assessed by dividing the differences by the appropriate between-player standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, 1.2, and >2.0 for small, moderate, large and very large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial (25, 109). Lastly, displacement data were log-transformed to reduce non-uniformity of error, and the differences were derived by back transformation as percent changes (108). To make inferences about the true (large-sample) value of an effect, the uncertainty in the effects were expressed as 90% confidence limits.

The interclass correlation (ICC) and coefficient of variation (CV) for box squat has been previously assessed in our laboratory using professional Rugby Union players and was r = 0.915 and 4.6%, respectively. The ICC's and CV% for jump squat at 0% and 50% of 1RM box squat were 0.834 and 4.2%, and 0.904 and 4.8%, respectively. All test-retest reliabilities were assessed seven days apart. Validity of the GymAware® optical encoder has been previously reported elsewhere (71). The sample size for this investigation was limited to the number of players in the squad. All players in the squad that were injury free were included and therefore no more players could be obtained.

Results

The mean predicted 1RM box squat was 147.9 kg (± 26.8 kg). The greatest lower-body peak power was 8880 W (± 2186 W) which occurred at bodyweight (Figure 7). The mean peak power produced during the bodyweight jump was greater (moderate to large effect size) than that of all other intensities assessed. Sixteen out of the eighteen players produced peak lower-body power at bodyweight. Due to the irregularity in the lower-body power results, whereby a quadratic could not be fitted to the points (see Statistical Analyses; Figure 6); we re-examined the GymAware® data to gain some insight into the potential reasons underlying this result. As the GymAware® system is a linear position transducer, we started by examining the displacement data to ascertain whether differences in technique between the different jump intensities may have contributed to this finding.

Analysis of the displacement data revealed that during the bodyweight jump, the self-selected depth (dip) prior to the propulsive phase of the jump was greater by 24% (±11%) to 40% (±16%; moderate to large effect size) than all positive loads. As the loads increased, the players continued to reduce the depth of their countermovement. Small differences in the countermovement depth ranging from 11% (±11%) to 17% (±14%) were observed between 20% and 40%, 20% and 50%, and 20% and 60% 1RM box squat load. Additionally, small differences ranging from 7% (±9%) to 14% (±9%) were also observed between 30% and 50%, 30% and 60%, and 40% and 60% 1RM box squat load.

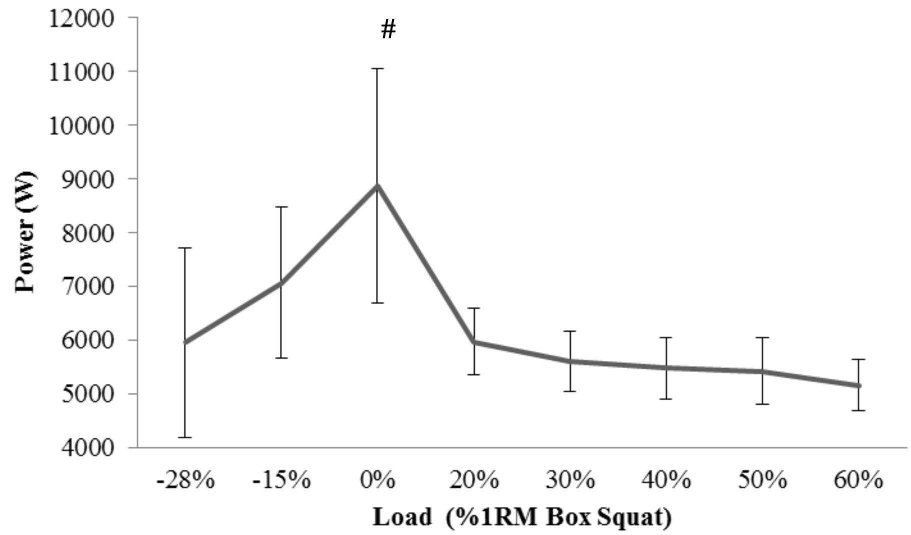

Figure 7. Mean jump squat peak power at a spectrum of relative loading intensities in elite Rugby Union players. RM, Repetition maximum. n = 18. #, denotes moderate to large differences (effect size) between 0% and all other loads.

Discussion

It has been hypothesized that training at Pmax is beneficial for increasing muscular power (19, 116, 159). Therefore the purpose of this investigation was to determine lower-body Pmax in elite Rugby Union players. By assessing power at negative loading we were able to identify a decline in power either side of the maximum power output which previous literature has not assessed (53, 55). Peak lower-body power occurred with no loading (bodyweight) in 16 of the 18 players. However, discontinuity in the power outputs of the lower-body was observed between bodyweight and all loaded jumps.

An interesting phenomenon occurred when assessing lower-body power across this spectrum of negative and positive loads. In all but two of the players assessed, power with no loading was substantially higher than all other loads assessed and was clearly above any quadratic curve that was fitted through all of the individual data points (Figure 6). On closer observation, there appeared to be discontinuity of the power outputs between bodyweight and all positive loads. Indeed, negative and bodyweight loads appeared to exhibit a different power-load relationship to the positive loads. As such, it may be that a separate quadratic curve needs to be fitted to each power-load relationship when loaded and unloaded intensities are assessed. However, this would result in two Pmax intensities, one for training with unloaded jumps and another for loaded jumps.

The separate power-load relationships may suggest that something substantially affects power output when players jump with an additional load. Analysis of the position data produced by GymAware® identified that during the bodyweight jump; the self-selected depth (dip) prior to the propulsive phase of the jump was greater than for all loaded jumps (24% - 40%). Similar to findings by Markovic and Jaric (145); as the loads increased to a greater percentage of 1RM there was a further reduction in the depth of the counter-movement. As such, the disproportionally higher power output at bodyweight may be due to the larger dip used in this jump. The use of a greater dip with the bodyweight load may have afforded this jump some biomechanical advantages that contributed to the greater power outputs. The deeper countermovement would have increased the time to produce force. According to the impulse-momentum relationship, greater time to produce force would increase the amount of impulse (force multiplied by time) generated, which in turn would result in a greater change in the momentum (velocity) of the system (130). Additionally, the greater dip would have increased the amount of stretch placed on the agonist musculature and, via the force-length relationship, would theoretically allow greater forces to be generated (179).

The methodological concerns observed could be controlled by keeping the depth consistent for all jumps. However, what should the constant depth be? If it is too low, velocity of the movement may be compromised and there is chance of increasing the likelihood of injury when jumping with heavy loads. If it is not low enough, it may prevent an optimal combination of force and velocity, thus reducing power output and defeating the purpose of assessing Pmax. Additionally, how should the depth be controlled? Cormie and colleagues (55) attempted to control depth by visually monitoring knee angle to a depth of 90°. However, Cormie and colleagues (55) still reported significant differences in depth between the different loading intensities. Harris and colleagues (99) controlled depth by performing a concentric only jump squat starting at a fixed knee angle of 110°. However, what if the purpose of your training was to improve stretch shortening cycle and countermovement peak power? Young and colleagues (213) suggested that executing a countermovement at a self-selected depth encouraged subjects to find their own optimum jumping conditions. Furthermore, as previously alluded to in the introduction, if the goal is to train at the Pmax load, Pmax needs to be assessed in the manner it is trained. For most players, they will train using a self-selected depth.

The discontinuity in jump technique (amount of dip) between each load makes determining Pmax for the lower-body problematic. If lower-body Pmax cannot be accurately determined; then the contention that training at the load that maximises power may provide favourable neural and muscular adaptations (116, 159, 207) would appear somewhat problematic.

Lower-body peak power occurred at bodyweight, a finding similar to Cormie and colleagues (53, 55) who reported that lower-body peak power occurred at bodyweight in well trained (football players, long jumpers and sprinters) (53) and untrained males (55). In contrast, Siegel and colleagues (183) reported that peak power occurred between 50% and 70% 1RM squat in untrained subjects, while Sleivert and Tainghue (184) reported that peak power occurred at 60% of 1RM squat in trained athletes. The difference in findings is likely due to the inclusion or exclusion of system mass (i.e. bar mass plus bodyweight) in the calculation of power. In the current investigation, and investigations by Cormie and colleagues (53, 55); all of which found peak power to occur at bodyweight, system mass was included in the calculation of power. Whereas the investigation by Sleivert and Taingahue (184) used bar mass only. Additionally, Siegel and colleagues (183) did not state that system mass was included in their calculations. This becomes extremely important when comparing findings as the inclusion or exclusion of bodyweight can cause a shift in peak power from 20% (system mass included) to 70% of 1RM (system mass excluded) (72). Therefore the higher Pmax observed in the two investigations may be artificially high due to the exclusion of system mass from the calculation.

Heavy strength training and/or high velocity training has been shown to be effective in improving explosive performance in some studies (116, 143, 148). However, it has been suggested that training at Pmax may enhance power and performance in explosive exercise more so than heavy strength and/or high velocity (19, 116, 159). It should be noted that there is only a limited and equivocal literature the comparisons of that compares training at Pmax with heavier and/or lighter loads, and as such the load that maximises performance adaptation is still somewhat unknown.

The load that maximizes peak power may be influenced by several factors including the spectrum of loads assessed and whether comparisons are made between loaded and unloaded conditions. Additionally, data calculation and reporting methods (i.e. inclusion or exclusion of bodyweight) can influence Pmax.

Practical Applications

Lower-body Pmax occurred at bodyweight in 16 of the 18 players. However, results indicated there was a discontinuity between loaded and unloaded jumps. As such lower-body current Pmax assessment procedures may be flawed due to the inability to accurately determine the load that maximises peak power. Methods that can assess and improve lower-body power in a training environment need to be developed. We suggest assessment using a range of heavy and lighter intensities for each individual in each exercise, in a manner similar to how an athlete commonly trains. This assessment will increase external validity and possibly result in an increased likelihood of enhanced training adaptations.

CHAPTER SEVEN

Study Six: Kinetic and Training Comparisons between Assisted, Resisted and Free Countermovement Jumps

Introduction

The ability to develop high levels of muscular power is critical for successful performance in many sports (98). However, as the training age of an athlete increases, there is a tendency toward a diminishing rate of improvement in muscular power (22). Furthermore, Argus and colleagues (10) recently reported that reductions in power may occur over a competitive season of professional Rugby Union. These observations highlight the need to develop training methods that promote positive adaptation in power output in well trained athletes, especially during the competitive phase of a season.

As power is the product of force and velocity, manipulation of these two variables in a periodised resistance training program via alterations of the training loads may be essential for positive power adaptation (159). The more highly developed a single component; the less potential there is for power adaptation to occur; therefore training schemes need to focus on the components of power which are less developed. For example, for athletes who have already acquired high levels of strength (force), the use of traditional strength training methods may be insufficient for enhancing explosive power. For these athletes, more specific training interventions focusing on the velocity of the movement may be required to improve power output (128, 159).

The use of assisted and resisted countermovement jump training with the aid of elastic bands may be a useful approach to manipulate the force velocity relationship and develop lower-body power. Cronin and colleagues (63) reported improvements in peak movement velocity (5.4%), peak power (14.3%) and single leg jump height (2.5%) following ten weeks of ballistic training when resistance was added to a countermovement jump exercise by elastic bands. Alternately, several authors have reported that greater power output and velocities can be produced during unloaded / assisted countermovement jumping (45, 122, 145), commonly with the aid of elastic bands (122, 145). Using elastic bands to perform assisted jump training therefore appears to have analogous benefits to those described in over-speed sprint training literature (56, 142).

It is commonly accepted that over-speed or downhill running can improve sprint performance. Corn and Knudson (56) reported a 7.1% increase in velocity in the acceleration phase of a 20 meter sprint using elastic cord to provide horizontal assistance. Additionally, Majdell and Alexander (142) reported increases in 40 yard sprint time following six weeks of over-speed sprint training. Thus, the possibility exists that assisted jump training would provide similar adaptations to those observed with over-speed or downhill running.

To date, research examining the kinetic differences between assisted, free (i.e. bodyweight) and resisted countermovement jumps is scarce. Understanding the kinetic characteristics of these jumps may help us to more accurately predict potential changes in performance following long term use. In turn, this understanding may allow for enhanced individualised prescription of training through more specific programming of the separate components of muscular power (159).

One way in which plyometric jumps are often incorporated into a resistance training program is by prescribing a contrast loading scheme. Contrast training is a method that combines low and high velocity resisted movements by alternating an exercise set of moderate to heavy load with a biomechanically similar exercise performed with a lighter load (20, 75). The moderate to heavy load is generally a strength-orientated exercise, whereas the lighter load is a velocity-orientated exercise during which acceleration occurs over the full range of the movement (20). Contrast training methods have been shown to acutely enhance power output in both the upper and lower extremities by approximately 5% (14, 20, 213), although it has been suggested that this method may be more advantageous in athletes with relatively high levels of strength (20, 75).

Therefore the purpose of this investigation was 1), to determine the kinetic differences between assisted, free, and resisted countermovement jumps; and 2), to investigate the effects of contrast training utilising either assisted, free, or resisted countermovement jump training on vertical jump performance in well trained athletes. We hypothesized that 1), jumping with assistance would result in the greatest maximal velocity; and 2), due to the lack of previous over-speed training, assisted jump training would produce the greatest improvements in counter-movement jump height.

Methods

Part One

Experimental Approach to the Problem

To determine the kinetic differences between assisted, free, and resisted countermovement jumps subjects performed three trials of each jump on a Kistler force plate (Kistler Instruments Inc., Winterthur, Switzerland) in a randomized order within a single session. Peak power relative to the adjusted bodyweight once assistance or resistance had been provided ($PP \cdot kg^{-1}$) and peak velocity were determined for all jumps using the vertical ground reaction force data (72). Power was calculated using methods described in Dugan and colleagues (72) where i = time point based on sampling frequency, F = force, t = 1/sampling frequency, m = total mass, v = velocity, P = power:

$$v_{(0)} = 0$$

$$F_{(i)}t = m(v_{(i+1)} - v_{(i)})$$

$$\Delta v = (F_{(i)}t) / m$$

$$P_{(i)} = F_{(i)} * v_{(i)}$$

The absolute force trace (which included the unloaded or increased bodyweight once assistance or resistance had been provided) for each jump was analysed in four separate phases (Figure 11). For each phase the peak force as well as the rate of force development and unloading were calculated as the slope of the force-time curve from minimum force to peak force, or peak force to minimum force, respectively (36). These dependent measures were selected as they are considered important factors that contribute to explosive muscular power (159). Each subject performed two familiarisation trials within the ten days prior to, but not within 36 hours of the testing day. Each familiarisation trial consisted of each subject performing three sets of five repetitions using each of the three jump conditions.

Subjects

Eight recreationally trained men volunteered to participate in this part of the investigation (mean ± SD; age, 27.5 ± 5.5 years; height, 179.9 ± 4.9 cm; mass, 84.2 ± 14.3 kg). All subjects had been performing resistance training which included plyometrics twice a week for at least six months prior to the beginning of the investigation. None of the subjects were participating in any competitive sport at the time of assessment. Subjects were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for the use of human subjects.

Procedures

Warm-up

Subjects performed a standardised warm-up of two sets of ten bodyweight squats at a self-selected velocity followed by two sets of five free countermovement jumps performed with maximal effort. Each warm-up set was separated by a one minute rest period. Subjects then performed each of the three jump conditions in a randomised order. There were six possible sequences of treatment (A-B-C, A-C-B, B-C-A, B-A-C, C-A-B, and C-B-A), which meant two sequences were performed twice.

Assisted Jumps

Subjects performed assisted jumps inside a squat cage whilst wearing a climber’s harness. An elastic band was attached to either side of the harness at the hip level, with the other end attached to the squat cage above the subject (Figure 8). The harness straps were adjusted (tightened/loosened) so the elastic bands provided upward vertical tension which reduced the bodyweight of each subject by 20% when in a standing position on the force platform with hip and knee fully extended. The jump execution consisted of subjects lowering themselves to a self-selected depth and then jumping for maximal height. The assistance provided by the bands decreased as the subject left the ground following the concentric phase of the movement and was greatest as subjects lowered themselves to a self-selected depth. An arm swing was permitted during each jump but was abbreviated due to the placement of the elastic bands.

Figure 8. Example of the assisted jump set up. A harness and elastic bands were attached to the participant and to the squat cage above.

Resisted Jumps

Subjects performed resisted jumps inside a squat cage whilst wearing a climber's harness. An elastic band was attached to either side of the harness at the hip level, with the other end attached to the squat cage below the subject (Figure 9). The harness straps were adjusted (tightened/loosened) so the elastic bands provided downward vertical tension which increased the bodyweight of each subject by 20% when in a standing position on the force platform with hip and knees fully extended. The resistance provided by the bands increased as the subject left the ground following the concentric phase of the movement and was at its least as subjects lowered themselves to a self-selected depth. The jump execution was consistent with that described above for the assisted jumps.

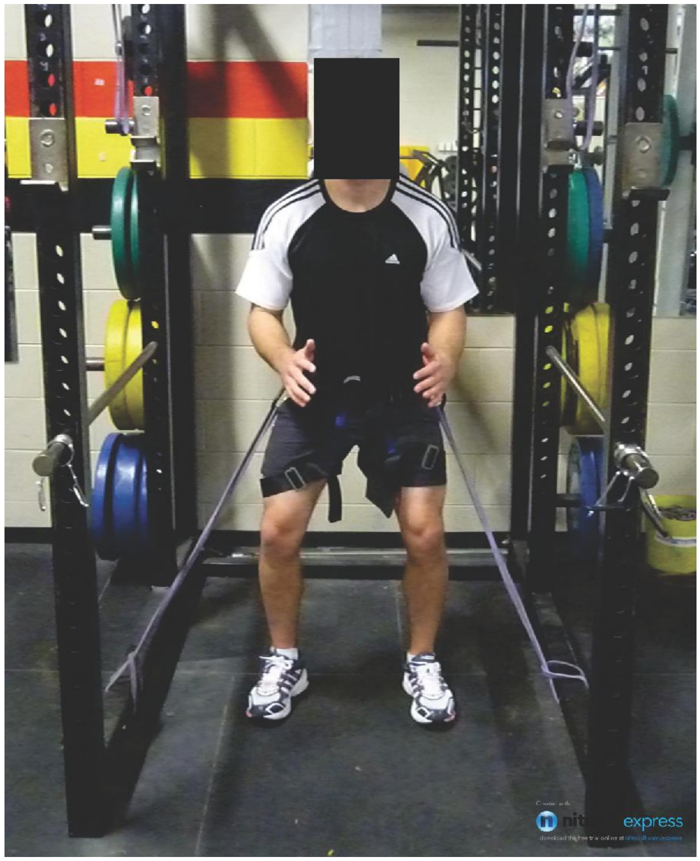

Figure 9. Example of the resisted jump set up. A harness and elastic bands were attached to the participant and to the squat cage below.

Free Jumps

Subjects performed free countermovement jumps with no assistance or resistance (i.e. bodyweight only). The jump execution was consistent with that described above for the assisted and resisted jumps (97).

Statistical Analyses

The greatest peak force produced during the loading phase was used to determine the best trial for each condition and was subsequently used for the analysis. All kinetic data were log-transformed to reduce non-uniformity of error, and the effects were derived by back transformation as percentage changes (108). Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-subject standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, 1.2, and <2.0 for small, moderate, large and very large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial. An effect size of 0.2 was considered the smallest worthwhile positive effect. To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The intra-class correlations for the each jump condition are presented in Table 23.

Table 23. Intra-class correlations (r) of peak force, peak velocity and peak power in three different countermovement jumps (assisted, free, and resisted) performed by eight recreationally trained men.

	Assisted	Free	Resisted
Force	0.964	0.987	0.996
Velocity	0.860	0.985	0.849
Power	0.908	0.990	0.989

Part Two

Experimental Approach to the Problem

Part two of the study sought to investigate the effect of contrast training utilising assisted, free, or resisted countermovement jumping on the vertical jump performance of professional Rugby players. Players were assessed for maximal jump height and performed four weeks of contrast training consisting of a power clean exercise alternated with an assisted, free, or resisted jumping exercise twice a week (Tuesday and Thursday mornings; Figure 10). Players were then re-assessed for maximal jump height at the end of the four week training phase. All training was performed in conjunction with, and during, the player's regular training program. Jump height was chosen as the primary outcome measure as it is a reliable and valid measure for the assessment of lower-body power and has been shown to correlate with sprint performance (201). Fifteen players were assessed one week apart to assess reliability of the measure. All assessments for vertical jump height were performed in the morning between 8.30am – 9.45am. All players were also requested to utilise similar nutrition and hydration strategies in the 24 hours proceeding each testing session.

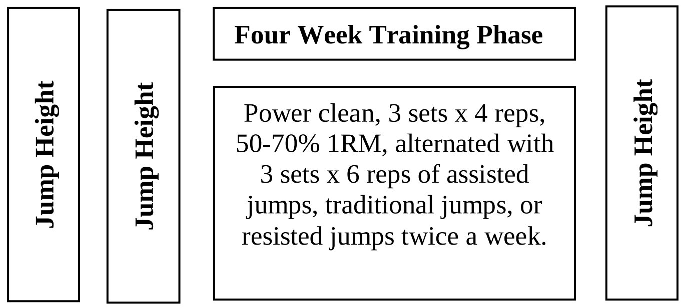

Figure 10. Outline of assessment and training in elite Rugby Union players. Seven days separated jump height assessments and training phases. Reps, repetitions; RM, repetition maximum. Assisted jumps, n=9; free, n=8; resisted jumps, n=11.

Subjects

Twenty-eight professional Rugby Union players from a New Zealand Super 14 Rugby team volunteered to take part in this study during their competitive season (Table 24). Each player had been performing intensive and regular resistance and plyometric training for a minimum of two years. The players were matched for jump height and playing positions, and were placed into one of three separate training groups: assisted jumps (n=9), free jumps (n=8), or resisted jumps (n=11). Players were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for the use of human subjects.

Table 24. Subject characteristics of three separate countermovement jump training groups.

	Assisted (n=9)	Free (n=8)	Resisted (n=11)
Age (y)	25 ± 2	24 ± 2	23 ± 2
Height (cm)	184 ± 8	186 ± 6	183 ± 4
Mass (kg)	101 ± 10	101 ± 10	100 ± 4

All data is mean ± standard deviation.

Procedures

Performance Assessment

Jump height was assessed using a countermovement jump. Players completed a standardised warm-up of two sets of ten bodyweight squats at a self-selected velocity followed by two sets of five, free countermovement jumps performed with maximal effort. Players then performed two sets of four maximal countermovement jumps with the highest jump used for analysis (160). Three minutes of rest was allowed between each set. Jump height was assessed and recorded using a GymAware® optical encoder (50 Hz sample frequency with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) using the methods described elsewhere (71). Briefly, GymAware® consists of a spring-powered retractable cord that passes around a pulley mechanically coupled to an optical encoder. The retractable cord is then attached to the broomstick and displacement was calculated from the spinning movement of the pulley upon movement of the barbell. The encoder gave one pulse approximately every three millimetres of load displacement, with each displacement value time stamped with a one-millisecond resolution (71).

Training

All players performed four repetitions of a power clean exercise 60 seconds prior to six repetitions of assisted, resisted, or free countermovement jumps. Each player performed three sets, with three minutes rest between each set. The load lifted for the power clean exercises was between 50% and 70% of one repetition maximum and was dependent on the training microcycle for each individual. Variation in the load lifted was due to a greater volume of Rugby Union game time completed by some players.

Assisted Jumps

Assisted jumps were performed in the same manner as described in Part One, but without rest between each repetition. The elastic bands provided upward vertical tension which reduced the bodyweight of each player by 28 ± 3 % when the player was in a standing position with the hip and knee fully extended. Each participant was weighed on two separate occasions to assess the assistance provided. The assistance varied from part one as no adjustments (tightening or loosening) were made to the harness. Time constraints of the training session made it impossible to weigh and adjust the weight of each player prior to each set of jumping.

Resisted Jumps

Resisted jumps were performed as described in Part One, but without rest between each repetition. The elastic bands provided a downward vertical tension, which increased the load by 27 ± 5 % above bodyweight when players were in a standing position with their hips and knees fully extended.

Free Jumps

Free jumps were performed as described in Part One.

Additional Training

All jump training was performed in conjunction with, and as part of, the player's regular resistance training sessions. Each week the players typically performed two resistance training sessions (30-50 min, 4-6 exercises, 1-6 repetitions [strength/power], 2-3 min rest), one speed development session (20-30 min, including fast foot ladders, mini hurdles, weighted sled towing, maximal sprinting), four team training sessions (30-75 min, including specific Rugby skill, tactical, and tackling), one competitive match, and one recovery session (20-40 min, including light exercise, stretching, hot and cold baths).

Statistical Analyses

All data were analysed in the same manner as Part One. Changes in jump height were presented as mean ± standard deviations, while comparisons between training conditions were presented as mean ± 90% confidence limits. An effect size of 0.2 was considered the smallest worthwhile positive effect. Validity of the GymAware® optical encoder has been previously reported elsewhere (71). The coefficient of variation (CV) and intra-class correlation (r) for the vertical jump height performance within this cohort was 4.3% and 0.83, respectively.

Results

Part One

The peak vertical velocity attained in the loading phase (Phase B, Figure 11; Table 25) of the assisted jump was 37.4% (±5.3%; 90% confidence limits, CL) and 6.3% (±3.7%) greater than attained in the resisted and free jump (effect size [ES], very large and moderate, respectively). A very large difference (33.5 ±6.8 %) in velocity between the free and resisted jump was also observed (Table 25).

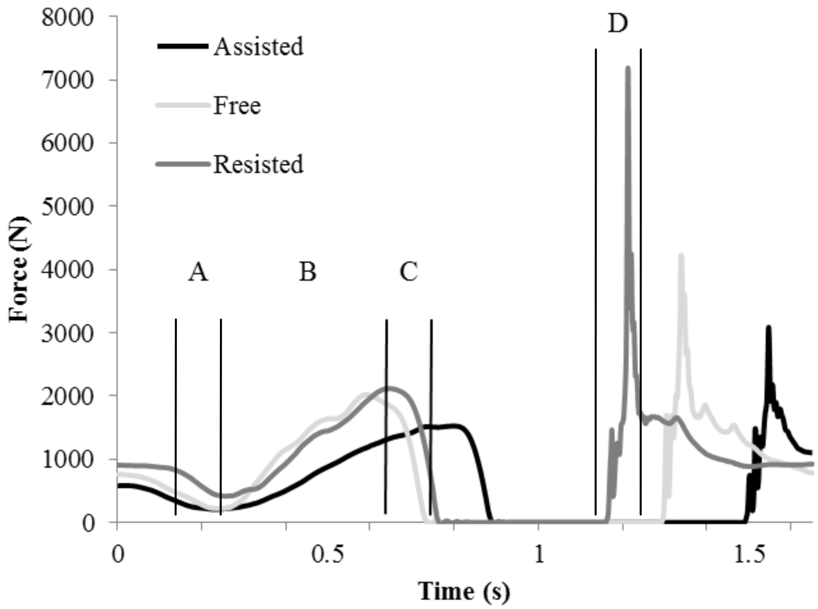

Figure 11. Example from one participant of forces produced in the three different jump conditions. The different phases of the movement have also been labelled (resisted jump only). A, early unloading phase; B, loading phase; C, unloading phase prior to flight; D, impact.

Table 25. Relative peak power and peak velocity produced in three different countermovement jump conditions (assisted, free, and resisted).

	Assisted (mean ± SD)	Free (mean ± SD)	Resisted (mean ± SD)
Peak Power ($W \cdot kg^{-1}$)	50.4 ± 8.0$^{\#}$	49.4 ± 6.0$^{\#}$	33.3 ± 8.3
Peak Velocity ($m \cdot s^{-1}$)	2.8 ± 0.3$^{\#*}$	2.7 ± 0.2$^{\#}$	1.8 ± 0.3

SD, standard deviation. n = 8. #, very large effect size vs. resisted jumps; *, moderate effect size vs. free jumps.

Relative peak power ($W \cdot kg^{-1}$) was greatest in the assisted jump and was 35.0% (±22.7%) greater than the resisted jump (very large ES). Additionally, relative peak power was 34.0% (±13.7%) greater in the free than the resisted jump (very large ES). There was no difference in relative peak power between the free and assisted jump conditions (Table 25). Figure 12 illustrates the variation in velocity, peak power, and peak force, in the separate countermovement jumps between subjects.

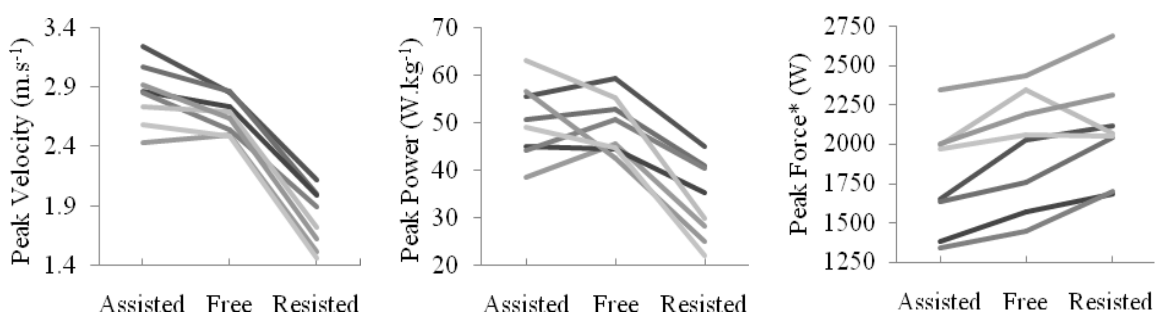

Figure 12. Subject variation (n=8) in peak velocity, peak power, and peak force, in three separate countermovement jumps, assisted, free, or resisted. *, peak ground reaction force during the concentric phase of the jump prior to flight. W, watts.

The amplitude of force unloading during the early unloading phase (Phase A) of the jump was 16.9% (±17.1%) greater in the resisted jump than the assisted jump (moderate ES; Table 26). There was no difference in the rate of force unloading during the early unloading phase.

The peak force produced during the loading phase (Phase B) was 5.8% (±6.4%) and 17.2% (±5.8%) greater in the resisted jump than the free and assisted jumps (small and moderate ES, respectively). Additionally, peak force was 10.7% (±4.0%) greater in the free jump compared to the assisted jump (small ES). A small difference was observed in the change in force during the loading phase and was 7.9% (±11.5%) greater in the resisted jump when compared to the assisted jump method.

The rate of force development, measured as the slope of the force-time curve in the loading phase (Phase B), was greatest in the resisted jump (4268 ± 2125 $N{\cdot}ms^{-1}$). A moderate difference of 21.6% (±26.5%; 90% CL) was observed in the rate of force development during the loading phase between the resisted jump and free jump.

The rate of force decline, calculated as the (negative) slope of the force-time curve from peak force to zero force (Phase C) was greatest in the resisted jump when compared to free (19.5 ±22.5 %; 90% CL) and assisted jumps (78.2 ±75.7 %; 90% CL) and represented a small and moderate effect size, respectively.

The greatest impact force was generated in the resisted jump (Phase D) and was 66.5% (±41.3%; 90% CL) and 22.0% (±25.0%; 90% CL) greater than the assisted jump and free jump, respectively (ES, moderate). Additionally, the free jump produced 36.4% (±35.3%; 90% CL) greater force on impact when compared to the assisted jump (ES, moderate). Similarly, the greatest rate of force development on impact was generated in the resisted jump, being 98.7% (±45.8%; 90% CL) and 35.7% (±33.4%; 90% CL) greater than the assisted jump and free jump (ES, moderate and small, respectively). Additionally, the rate of force development on impact was 46.4% (±39.8%; 90% CL) greater in the free jump when compared to the assisted jump (ES, moderate).

Table 26. Comparison of jump force data between assisted, free and resisted countermovement jumps in eight recreational level subjects.

	Assisted (mean ± SD)	Free (mean ± SD)	Resisted (mean ± SD)
Phase A: Early Unloading Phase			
Max (N)	680 ± 110	840 ± 140	1030 ± 180
Min (N)	230 ± 130	360 ± 150	500 ± 240
Amplitude (N)	440 ± 100	490 ± 220	540 ± 230
Rate ($N \cdot ms^{-1}$)	-2.1 ± 1.2	-2.1 ± 1.1	-2.6 ± 1.7
Phase B: Loading Phase			
Max (N)	1790 ± 350	1980 ± 360	2080 ± 320
Min (N)	230 ± 130	360 ± 150	500 ± 240
Amplitude (N)	1550 ± 270	1620 ± 430	1580 ± 240
Rate ($N \cdot ms^{-1}$)	3.4 ± 1.3	3.5 ± 1.7	4.3 ± 2.1
Phase C: Unloading Phase Prior to Flight			
Max (N)	1790 ± 350	1980 ± 360	2080 ± 320
Rate ($N \cdot ms^{-1}$)	-11.3 ± 6.5	-15.1 ± 6.5	-17.3 ± 5.5
Phase D: Impact			
Max (N)	3180 ± 1260	4130 ± 840	5330 ± 1970
Rate ($N \cdot ms^{-1}$)	46.1 ± 21.4	62.7 ± 12.9	94.0 ± 43.4

SD, standard deviation.

Part Two

The analysis revealed that both assisted and resisted jump training groups had a small increase in jump height of 6.7% (± 9.6%) and 4.0% (± 8.8%), respectively, whilst the free jump group produced a trivial increase in jump height of 1.3% (± 9.2%). A small effect was observed for the between-group difference in the change in jump height between assisted and free jump training (5.6, 90% confidence limit ±6.8%), and resisted and free jump training (3.7 ±6.1 %). Trivial but unclear between-group differences were observed in the change in jump height between the assisted and resisted jump training protocols. Figure 13 illustrates the variation in vertical jump height change of each player in the three separate conditions.

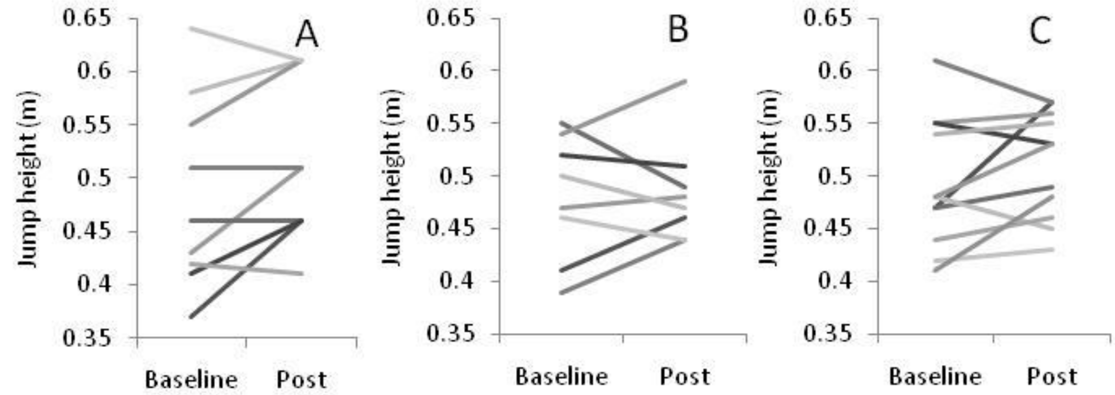

Figure 13. Subject variation in vertical jump height change following a four week training phase of assisted (A, n=9), free (B, n=8), or resisted (C, n=11) countermovement jumps.

Discussion

The purpose of Part One was to examine the differences in the kinetics of assisted, resisted, and free countermovement jumps. The findings were then used to help plan and implement the training protocols in Part Two, which examined the difference in training effect of these training methods.

As expected from the concentric force-velocity relationship, the greatest peak velocity was achieved during the assisted jump as the vertical assistance provided by the elastic bands reduced the effective bodyweight of the subject and provided an upward propulsive force. The assisted jump therefore allowed subjects to accelerate vertically more quickly than was possible without assistance. Previous literature has shown increased neural activation (via IEMG) when performing at supra-maximal velocities (153) and may have positive training implications. The greatest peak power relative to bodyweight was also achieved in the assisted jump condition, with this effect likely due to the increased velocity of the movement. Assisted training may be particularly beneficial for athletes who have already obtained high levels of strength, but lack the ability to produce higher power outputs or movement velocity, especially at low loads.

There was reduced amplitude of force unloading in the early unloading phase of the assisted jump in comparison to resisted and free jumps, which may have reflected a decreased stretch-shortening cycle force contribution. Reductions in force unloading and rate of unloading may have resulted in a lesser stretch on the muscle-tendon complex, and therefore the tendon would have recoiled with reduced force (131). As such, the total force produced during the assisted jump would have had a greater reliance on concentric-only muscle force production which may help to explain the smaller change in force compared to the resisted jump during the loading phase (131).

The assisted jump was associated with substantially smaller impact forces than both resisted and free jumps. In a training environment, the reduced impact forces observed during assisted jumps may be a safer way to graduate the intensity of plyometric loading, especially following recovery from lower-body injury or in large athletes who may not tolerate high landing ground reaction forces.

Maximum force, rate of force development and impact force were greatest in the resisted jump condition. The observation that the greatest peak force was seen in the resisted jump condition is likely due to the increased resistance reducing movement velocity. Indeed, according to the force-velocity relationship, force is greater at slower concentric contraction speeds and reduces as the velocity of the concentric action increases (104). In contrast to assisted jumping, the greater force and rate of force development produced in the resisted jumps may have been due to the larger force unloading in the early unloading phase of the jump. Greater unloading forces and rate of force unloading during this phase may have increased tendon recoil thus enhancing stretch-shortening cycle function. Indeed, Kubo and colleagues reported that a faster pre-stretch of human muscle led to greater muscle-tendon complex lengthening with 22.3% greater work completed in the following concentric action than at a slower pre-stretch rate (131).

It is well known that power production during complex movement is influenced by many different factors (e.g. force, velocity, rate of force development, stretch-shortening cycle efficiency) (159). Part one of this investigation determined that both assisted and resisted jump methods produced distinct maximal outputs, which may be expected to develop different components of muscular power (high speed / low force and low speed / high force, respectively). The free jump did not result in a greater output than the assisted or resisted jumps in any of the measured variables.

There are some limitations which should be considered before attempting to interpret the results from Part Two of this investigation. Firstly, the assistance and resistance provided varied between participants and was not assessed on every set of every training session; and secondly, the weekly competition game performed by the subjects could not be completely controlled in terms of specific role each player played within the match, tasks completed or time on the field.

Results of Part Two indicated that assisted and resisted jump training led to small improvements (4.0-6.7 %) in vertical jump height in well-trained Rugby players during the competitive phase of their season. In contrast, trivial improvements (1.3 ± 9.2 %) in jump height were observed following free countermovement jump training. These findings are important considering prior research from this group indicated a small but substantial 3.3% decrease in lower-body power in similar well trained Rugby players over a competitive season (10). It is also important to note that in well trained athletes Baker and Newton (22) reported 5% improvements in power over a four year training period, as such, trivial performance improvements may still be important. If 4.0-6.7% improvements in jump height can be achieved with assisted or resisted jump training over a four week training period with minimal disturbance to training, without risk of injury and at minimal cost, then coaches should confidently employ such training methods. Furthermore, it should be restated that these results were obtained where resistance training, speed development, team skills and training sessions, along with competitive matches were being performed within the same training phase. As such, these findings are likely more transferable to real-world applications compared to what is observed in single training session or laboratory based investigations.

Assisted jump training resulted in the greatest increase in vertical jump height and was associated with the greatest acute peak velocity and power outputs. Findings from Part One revealed that performing assisted jump training allowed participants to jump with a movement velocity greater than in the free and resisted jump conditions. Training at a higher movement speed may have resulted in decreased antagonist co-activation or an increase in MHC-II fibre activation (4). Indeed, there is a close relationship between muscle shortening speeds and the expression of the different (MHC) isoforms (38, 133). Additionally, muscle fibres that contain MHC-I have slower maximal shortening velocities and lower power outputs than muscle fibres containing MHC-II isoforms (38, 133). Although it was not assessed in this investigation, our results suggest that the higher velocity training resulted in very specific morphological adaptations. Neuromuscular adaptations should not be discounted as possible mechanisms for the improvements observed in jump height. Indeed, Newton and colleagues (161) reported that greater velocity and force production (as observed in assisted and resisted jumps in the current investigation) provides superior loading conditions for the neuromuscular system. As such, the greater stimulus may have promoted positive adaptation (30).

Resisted jump training also improved vertical jump height and was associated with the greatest peak force and rate of force development. It is likely that the increased force requirements of resisted jumping led to the positive adaptive responses observed. Attempting to move at high speeds against a larger external load may induce numerous adaptations including an increase in contractile force, perhaps through increased neural activation, reduced co-activation, and muscle architectural and fibre size adaptations, although the mechanisms are yet to be completely defined (33, 63, 143, 160).

In support of the current findings, Cronin, McNair and Marshall (63) reported that resisted bungy countermovement jump training (performed on a isoinertial supine squat machine) improved a variety of lower-body strength and power measures following a ten-week training phase. Cronin and colleagues (63) also reported that resisted bungy countermovement jump training produced greater EMG activity (70-100%) during the later stages of the eccentric phase of the jump, when compared to a non-bungy training method. Accentuated eccentric loading increases the force that can be produced in the concentric phase of the movement, and may be due to increased elastic energy storage as a result of the greater eccentric load increasing tendon elongation (68). Sheppard and colleagues (182) reported that five weeks of accentuated eccentric loading countermovement jump training increased vertical jump height by 11% in high performance volleyball players. The increase was significantly larger than the control group who performed regular countermovement jumps. Therefore improvements in vertical jump following resisted jump training might also be related to an increased eccentric loading following the flight phase of the jump, and similar to those observed following drop jump training.

The free jump training group produced a trivial increase in vertical jump height. The lack of improvement may be due to the player's regular use of the free jumps as part of their training program prior to the beginning of the study. As such, the kinetic components of power that are optimized by free jump training may have been previously developed and, as a result, there was less potential for further adaptation to occur (182).

Practical Applications

Inclusion of assisted or resisted jumping (three sets of six) twice a week to a conditioning program can improve vertical jump height over a four week training phase to levels comparable to that found over a four year period in similarly trained Rugby League players (22). Conditioning coaches and athletes can simply integrate these methods of jump training into their current resistance training using contrast training methods or as a part of their plyometric training sessions. The improvements in jump height in the current investigation were made in well trained Rugby players; however, we believe that the improvements are not limited to this form of athlete and should be performed by any athlete where jumping, sprinting, or any explosive lower-body movements are performed in competition. Finally, assisted jumping may also provide a lower impact method of plyometrics which may be useful for progressing the intensity of plyometric loading following lower-body injury or for heavy athletes who may not tolerate the high impact ground reaction forces on landing. Future research in this area should look at investigating the effects of individualised prescription of assisted compared to resisted jump methods for athletes with limitations in their velocity and force components of power, respectively. When combined with appropriate testing methodologies, such an approach may maximise the potential for power gain in well-trained athletes.

CHAPTER EIGHT

Study Seven: Effects of Two Contrast Training Programs on Jump Performance in Rugby Union Players during a Competition Phase

Introduction

The level of power an athlete possesses has been shown to distinguish between different levels of athletic ability and as such, increasing an athlete's ability to produce power may improve sporting performance (15). Improving power in well trained team sport athletes, especially during the competition phase of the season can be difficult to achieve. Baker (13) reported a 1% decrease in lower-body mean power throughout a 29 week competition phase in professional and college aged Rugby League players. While more recently, a 3% decrease in lower-body peak power was observed during a 13 week competition phase in professional Rugby Union players (10). Consequently, training methods that improve power in already well trained athletes during the competitive phase of the season need to be identified.

Programming methods consisting of the combination of strength training (lower velocity / higher force) and power training (higher velocity / lower force) have been regularly reported to be superior to strength or power training in isolation (98, 143). Combined resistance training is commonly referred to as either compound training (heavy resistance day alternated with a lighter resistance day), complex training (several sets of a heavy resistance exercise that are followed by sets of a lighter resistance exercise) or contrast training (alternating heavy and lighter exercises set for set) (75). Previous authors have reported larger improvements following combined training when compared to high strength or high power training alone (98, 143). It has been postulated that combined training provides broader neuromuscular adaptations resulting in greater transfer to a wider variety of performance variables (98).

Although, combined training methods consisting of heavy loads (>80% 1RM) in conjunction with lighter loads performed ballistically have been reported to improve power (98); authors have also investigated the acute effects of combined training with lighter loads. Smilios and colleagues (186) investigated the effect of contrast training with 30% 1RM half squat on bodyweight jump performance in trained regional-level team sport athletes. It was reported that loaded jump squats of 30% 1RM produced significant improvements (4%) in a subsequent bodyweight jump (186). Additionally, Baker (14) reported similar improvements (5%) in a jump squat that was preceded by a ~60 %1RM jump squat in professional Rugby League players. However, the chronic effect of heavy versus light contrast training in elite athletes has not been established. Previous research has determined the training effects of heavy versus light ballistic training (without contrast training). McBride and colleagues (148) investigated the effects of eight weeks of heavy or light jump squat training on strength and power development. It was reported that the velocity of the movement, as controlled by the load, played a key role in velocity-specific training adaptations i.e. the heavy group produced greater improvements in force output, while the light group had greater improvements in velocity. Interestingly, both groups significantly increased lower-body strength. Whether chronic improvements can be made with lighter contrast training loads over a longer training period needs to be established.

Many professional athletes, including those playing Rugby Union taper training load during each competition week in an attempt to optimise physical preparation. This taper allows athletes to express themselves in a non-fatigued and primed state for the weekly competition / game. High force, lower velocity training is normally performed at the beginning of each training week, while lighter, higher velocity training is performed in the latter stages of the week (typical of compound training). Additionally, in an attempt to maximise training quality, athletes may also perform complex or contrast training as part of their resistance training programs. Although the effects of combined training have been relatively well established; the effects of combined training methods with different intensities (heavy versus light contrast training) performed within a weekly taper (heavy days and lighter days) requires further attention. Anecdotally, the current best practice is to lift with heavier contrast training loads.

Professional Rugby Union players perform a variety of different training modes concurrently within a training phase i.e. strength and power, speed, anaerobic and aerobic conditioning, along with a variety of Rugby specific training (skills, team plays, technical and tactical sessions). However, much of the current strength and conditioning literature does not address the issue of how concurrent training may influence strength and power adaptations; while the application of research studies involving single-mode (e.g. resistance training) are still applied to team sport athletes who perform concurrent training. Understanding the effects of different resistance training methods within a competition phase involving concurrent training will enhance programming and subsequent training adaptation, enabling athletes to be better prepared for the weekly competition that occurs in many team sports. Therefore, the purpose of this investigation was to compare the effects of two contrast training programs on a range of lower-body performance measures in high-level Rugby Union players during the competition phase of their season. Each program included a tapering of loading (higher force early in the week, higher velocity later in the week); with the major difference between the two programs being the loading. Either a heavy (strength-power) or a lighter (speed-power) resistance program was performed, which therefore affected the movement velocity that could be produced during each exercise set. It was hypothesised that the strength-power program would result in greater improvements in performance measures requiring higher force production (e.g. weighted jumps), whilst the speed-power program would result in greater improvements in performance where high levels of velocity were required (e.g. bodyweight jumps).

Methods

Experimental Approach to the Problem

Following a four week baseline training and familiarisation phase consisting of three resistance training sessions per week, players were assessed for peak power outputs during a bodyweight countermovement jump (BWCMJ), bodyweight squat jump (BWSJ), 50-kg countermovement jump (50CMJ), 50-kg squat jump (50SJ), depth jump (DJ) and broad jump (BJ). Players were then matched on playing position and BWCMJ power and were randomly allocated to either the strength-power or speed-power training group. Each group completed a four week training intervention consisting of two training sessions per week and were reassessed at the end of the training intervention. These exercises were selected due to their common usage in power training programs and research studies and their ability to represent lower-body power (10, 19, 32, 65). Additionally, these exercises were selected as they provide a 'profile' of the specific areas of power production, i.e. loaded and unloaded, inclusion or exclusion of stretch shortening cycle, vertical and horizontal axis, and tendon compliance (149). Peak power was selected as the dependent measure as it has been reported to have the greatest association with athletic performance (72).

Subjects

Eighteen high-level Rugby Union players from a New Zealand provincial representative team (semi-professional and professional players) volunteered to take part in this study (Table 27) during the final two weeks of pre-season training and the first seven weeks of the competitive phase of the season. The intervention period included a four week baseline training and familiarisation phase, during which time a lower-body maximal strength assessment (box squat) took place using methods previously described (8, 10) to characterise the training level of the subjects. Each player had at least two years of resistance training experience and was deemed highly trained (see box squat strength, Table 27). Players were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for use of human subjects.

Table 27. Characteristics of high-level Rugby Union players in two separate training groups. Data are mean ± SD.

	Strength-power (n=9)	Speed-power (n=9)
Age (y)	23 ± 2	25 ± 2
Height (cm)	186 ± 1	187 ± 1
Weight (kg)	99 ± 10	102 ± 9
Box squat 1RM (kg)	160 ± 27	176 ± 17

RM, repetition maximum.

Procedures

To characterise the training level of each subject, players were assessed for maximal lower-body strength using the box squat exercise. Briefly, each player was required to perform three sets (50%, 70%, 90% effort, two-six repetitions) of sub-maximal box squat followed by one set to failure of one to four repetitions. During the box squat, players used a self-selected foot position, and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each player to allow the top of the thighs to be parallel to the floor while in the seated position (8, 10). Three minutes rest was allowed between each set. Each set to failure was used to predict the players' one repetition maximum (1RM) (132, 136).

Players performed two repetitions of BWCMJ, BWSJ, 50CMJ, 50SJ, DJ and BJ. Each jump was performed on a commercially available portable force plate (400 Series Performance Force Plate, Fitness Technology, Australia). For all jumps, no arm swing was allowed, the only exception being the BJ in which an arm swing was permitted. A position transducer (PT5A, Fitness Technology, Australia) was connected to a broomstick (vertical bodyweight jumps) or Olympic weightlifting bar (vertical weighted jumps) and was held across the posterior deltoids at the base of the neck. For the BWSJ and 50SJ players lowered themselves to approximately 90° flexion of the knee, paused for three seconds and then jumped on the command "go" (149). BWCMJ and 50CMJ were performed in the same manner with no pause between eccentric and concentric movements. The DJ consisted of participants standing on a box 30 cm above the force plate, stepping off the box and attempting to jump as quickly and as high as possible after foot contact (players were given the instructions to pretend that the force plate was "very hot" to minimize contact time on the force plate). The DJ score was determined by dividing the jump height by the contact time and will be referred to herein as the reactive strength index (RSI) (76, 80). The BJ was performed without the use of the force plate, and were instructed to jump horizontally for maximal distance from a stationary position. Broad jump distance was measured as the distance from the front of the toes prior to take off, to the back off the heel on landing. The testing protocol was performed seven days prior to the beginning of the first training session. All players had been familiarised with the testing battery prior to testing.

Both the force plate and position transducer were interfaced with computer software (Ballistic Measurement System, Fitness Technology, Australia) that allowed direct measurement of force-time characteristics (force plate) and displacement-time and velocity-time (position transducer) variables as outlined by Dugan and colleagues (72). The highest power output for each jump type was used for analysis.

Training

It has been previously reported that performance gains in a pre-season training phase may essentially be a return to prior fitness levels (8). Therefore, as this investigation commenced during the pre-season training phase, all players underwent a monitored four week base training phase to ensure that they were in a well-trained state prior to the beginning of the training intervention. The base training phase consisted of two 60 min Rugby training sessions per week, three 45-60 min conditioning training sessions per week, one strength and plyometrics session (strength, 3-4 sets x 2-6 RM, 3 min rest for 4-6 exercises; plyometrics, 3 sets x 4 reps, 3 min rest for 3 exercises); one hypertrophy session (4 sets x 8-12 RM, 90 s rest for 5 exercises); and a circuit training session (6-12 reps, 30 s rest for 10 exercises, 30 min duration). On the final week of the base training phase, all players were assessed for the maximum load that could be lifted for 2-4 repetitions in all of the training exercises used in the intervention (except for sled sprint where a standardised load was used during the intervention phase (119)). The maximal 2-4 repetition testing allowed specific intensities and loads based on 1RM to be set for each individual during the intervention phase.

The intervention phase consisted of either a strength-power or speed-power resistance training performed twice a week for four weeks during the competition phase of the season (Table 28). Each program included a tapering of loading (higher force early in the week, higher velocity later in the week). All of the training sessions for the strength-power intervention were performed at a greater percentage of 1RM than the speed-power intervention. For both interventions, exercises in the first training session were performed at a greater percentage of 1RM, than in the second training session. The exercises in each training group (i.e. strength-power and speed-power training) were matched for similar movement patterns e.g. concentric focus, bilateral exercise. Therefore, the major difference between each group was the load used which, based on the force-velocity relationship, was intended to influence~~d~~ the muscular forces and movement velocity that could be produced during the exercises. Players were instructed to perform all exercises as explosively as possible, and with maximal intent.

Table 28. Outline of lower-body resistance training exercises in two separate lower-body resistance training programs (strength-power & speed power) in two groups of high-level Rugby Union players during a competition training phase.

	Session One		**Session Two**	
Exercise	Strength-Power Group	Speed-Power Group	Strength-Power Group	Speed-Power Group
1	Box squat (heavy)	Box squat (light)	Jump squat (heavy)	Jump squat (light)
2	10m sled sprint 120kg#	10m sled sprint 30kg#	10m sled sprint 30kg#	10m sprint#
3	Deadlift	⅓ Rack squat	Power clean	90° Static jump*
4	20kg box jump	Assisted jump*	High box depth jump*	Low box depth jump*

		Week 1		**Week 2**		**Week 3**		**Week 4**	
		Intensity (%1RM)	Reps	Intensity (%1RM)	Reps	Intensity (%1RM)	Reps	Intensity (%1RM)	Reps
Strength-Power	Session 1	80-90%	6,6,4,4	90-95%	4,4,3,2	95-98%	4,3,3,2	90-95%	4,4,3,2
	Session 2	40-45%		45-50%		50-55%		45-50%	
Speed-Power	Session 1	55-60%	6,6,4,4	60-65%	4,4,3,2	65-70%	4,3,3,2	60-65%	4,4,3,2
	Session 2	20-25%		25-30%		30-35%		20-25%	

*bodyweight exercise (repetitions 4,4,4); # repetitions 1 x 10m x 4 sets; RM, repetition maximum. Exercises 1 and 2, along with exercises 3 and 4 were performed using a contrast training method.

Additional Training

In addition to the training described above, players also performed three upper-body resistance exercises (85-95% 1RM, three sets of four repetitions) during session 1. During session 2 players performed two upper-body resistance exercises in a ballistic fashion (40-60% 1RM, three sets of four repetitions). Players also performed one speed development session with low resistance (20-30 min, including fast foot ladders, mini hurdles, maximal sprinting, over-speed sprinting), three team training sessions (30-75 min, including specific Rugby skill, tactical, tackling, etc), one competitive match, and one recovery session (20-40 min, including light exercise, stretching, and hot and cold baths) each week.

Statistical Analyses

All outcome measures (i.e. peak power, reactive strength index and broad jump distance) are presented as mean ± standard deviation. All data were log-transformed to reduce non-uniformity of error, and the effects of the training phase were derived by back transformation as percentage changes (108). Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the between-player standard deviation. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate and large, respectively. Standardised effects of between -0.19 and 0.19 were termed trivial (187). To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects (25). To gain insight into the relative influence of the force and velocity components to the improvements in jump power, subsequent analysis of peak force and velocity data was then completed for measures that responded favourably to the training. Finally, correlational analysis was performed to assess the possibility of the difference in baseline strength affecting the magnitude of change in power. The kinetic and kinematic variables measured in this investigation have been shown to have good test-retest reliability ($r \leq 0.95$; $CV < 3.5\%$) when similar testing procedures were used with a comparable population (52, 149).

Results

Baseline data for all measures are presented in Table 29. Both training groups were reasonably well matched for baseline scores with between-group differences reaching small magnitudes for the BWSJ and 50SJ only.

Table 29. Baseline values (mean ± SD) produced during different jumps in two separate groups of high-level Rugby Union players during a competition training phase.

	Strength-power	Speed-power
BWCMJ (W)	6560 ± 820	6740 ± 930
BWSJ (W)	6650 ± 840	6390 ± 660
50CMJ (W)	5440 ± 990	5530 ± 660
50SJ (W)	5280 ± 920	5050 ± 490
RSI ($m.s^{-1}$)	1.83 ± 0.27	1.86 ± 0.30
BJ (cm)	252 ± 22	253 ± 19

SD, standard deviation; BWCMJ, bodyweight countermovement jump; BWSJ, bodyweight static jump; 50CMJ, 50-kg countermovement jump; 50SJ, 50-kg static jump; RSI, reactive strength index; BJ, broad jump.

Inferences about the effect of each training program are shown separately (percentage change) and comparatively (percentage effect) in Table 30. There were smaller mean changes and larger standard deviations in the speed-power group for the 50CMJ and 50SJ exercises which suggests that there were individuals that responded negatively to this type of training. Relative to the changes in the speed-power group, the strength-power group produced small increases in 50CMJ (410 W; 90% confidence limits, ±380 W), 50SJ (360; ±480 W) and BJ (4; ±7 cm). Alternatively, unclear between-group differences were observed in BWCMJ, BWSJ and RSI (Table 30).

Table 30. Percentage change (mean ± SD), percentage effect (difference; ±90% confidence limits) and magnitudes produced during different jumps following four weeks of lower-body resistance training in two separate groups (strength-power & speed-power) of high-level Rugby Union players during a competition training phase.

	Strength-power (%)	Speed-power (%)	Strength-speed difference* (%)
BWCMJ	1.6 ± 3.1 trivial	0.8 ± 3.4 trivial	0.8; ±4.3 unclear
BWSJ	-1.4 ± 4.2 trivial	0.4 ± 4.0 unclear	-1.9; ±5.5 unclear
50CMJ	11.7 ± 6.5 moderate	3.1 ± 4.8 trivial	7.7; ±7.7 small
50SJ	11.2 ± 5.6 moderate	4.4 ± 9.6 unclear	6.9; ±9.7 small
RSI	0.8 ± 5.8 unclear	3.4 ± 19.1 unclear	-2.6; ±22.8 unclear
BJ	3.6 ± 2.5 small	1.8 ± 1.5 small	1.7; ±2.8 small

SD, standard deviation; BWCMJ, bodyweight countermovement jump; BWSJ, bodyweight static jump; 50CMJ, 50-kg countermovement jump; 50SJ, 50-kg static jump; RSI, reactive strength index; BJ, broad jump. *change in strength-power group compared to change in speed-power group.

Changes in peak force and velocity data were assessed in measures that responded favourably to training (i.e. 50CMJ, 50SJ). Following the strength-power training, peak force improved by 12% (± 19%; small effect size, ES) and 26% (± 22%; large ES) in the 50CMJ and 50SJ, respectively. Only trivial improvements in peak force were observed for any of the measures in the speed-power group. A small increase in peak velocity was observed in the strength-power group for the 50CMJ (5 ± 8%); whilst a small decrease in peak velocity occurred in the speed-power group in the 50SJ (-2 ± 5%).

Correlations between baseline strength and the magnitude of the change in 50CMJ and 50SJ power ranged from r = 0.17 to r = -0.16 suggesting that up to 3% of the variation in the change in power was due to differences in baseline strength. However, moderate correlations between baseline squat strength and change in 50CMJ were observed for force (r = -0.53) and velocity outputs during the 50CMJ (r = -0.37); suggesting that up to 29% and 14% of the change in force and velocity outputs could be explained by differing baseline strength levels. Only trivial correlations were observed between squat strength and change in 50SJ force and velocity. Finally, the correlation between baseline strength and change in BJ distance was r = -0.30, explaining up to 9% of the variation of the change in BJ.

In addition to maximal lower-body strength being assessed prior to the training program so that training intensities could be set; lower-body strength was also assessed by the conditioning coach in eight players from the strength-power program, and four players from the speed power program following the four week training phase. A small increase of 5%; (± 13%) was observed in the 12 players assessed. Players in the strength-power program increased strength by 3% (± 17%), while speed-power program players improved by 8% (± 3%).

Discussion

Findings from the current investigation suggested that the strength-power program was superior to the speed-power program, resulting in larger and more uniform improvements in various measures of lower-body power. The strength-power program also successfully improved power in a greater number of performance measures; whilst the speed-power program only resulted in a small increase in a single measure. However, this single improvement for the speed-power program was less than that in the strength-power program.

Previous investigations examining changes in lower-body power during a competitive season in the Rugby codes have reported maintenance at best (10, 13). Argus and colleagues (10) reported a small 3.3% decrease, while Baker (13) reported a trivial 0.3%

increase in weighted countermovement jump power. However, attempting comparisons between the current and previous investigations (10, 13) has several limitations. Firstly, the current investigation only consisted of a short phase at the start of a competitive season. Secondly, the specific detail of the resistance training programs used in the previous investigations was not fully reported. Future research should attempt to monitor changes over a longer competitive phase of the season using similar programming strategies to allow for more detailed comparisons. Nonetheless, the strength-power training program in the current investigation resulted in moderate improvements in both weighted countermovement jump power (12%) and weighted squat jump power (11%).

Strength-power training was superior to the speed-power training program resulting in larger improvements in a greater number of measures of jump performance. In contrast, McBride and colleagues (148) who investigated the effects of training with heavy (80% 1RM) or light (30% 1RM) jump squats reported that light jump squat training improved performance in a greater number of measures than heavy jump squat training. Harris and colleagues (98) reported improvements in a greater number of performance measures following a high power training program when compared to a high force program. Although in both investigations (98, 148) the higher load group improved to a greater extent in high force output measures (1RM values), whereas the lower load group showed the greatest improvement in higher velocity–related movements. Differences in methodology, including the length of the intervention period and utilisation of the contrast training method may help to explain some of the variation between the current investigation and previous literature (98, 148).

It should be noted that, although similar exercises, sets and repetitions were performed by the two groups, the current investigation did not match training volume. As such, unequal resistance training volume between the strength-power and speed-power groups may have been partially responsible for the different strength and power changes observed. Although the resistance training volume performed cannot be easily determined post training due to some of the exercises performed (e.g. sled sprints and bodyweight exercises), and with force outputs or repetition contraction time not measured during training; it is likely that the strength-power group performed a greater training volume. Indeed, Crewther and colleagues (58) reported that when repetitions are performed with maximal intent, as in the current study, an increase in load of 10% results in a 14% increase in time under tension (TUT) and a 15% increase in work done. The participants in the strength power group performed on average 25%1RM greater intensity than the speed-power group during the four week intervention (although bodyweight exercises and sled pulls could not be accounted for in this calculation). Therefore the greater intensity performed in the strength-power group may have resulted in approximately 35% greater TUT and 38% more work done and may be the differentiating factor between the two training programs. In the investigation by McBride and colleagues (148) discussed above, participants in the light jump squat group performed an additional set of jumps in an attempt to equate overall workloads over the training period. The equal-volume training load may help to explain the performance improvements observed by McBride and colleagues (148) in both the heavy and light jump squat training groups

The greatest improvements in performance measures for the present study were observed in the weighted jumps. Tuomi and colleagues (197) suggested that initial performance adaptations during combined training methods have a greater effect on higher force rather than lower force producing activities. Additionally, previous authors have reported that heavier resistance training results in greater improvements to the higher end of the force-velocity curve while lighter resistance training result in improvements at the lower end (98, 148). Training intensities for the strength-power program in Session One ranged from 80% to 98% 1RM which emphasises the higher end of the force-velocity curve. The strength-power program also trained with intensities ranging from 45-55% 1RM during Session Two which was slightly heavier than the testing weight. It is likely that the higher training load performed by the strength-power group resulted in a greater adaptation in the weighted jumps due to the greater volume of training performed at similar resistances. Attempting to move large external loads may induce a number of adaptations including an increase in contractile force which may be realised through increased neural activation, reduced co-activation as well as a number of muscular architectural or fibre size adaptations (33, 63, 143, 160). Therefore, training with greater resistance regularly, as in the strength-power program, may have provided an increased neuromuscular stimulus resulting in greater performance benefits. Likewise, the lack of improvement in the weighted jump measures in the speed-power program may have been due to inadequate exposure to higher loads. The speed-power program only trained with moderate to heavy loads (55% to 70% 1RM) once a week, whilst the second session was performed using loads from bodyweight to 35% 1RM. As such, high intensity training once each week appears to be inadequate for this athletic population to improve performance in measures which require higher force production.

Similarly, the lack of improvement in the bodyweight jumps (excluding broad jump) in both programs may have been due to the insufficient total volume or stimulus of the jump training performed. It has been suggested that improvements in activities requiring greater velocity (i.e. bodyweight or low resistance plyometrics) may need a longer training period or greater training volume for adaptations to present (65, 197). In a recent meta-analysis, de Villarreal and colleagues (65) reported that training volumes of more than ten weeks maximise the probability of obtaining significantly greater improvements in bodyweight vertical jump performance. De Villarreal and colleagues (65) reported that for optimal improvements in bodyweight vertical jump performance, training programs should include 50 contacts twice a week (100 total). In the current investigation, neither program performed 100 contacts per week. The strength-power program performed between 38-52 contacts each week while the speed-power program performed between 49-56 contacts per week. It appears that the total volume of contacts may have been inadequate to produce improvements in bodyweight vertical jump performance. The volume of contacts performed in the current study was limited by the players' strength and conditioning coach. The players were not accustomed to performing 100 jump contacts within their resistance training sessions, and it was deemed that the increased jump volume may have had potential for injury.

The players in the current investigation performed resistance training in addition to several different training modes. Power development may be compromised by higher volumes of training performed (i.e. during concurrent training); whereas high force development may be less affected (13, 129). Indeed, in two separate investigations Argus and colleagues (8,

10) reported that power development was more affected than strength (high force) development during a pre-season and in-season training phase where concurrent training was performed. Although the 50kg jumps performed in the current investigation were not a strength task; jumping with heavier loads produces greater force output than with lighter loads, such as bodyweight (57). Based on previous findings it may be speculated that the higher force producing weighted jumps may have been less affected by the higher volume of concurrent training performed. Therefore, the current investigation's intervention period and contact volume may not have been adequate stimuli for improvements to be made in bodyweight vertical jump measures. Additionally, the concurrent training performed by the participants may have affected the higher velocity (bodyweight) jumps more so than the higher force producing weighted jumps.

The speed-power program resulted in smaller mean changes with larger standard deviation for the 50CMJ, 50SJ exercises and the RSI. These findings suggest that some individuals actually had performance decrements over the four week training period. There were no similarities in baseline characteristics (e.g. high power output) between the responders and non-responders to explain the variability in the change of performance to the same training program. One mechanism proposed by Beaven and colleagues (27) suggested that players have differing individual hormonal responses to a single resistance training session. Furthermore, when players trained using resistance training that elicited the greatest testosterone response, significant improvements in strength occurred. Conversely, when players trained using resistance training that produced the smallest testosterone response, 75% of players showed either no change or a significant decline in 1RM performance (26). Further research is still required to determine the factors that affect individual responses to a training program.

Both programs produced small improvements in broad jump distance. Interestingly, neither of the programs included any expression of force in the horizontal plane, the only exception being the weighted sled sprints. The players in the current investigation had traditionally performed vertically dominated plyometric training, and thus minimal horizontal plyometric training prior to this investigation. The small amount of horizontal training (weighted sled sprints) performed by the two programs may have been adequate to elicit improvements in broad jump distance due to this relativity unfamiliar stimulus. In conjunction with the weighted sled training, transference of training adaptation from horizontal training performed during the players' additional Rugby trainings (e.g. scrimmaging, mauling) may have also provided stimulus for adaption to occur. Indeed, if there had been a greater focus on horizontal power within the program there may have been greater increases in the broad jump for both groups and a potential between-group difference in response.

Although it has been suggested that the ability to develop high levels of muscular power is critical for successful performance in many sports (98); maximal strength is also important in most contact sports (13). For most athletes and conditioning coaches, improving maximal strength will be one of the performance goal priorities of the program. As such, it should be noted that maximal box squat strength was assessed by the players' strength coach prior to and following the intervention phase 12 of the players participating in this investigation (eight from the strength-power group, and four from the speed-power group). A small increase of 5%; (± 13%) was observed in the 12 players assessed. Players in the strength-power program increased strength by 3% (± 17%), while speed-power program players improved by 8% (± 3%).

Practical Applications

Performing a relatively heavy combined training twice a week is an effective method for improving a range of jump performance measures in high-level Rugby Union players over a four week competitive phase. Our findings suggest that improvements in jump performance can be made in team sport athletes during the competitive season when athletes are exposed to higher volume-load stimuli which includes one heavy lifting session each week. Indeed, the use of heavier resistance combined training (strength-power) produced larger improvements in a greater number of performance measures than similar programming performed with lighter resistances. For practitioners and athletes who regularly compete once a week during the competition phase, the use of high force combined training consisting of contrast training with a heavy day and lighter day is an effective way to make improvements in performance over a short training phase during the competitive season. Finally, a greater volume of lower resistance plyometric training may be required for athletes to enhance vertical bodyweight jump performance.

CHAPTER NINE

Primary Findings and Conclusions

Chapter nine discusses the primary findings and conclusions with regards to the aims of the thesis. Practical applications from each study are then highlighted. Finally, the limitations of the thesis, along with potential future research are outlined.

Characterisation of Strength and Power in Rugby Union

The first aim of this thesis was to characterise strength and power in Rugby Union. This aim was formulated due to the paucity of literature examining differences in strength and power across different levels of competition and also different training phases. Additionally, there was a lack of literature identifying potential correlates of change, thus, in order to improve programming strategies, these factors needed to be investigated.

Findings from study one confirmed that both strength and power can discriminate between athletes competing in higher (professional and semi-professional) and lower (academy and high school) levels of competition. Additionally it was noted that the ability to produce high levels of power, rather than strength, may be a better determinate of playing ability between professional and semi-professional athletes. While normalising performance to body mass reduced the magnitude of the difference between the levels of competition; higher level athletes remained stronger and more powerful than the lower level athletes.

Correlations between upper body strength and power ranged from $r = 0.40$ in the professionals to $r = 0.92$ in the high school level athletes. These findings suggest that the lower level athletes who possess lower levels of strength rely heavily on muscular strength for power output; whereas higher level athletes who have already developed high levels of strength rely on factors other than maximal strength to produce power. These findings have implications for selection of appropriate training and development methods for the upper body. Interestingly lower body correlations ($r = -0.13$ to 0.30) of strength and power were much smaller than that of the upper body ($r = 0.40$ to 0.92). It was suggested that the small correlations observed may have been due to differences in the movement pattern of the lower body exercises performed.

Findings from the different training phases (studies two and three) indicated that improvements in body composition can be achieved in a relatively short time during a high volume, short term concurrent training phase. Additionally these increases in body composition were shown to account for a small percentage of the improvement in strength observed. Conversely, levels of power are negatively affected during these training phases. The reduction in power may be reflective of the high volume of concurrent training performed in the pre-season or the reduction in resistance training volume and possible increase in residual fatigue throughout the in-season. As some loss of power production may occur during significant loading phases, specific training phases involving a lower volume work and less cumulative fatigue may be required if power is to be maintained or improved.

Moderate increases in testosterone and cortisol were observed over the competitive season, with the testosterone to cortisol ratio showing a small decline. However, relationships between hormonal concentrations and performance were mainly trivial. Although the statistical analysis identified that there may be some crossover effect between performance measures, it was noted that the required change in many of the predictor measures to improve a dependent measure may be too large to obtain throughout a single competitive season. Therefore it was suggested that to improve an individual performance measure, such as upper or lower body strength or power, athletes need to train specifically for that measure to maximise potential adaptation.

Development and Assessment of Methods to Improve Strength and Power in Rugby Union Players

The second aim to this thesis was to develop and assess methods to improve the areas of performance highlighted in the characterisation studies. The importance of obtaining high levels of strength and especially power, in Rugby Union athletes was highlighted in study one. Upon characterising the effects of a pre-season and in-season training phase on these measures, it was observed that strength could be maintained or improved; however a decline in power may occur. These findings emphasised that methods improving power need to be developed and assessed in the high performance Rugby environment. However, the statistical analysis which attempted to identify covariates which may enhance adaptation (e.g. steroid hormones) revealed no (obtainable) relationships with positive adaptation of power. Therefore, based on the review of the literature we determined that several different methodologies may have potential to provide benefit to improving power in Rugby Union athletes. These methods included augmented feedback (verbal feedback), Pmax training, and combined training methods; specifically contrast training (rather than complex) was identified to have the potential to provide the greatest benefit in power adaptation.

Findings from study four showed that when athletes receive augmented feedback throughout a typical resistance training session, improvements in training quality can be made. Specifically, the application of verbal feedback resulted in acute increases in upper body mean peak power and velocity which were greatest in the latter training sets. This study was the first to show acute improvements in power outputs over a typical training session consisting of multiple sets and repetitions. If acute improvements can be made over multiple sessions, chronic improvements would be expected.

Recent research had reported that the lower body Pmax can occur at bodyweight rather than the previously believed 30-60% of 1RM (55). However, the authors of these recent studies did not appear to assess loads below bodyweight to see if negative loading may have allowed for greater power production to occur. Findings in study five established that by assessing power at negative loads we were able to identify a decline in power either side of the maximum power output found with bodyweight loads. Consistent with recent findings, peak lower body power occurred with no loading (bodyweight) in 16 of the 18 subjects. However, discontinuity in the power outputs of the lower-body was observed between bodyweight and all loaded jumps. It was suggested that differences in jump technique (i.e. amplitude of eccentric dip) between loaded and bodyweight conditions may contribute to the discontinuity observed. Results of this study indicate that the load that maximizes peak power may be influenced by several factors including the spectrum of loads assessed and whether comparisons are made between loaded and unloaded conditions. The chronic effect of performing jump training with either assisted, bodyweight or resisted loads was then assessed in study six.

Studies six and seven assessed the effects of different contrast training methods. In study six it was determined jumping with different levels of assistance or resistance resulted in distinct maximal outputs (force, velocity) which may be expected to develop different components of muscular power. Following a four week training phase it was reported that relative to changes in the control group (who performed free countermovement jumps using bodyweight loads); there were small improvements in jump height in the assisted and the resisted jump training group. It was concluded that elastic band assisted and resisted jump training are both effective methods for improving jump height and can be easily implemented into current training programs via contrast training methods or as a part of plyometric training sessions.

Findings from study seven assessed the difference between two contrast training programs consisting of heavier (strength-power) or lighter (speed-power) intensities, with both programs including a taper (heavier day earlier in the week, lighter day later in the week). It was identified that a strength-power contrast training program was superior to a speed-power contrast training program resulting in a greater number of larger and more uniform improvements in various measures of lower body power. Our findings suggested that high-level Rugby Union athletes should be exposed to higher volume-load contrast training which includes one heavy lifting session each week for improvements to occur in explosive lower body power throughout a competitive phase of the season.

The work from this thesis has identified that muscular power can be negatively affected by pre-season and in-season training phases in high performance Rugby players. Subsequently, potential methods that can better maintain or even improve power in elite Rugby Union athletes throughout a training phase where concurrent training was performed were identified from the literature. Results of the latter chapters of this thesis indicate that the appropriate application of these methods within an athlete's training program may enhance playing potential and possibly the overall success of a team.

Practical Applications

This thesis has provided insight into areas in which strength and conditioning coaches should consider when programming and assessing their athletes.

- As strength and power output can discriminate between different levels of competition; younger athletes should strive to attain greater levels of strength and power in an attempt to reach, or to be physically prepared for the next level of competition.
- Athletes with greater training history who have already developed high levels of strength should focus on methods to improve power. However, training should not focus exclusively on this one mode. For these athletes, contrast training methods may be more appropriate. It should be noted however, that it is difficult to prescribe what a 'high level of strength' is, and should be assessed on an individual basis. Some possible ways to identify this level of strength *may* include a comparison of normative data or identifying that a plateau in strength development has occurred.
- Power training should be focused on during periods where training volume is lower, as increased levels of fatigue may attenuate development.
- Due to lack of relationship with covariates, athletes of a high training status may need to train more specifically to enhance performance in individual performance measures. For example, to develop power, identifying which aspect of power (i.e. force or velocity) requires the greatest development and then programming accordingly. Furthermore, elite athletes may need increased volume of training (minimum of two sessions a week) to develop a specific performance measure.
- Providing augmented feedback (knowledge of results; peak velocity) during the performance of a typical power training exercise improves the quality of resistance training in well trained athletes. Conditioning coaches and athletes should consider the use of specific feedback (i.e. velocity) during a resistance training session to improve performance and maximise training quality.

- Assessment protocols using a range of heavy and lighter intensities for each individual across multiple exercises, performed in a manner similar to training will increase external validity and possibly result in a greater likelihood of enhanced training adaptations. For example, rather than simply assessing a vertical jump to determine lower-body power; practitioners should include measures of weighted and unweighted countermovement and static jumps, along with tests that assess horizontal components and reactive strength. This assessment ‘profile’ will provide a better understanding of how a training program or intervention has influenced change or adaptation.

- Assisted jumping may provide a lower impact method of plyometrics which may be useful for progressing the intensity of plyometric loading following lower-body injury or for athletes who have a high training jump volume to minimise landing loads. Additionally, assisted jumping may be beneficial for developing velocity or speed of a movement, similar to that of over-speed sprint training. This exercise would be particularly useful for athletes who need to improve the velocity component of power.

- Inclusion of assisted or resisted jumping twice a week into a conditioning program can improve vertical jump height over a four week in-season training phase.

- The use of high force combined training consisting of contrast training with a heavy day and lighter day is an effective way to make improvements in performance over a short training phase during the competitive season.

Limitations

The following limitations of this thesis are acknowledged.

- This thesis aimed to characterise and then develop methods to improve measures of performance in elite/professional Rugby Union athletes. However, as there is only a limited pool of athletes within a professional team, the sample size is limited to this number. Adding in lower level athletes to improve sample size would have lowered the ability to apply findings to the target group. As such (excluding part one of study 6 where a group-sequential design was used), the number of participants recruited was limited to the number of athletes without any significant injuries made available by the coaches and strength and conditioning staff within the team.
- Strength and power are only indirect measures of performance; however, they are believed to reflect the physical performance characteristics representative of playing potential.
- With the exception of steroid hormone monitoring, all assessments were field based test performed in the team's gymnasium, and thus suffer from limitations associated with such trails. Indeed, variables such as temperature and humidity cannot be closely monitored or controlled as effectively and lab based assessments, and may affect possible findings. However, as these athletes would typically train in these conditions, field based assessments can be viewed as adding ecological validity to the findings.
- Decreases in power following the pre-season training phase observed in study two may have been due to residual fatigue. It is possible that if there had been several days rest prior to re-testing, results may have differed.
- While testosterone and cortisol can reflect the balance between anabolic and catabolic environments; these steroid hormones are only part of a vast signalling system. As such muscular adaptation is not limited to these hormones.
- The intervention studies in this thesis assessed training methods over a four week training phase throughout an in-season; whereas the length of an in-season is much greater. Whether these methods can improve performance over a longer time frame is unclear.

- All studies were completed within a pre-season or in-season training phase. As such, findings from the intervention studies 6 and 7 cannot be entirely explained by the different interventions and may be in part due to the other concurrent training performed. However, all players work from the same weekly schedule, meaning that time of training, mode of training, and volume and intensity of training are all very similar for each individual. This would suggest that the only real difference in training between the groups was the intervention program.

Future Research

- Future research should expand the findings within this thesis by examining similar training programs over the entire duration of an in-season which may span more than 20 weeks, rather than short training phases (i.e. 4 weeks).
- Based on a recent meta-analysis (65) and findings from this thesis, training programs consisting of a greater volume of jump contacts (2x50 each week) in elite athletes needs to be conducted to assess if improvements in bodyweight countermovement jump performance can be made with this type of loading.
- Identification of the mechanisms that lead to performance (power) improvements with augmented feedback is required as this may allow the nature of the feedback to be altered to further augment performance improvements.
- Investigating the chronic training effects of receiving augmented feedback during training is required to determine if the acute improvements observed in this thesis will continue over multiple training sessions and phases.
- Future research should investigate the effects of individualised prescription of assisted compared to resisted jump methods for athletes with limitations (weaknesses) in their velocity or force components of power, respectively. Greater improvements in power may be obtained through this form of prescription as the less developed a component of power is, the greater scope for improvement.
- Whether contrast training with two heavier days can improve performance to a greater extent than contrast training with one heavy and one lighter day needs to be determined. Whether this can be done without affecting an athlete’s game preparation is unknown.

REFERENCES

1. Adams K, O'Shea JP, O'Shea KL, and Climstein M. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *J Appl Sport Sci Res* 6: 36-41, 1992.
2. Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, and Hakkinen K. Short vs. long rest period between the sets in hypertrophic resistance training: influence on muscle strength, size, and hormonal adaptations in trained men. *J Strength Cond Res* 19: 572-582, 2005.
3. Allerheiligen B, Arce HH, Arthur M, Chu D, Vermeil A, Lilja L, Semenick D, Ward B, and Woicik M. Coaches Roundtable: Testing for football. *Natl Str Cond Assoc* 5: 12-19; 62-68, 1983.
4. Andersen JL, Klitgaard H, and Saltin B. Myosin heavy chain isoforms in single fibres from m. vastus lateralis of sprinters: influence of training. *Acta Physiologica Scandinavica* 151: 135-142, 1994.
5. Anderson A and Vogel P. The effect of instructional self-talk on the overhand throw. *Phys Educator* 56: 215, 1999.
6. Andrews J, Wadiwalla M, Juster RP, Lord C, Lupien SJ, and Pruessner JC. Effects of manipulating the amount of social-evaluative threat on the cortisol stress response in young healthy men. *Behav Neurosci* 121: 871-876, 2007.
7. Appleby B, Hori N, and Dorman C. The characteristics of professional rugby union players in strength, power and anthropometrics. *J Aust Strength Cond* 17: 9-17, 2009.
8. Argus CK, Gill N, Keogh J, Hopkins WG, and Beaven CM. Effects of a short-term pre-season training programme on the body composition and anaerobic performance of professional rugby union players. *J Sports Sci* 28: 679-686, 2010.
9. Argus CK, Gill ND, Keogh JW, Blazevich AJ, and Hopkins WG. Kinetic and training comparisons between assisted, resisted, and free countermovement jumps. *J Strength Cond Res* 25: 2219-2227, 2011.

10. Argus CK, Gill ND, Keogh JWL, Hopkins WG, and Beaven CM. Changes in strength, power and steroid hormones during a professional rugby union competition. *J Strength Cond Res* 23: 1583-1592, 2009.

11. Baker D. Applying the in-season periodization of strength and power training to football. *Strength Cond* 20: 18-24, 1998.

12. Baker D. Comparison of upper-body strength and power between professional and college-aged rugby league players. *J Strength Cond Res* 15: 30-35, 2001.

13. Baker D. The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *J Strength Cond Res* 15: 172-177, 2001.

14. Baker D. A series of studies on the training of high-intensity muscle power in rugby league football players. *J Strength Cond Res* 15: 198-209, 2001.

15. Baker D. Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. *J Strength Cond Res* 16: 581-585, 2002.

16. Baker D. Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *J Strength Cond Res* 17: 493-497, 2003.

17. Baker D and Nance S. The relation between strength and power in professional rugby league players. *J Strength Cond Res* 13: 224-229, 1999.

18. Baker D, Nance S, and Moore M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res* 15: 20-24, 2001.

19. Baker D, Nance S, and Moore M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J Strength Cond Res* 15: 92-97, 2001.

20. Baker D and Newton RU. Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. *J Strength Cond Res* 19: 202-205, 2005.

21. Baker D and Newton RU. Methods to increase the effectiveness of maximal power training for the upper body. *Strength Cond J* 27: 24, 2005.

22. Baker D and Newton RU. Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes. *J Strength Cond Res* 20: 541-546, 2006.

23. Baker D and Newton RU. Change in power output across a high-repetition set of bench throws and jump squats in highly trained athletes. *J Strength Cond Res* 21: 1007-1011, 2007.

24. Baker D and Newton RU. Comparison of lowerbody strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res* 22: 153-158, 2008.

25. Batterham AM and Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform* 1: 50-57, 2006.

26. Beaven CM, Cook CJ, and Gill ND. Significant strength gains observed in rugby players after specific resistance exercise protocols based on individual salivary testosterone responses. *J Strength Cond Res* 22: 419-425, 2008.

27. Beaven CM, Gill ND, and Cook CJ. Salivary testosterone and cortisol responses in professional rugby players after four resistance exercise protocols. *J Strength Cond Res* 22: 426-432, 2008.

28. Beaven CM, Gill ND, Ingram JR, and Hopkins WG. Acute salivary hormone responses to complex exercise bouts. *J Strength Cond Res* 25: 1072-1078.

29. Beaven CM, Hopkins WG, Hansen KT, Wood MR, Cronin JB, and Lowe TE. Dose effect of caffeine on testosterone and cortisol responses to resistance exercise. *Int J Sport Nutr Exerc Metabol* 18: 131-141, 2008.

30. Behm DG. Neuromuscular implications and applications of resistance training. *J Strength Cond Res* 9: 264-274, 1995.

31. Bevan HR, Owen NJ, Cunningham DJ, Kingsley MIC, and Kilduff LP. Complex training in professional rugby players: influence of recovery time on upper-body power output. *J Strength Cond Res* 23: 1780-1785, 2009.

32. Bissas AI and Havenetidis K. The use of various strength-power tests as predictors of sprint running performance. *J Sports Med Phys Fit* 48: 49-54, 2008.

33. Blazevich AJ, Gill ND, Bronks R, and Newton RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. *Med Sci Sports Exerc* 35: 2013-2022, 2003.
34. Blazevich AJ, Gill ND, Deans N, and Zhou S. Lack of human muscle architectural adaptation after short-term strength training. *Muscle Nerve* 35: 78-86, 2007.
35. Blazevich AJ, Gill ND, and Shi Z. Intra- and intermuscular variation in human quadriceps femoris architecture assessed in vivo. *J Anat* 209: 289-310, 2006.
36. Blazevich AJ, Horne S, Cannavan D, Coleman DR, and Aagaard P. Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. *Muscle Nerve* 38: 1133-1146, 2008.
37. Borg G. A category scale with ratio properties for intermodal and interindividual comparisons, in: *Psychophysical judgement and the process of perception*. HG Geissler, P Petzold, eds. Berlin: VEB Deutscher Verlag der Wissenschaften, 1982, pp 25-34.
38. Bottinelli R, Canepari M, Pellegrino MA, and Reggiani C. Force-velocity properties of human skeletal muscle fibres: myosin heavy chain isoform and temperature dependence. *J Physiol* 495 (Pt 2): 573-586, 1996.
39. Brown BS, Daniel M, and Gorman DR. Visual feedback and strength improvement. *Natl Str Cond Assoc J* 6: 22-24, 1984.
40. Burger T. Complex training compared to a combined weight training and plyometric training program. Eugene, Or.; United States: Microform Publications, University of Oregon, 1999.
41. Burr JF, Jamnik VK, Dogra S, and Gledhill N. Evaluation of jump protocols to assess leg power and predict hockey playing potential. *J Strength Cond Res* 21: 1139-1145, 2007.
42. Caldwell BP and Peters DM. Seasonal variation in physiological fitness of a semiprofessional soccer team. *J Strength Cond Res* 23: 1370-1377, 2009.
43. Campenella B, Mattacola CG, and Kimura IF. Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. *Isokinet Exerc Sci* 8: 1-6, 2000.

44. Cardinale M and Stone MH. Is testosterone influencing explosive performance? *J Strength Cond Res* 20: 103-107, 2006.
45. Cavagna GA, Zamboni A, Faraggiana T, and Margaria R. Jumping on the moon: power output at different gravity values. *Aerosp Med* 43: 408-414, 1972.
46. Chiu LZF and Barnes JL. The fitness-fatigue model revisited: implications for planning short- and long-term training. *Strength Cond J* 25: 42-51, 2003.
47. Cleak MJ and Eston RG. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *Br J Sports Med* 26: 267-272, 1992.
48. Clutch D, Wilton M, McGown C, and Bryce GR. Effect of depth jumps and weight training on leg strength and vertical jump. *Res Q Exerc Sport* 54: 5-10, 1983.
49. Comyns TM, Harrison AJ, Hennessy L, and Jensen RL. Identifying the optimal resistive load for complex training in male rugby players. *Sports Biomech* 6: 59-70, 2007.
50. Comyns TM, Harrison AJ, and Hennessy LK. Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *J Strength Cond Res* 24: 610-618, 2010.
51. Corcoran C and Corcoran G. Analysis of the anatomical, functional, physiological and morphological requirements of athletes in rugby union. *J Aust Strength Cond* 18: 24-28, 2010.
52. Cormack SJ, Newton RU, McGuigan MR, and Doyle TLA. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform* 3: 131-144, 2008.
53. Cormie P, Grant OM, Triplett NT, and McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340-349, 2007.
54. Cormie P, McBride JM, and McCaulley GO. The influence of body mass on calculation of power during lower-body resistance exercises. *J Strength Cond Res* 21: 1042-1049, 2007.
55. Cormie P, McBride JM, and McCaulley GO. Power-time, force-time, and velocity-time curve analysis during the jump squat: Impact of load. *J Appl Biomech* 24: 112-120, 2008.

56. Corn RJ and Knudson D. Effect of elastic-cord towing on the kinematics of the acceleration phase of sprinting. *J Strength Cond Res* 17: 72-75, 2003.

57. Crewther B and Cronin J. A comparison of heavy and light load training and their proposed effects on increasing strength and hypertrophy. *Strength Cond Coach* 10: 15-18, 2002.

58. Crewther B, Cronin J, and Keogh J. Possible stimuli for strength and power adaptation: Acute metabolic responses. *Sports Med* 36, 2006.

59. Crewther BT, Gill N, Weatherby RP, and Lowe T. A comparison of ratio and allometric scaling methods for normalizing power and strength in elite rugby union players. *J Sports Sci* 27: 1575-1580, 2009.

60. Crewther BT, McGuigan MR, and Gill ND. The ratio and allometric scaling of speed, power, and strength in elite male rugby union players. *J Strength Cond Res* 25: 1968-1975, 2011.

61. Cribb PJ, Williams AD, and Hayes A. A creatine-protein-carbohydrate supplement enhances responses to resistance training. *Med Sci Sports Exerc* 39: 1960-1968, 2007.

62. Cronin J, McNair PJ, and Marshall RN. Developing explosive power: a comparison of technique and training. *J Sci Med Sport* 4: 59-70, 2001.

63. Cronin J, McNair PJ, and Marshall RN. The effects of bungy weight training on muscle function and functional performance. *J Sports Sci* 21: 59, 2003.

64. Cronin J and Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med* 35: 213-234, 2005.

65. De Villarreal ESZ-S, Kellis E, Kraemer WJ, and Izquierdo M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *J Strength Cond Res* 23: 495-506, 2009.

66. Denton J and Cronin JB. Kinematic, kinetic, and blood lactate profiles of continous and intraset rest loading schemes. *J Strength Cond Res* 20: 528-534, 2006.

67. Deutsch MU, Kearney GA, and Rehrer NJ. Time motion analysis of professional rugby union players during match-play. *J Sports Sci* 25: 461-472, 2007.

68. Doan BK, Newton RU, Marsit JL, Triplett-McBride NT, Koziris LP, Fry AC, and Kraemer WJ. Effects of increased eccentric loading on bench press 1RM. *J Strength Cond Res* 16: 9-13, 2002.
69. Dodd DJ and Alvar BA. Analysis of acute explosive training modalities to improve lower-body power in baseball players. *J Strength Cond Res* 21: 1177-1182, 2007.
70. dos Remedios KA, dos Remedios RL, Loy SF, Holland GJ, Vincent WJ, Conely LM, and Hing M. Physiological and field test performance changes of community college football players over a season. *J Strength Cond Res* 9: 211-215, 1995.
71. Drinkwater EJ, Galna B, McKenna MJ, Hunt PH, and Pyne DB. Validation of an optical encoder during free weight resistance movements and analysis of bench press sticking point power during fatigue. *J Strength Cond Res* 21: 510-517, 2007.
72. Dugan EL, Doyle TLA, Humphries B, Hasson CJ, and Newton RU. Determining the optimal load for jump squats: A review of methods and calculations. *J Strength Cond Res* 18: 668-674, 2004.
73. Duthie G, Pyne D, and Hooper S. Applied physiology and game analysis of rugby union. *Sports Med* 33: 973-991, 2003.
74. Duthie G, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J Sports Sci* 23: 523-530, 2005.
75. Duthie GM, Young WB, and Aitken DA. The acute effects of heavy loads on jump squat performance: An evaluation of the complex and contrast methods of power development. *J Strength Cond Res* 16: 530-538, 2002.
76. Ebben WP and Petushek EJ. Using the reactive strength index modified to evaluate plyometric performance. *J Strength Cond Res* 24: 1983-1987, 2010.
77. Elloumi M, Maso F, Michaux O, Robert A, and Lac G. Behaviour of saliva cortisol [C], testosterone [T] and the T/C ratio during a rugby match and during the post-competition recovery days. *Eur J Appl Physiol* 90: 23-28, 2003.
78. Etias M. Serum cortisol, testosterone, and testosterone-binding globulin responses to competitive fighting in human males. *Aggressive Behav* 7: 215-224, 1981.
79. Figoni SF and Morris AF. Effects of knowledge of results on reciprocal, isokinetic strength and fatigue. *J Orthop Sports Phys Ther* 6: 190-197, 1984.

80. Flanagan EP and Comyns TM. The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength Cond J* 30: 32-38, 2008.
81. Florini JR. Effects of testosterone on qualitative pattern of protein synthesis in skeletal muscle. *Biochemistry* 9: 909-912, 1970.
82. Florini JR. Hormonal control of muscle cell growth. *J Anim Sci* 61: 21-37, 1985.
83. Fowles JR and Green HJ. Coexistence of potentiation and low-frequency fatigue during voluntary exercise in human skeletal muscle. *Can J Appl Physiol Pharmacol* 81: 1092-1100, 2003.
84. French DN, Kraemer WJ, and Cooke CB. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J Strength Cond Res* 17: 678-685, 2003.
85. Fry AC and Kraemer WJ. Physical performance characteristics of American collegiate football players. *J Appl Sport Sci Res* 5: 126-138, 1991.
86. Fry RW and Morton AR. Physiological and kinanthropometric attributes of elite flatwater kayakists. *Med Sci Sports Exerc* 23: 1297-1301, 1991.
87. Gabbett TJ. Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *J Strength Cond Res* 19: 400-408, 2005.
88. Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in junior rugby league players. *Br J Sports Med* 39: 675-680, 2005.
89. Gabbett TJ. Physiological and anthropometric characteristics of junior rugby league players over a competitive season. *J Strength Cond Res* 19: 764-771, 2005.
90. Gabbett TJ. Science of rugby league football: A review. *J Sports Sci* 23: 961-976, 2005.
91. Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. *J Sports Sci* 24: 1273-1280, 2006.
92. Gill ND, Beaven CM, and Cook C. Effectiveness of post-match recovery strategies in rugby players. *Br J Sports Med* 40: 260-263, 2006.

93. Hãkkinen K. Neuromuscular and hormonal adaptations during strength and power training: A review. *J Sports Med Phys Fitness* 29: 9-26, 1989.

94. Hãkkinen K and Komi PV. Changes in electrical and mechanical behavior of leg extensor muscles during heavy resistance strength training. *Scand J Sports Sci* 7: 55-64, 1985.

95. Halson SL and Jeukendrup AE. Does overtraining exist?: An analysis of overreaching and overtraining research. *Sports Med* 34: 967-981, 2004.

96. Haneishi K, Fry AC, Moore CA, Schilling BK, Yuhua L, and Fry MD. Cortisol and stress responses during a game and practice in female collegiate soccer players. *J Strength Cond Res* 21: 583-588, 2007.

97. Hanson ED, Leigh S, and Mynark RG. Acute effects of heavy- and light-load squat exercise on the kinetic measures vertical jumping. *J Strength Cond Res* 21: 1012-1017, 2007.

98. Harris GR, Stone MH, O'Bryant HS, Proulx CM, and Johnson RL. Short-term performance effects on high power, high force, or combined weight-training methods. *J Strength Cond Res* 14: 14-20, 2000.

99. Harris NK, Cronin JB, and Hopkins WG. Power outputs of a machine squat-jump across a spectrum of loads. *J Strength Cond Res* 21: 1260-1264, 2007.

100. Harris NK, Cronin JB, Hopkins WG, and Hansen KT. Inter-relationships between machine squat-jump strength, force, power and 10 m sprint times in trained sportsmen. *J Sports Med Phys Fitness* 50: 37-42.

101. Harris NK, Cronin JB, Hopkins WG, and Hansen KT. Relationship between sprint times and the strength/power outputs of a machine squat jump. *J Strength Cond Res* 22: 691-698, 2008.

102. Harris NK, Cronin JB, Hopkins WG, and Hansen KT. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. *J Strength Cond Res* 22: 1742-1749, 2008.

103. Hatzigeorgiadis A, Theodorakis Y, and Zourbanos N. Self-talk in the swimming pool: The effects of self-talk on thought content and performance on water-polo tasks. *J Appl Sport Psychol* 16: 138-150, 2004.

104. Hill A. The heat of shortening and the dynamic constants of muscle. *Proc R Soc Lond* 126: 136-195, 1938.

105. Hoffman JR and Kang J. Strength changes during an in-season resistance-training program for football. *J Strength Cond Res* 17: 109-114, 2003.

106. Hoffman JR, Kraemer WJ, Fry AC, Deschenes M, and Kemp M. The effects of self-selection for frequency of training in a winter conditioning program for football. *J Appl Sport Sci Res* 4: 76-82, 1990.

107. Hopkins WG. Probabilities of clinical or practical significance. *Sportscience* 6 (available at: sportsci.org/jour/0201/wghprob.htm), 2002.

108. Hopkins WG. Spreadsheets for analysis of controlled trials with adjustment for a predictor. *Sportscience* 10 (sportsci.org/2006/wghcontrial.htm), 2006.

109. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-12, 2009.

110. Hopper DM, Anders M, Berg A, Andersen H, and Madan R. The influence of visual feedback on power during leg press on elite women field hockey players. *Phys Ther Sport* 4: 182-186, 2003.

111. Hrysomallis C. Upper-body strength and power changes during a football season. *J Strength Cond Res* 24: 557-559, 2010.

112. Ingle L, Sleap M, and Tolfrey K. The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. *J Sports Sci* 24: 987-997, 2006.

113. Jarimae J, Maestu J, Purge P, and Jarimae T. Changes in stress and recovery after heavy training in rowers. *J Sci Med Sport* 7: 335-339, 2004.

114. Jung M-C and Hallbeck MS. Quantification of the effects of instruction type, verbal encouragement, and visual feedback on static and peak handgrip strength. *Int J Ind Ergonom* 34: 367-374, 2004.

115. Jurimae J, Purge P, Maestu J, and Jurimae T. Physiological responses to successive days of intense training in competitive rowers. *Hungarian Rev Sports Med* 43: 11-19, 2002.

116. Kaneko M, Fuchimoto T, Toji H, and Suei K. Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scand J Sports Sci* 5: 50-55, 1983.

117. Kellis E and Baltzopoulos V. Resistive eccentric exercise: effects of visual feedback on maximum moment of knee extensors and flexors. *J Orthop Sports Phys Ther* 23: 120-124, 1996.

118. Keogh J. The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *J Sci Med Sport* 2: 125-133, 1999.

119. Keogh JWL, Newlands C, Blewett S, Chun E-L, and Payne A. A kinematic analysis of a strongman-type event: the heavy sprint-style sled pull. *J Strength Cond Res* 24: 3088-3097, 2010.

120. Kilduff LP, Bevan HR, Kingsley MIC, Owen NJ, Bennett MA, Bunce PJ, Hore AM, Maw JR, and Cunningham DJ. Postactivation potentiation in professional rugby players: optimal recovery. *J Strength Cond Res* 21: 1134-1138, 2007.

121. Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MIC, and Cunningham D. Influence of recovery time on post-activation potentiation in professional rugby players. *J Sports Sci* 26: 795-802, 2008.

122. Kilgallon M and Beard A. The assisted jump squat. *J Aust Strength Cond* 17: 30-32, 2009.

123. Kim HJ and Kramer JF. Effectiveness of visual feedback during isokinetic exercise. *J Orthop Sports Phys Ther* 26: 318-323, 1997.

124. Kirwan JP, Costill DL, Flynn MG, Mitchell JB, Fink WJ, Neufer PD, and Houmard JA. Physiological responses to successive days of intense training in competitive swimmers. *Med Sci Sports Exerc* 20: 255-259, 1988.

125. Knight CA and Kamen G. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. *J Electromyogr Kines* 11: 405-412, 2001.

126. Kraemer WJ, French DN, Paxton NJ, Hakkinen K, Volek JS, Sebastianelli WJ, Putukian M, Newton RU, Rubin MR, Gamez AL, Vescovi JD, Ratamess NA, Fleck SJ, Lynch JM, and Knuttgen HG. Changes in exercise performance and hormonal

concentrations over a big ten soccer season in starters and nonstarters. *J Strength Cond Res* 18: 121-128, 2004.

127. Kraemer WJ and Hakkinen K. *Strength training for sport.* Oxford, England; United Kingdom: Blackwell Science, 2002.

128. Kraemer WJ and Newton RU. Training for muscular power. *Phys Med Rehabil Clin N Am* 11: 341, 2000.

129. Kraemer WJ, Patton JF, Gordon SE, Harman EA, Deschenes MR, Reynolds K, Newton RU, Triplett NT, and Dziados JE. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J Appl Physiol* 78: 976-989, 1995.

130. Kreighbaum E and Barthels K, eds. *Linear momentum and kinetic energy*. Needhham Heights, MA: Allyn and Bacon, 1996.

131. Kubo K, Kanehisa H, Takeshita D, Kawakami Y, Fukashiro S, and Fukunaga T. In vivo dynamics of human medial gastrocnemius muscle-tendon complex during stretch-shortening cycle exercise. *Acta Physiologica Scandinavica* 170: 127-135, 2000.

132. Lander J. Maximums based on reps. *Natl Str Cond Assoc* 6: 60-61, 1985.

133. Larsson L and Moss RL. Maximum velocity of shortening in relation to myosin isoform composition in single fibres from human skeletal muscles. *J Physiol* 472: 595-614, 1993.

134. Lee RC, Wang Z, Heo M, Ross R, Janssen I, and Heymsfield SB. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 72: 796-803, 2000.

135. Legaz-Arrese A, Reverter-Masa J, Mungua-Izquierdo D, and Ceballos-Gurrola O. An analysis of resistance training based on the maintenance of mechanical power. *J Sports Med Phys Fitness* 47: 427-436, 2007.

136. LeSuer DA, McCormick JH, Mayhew JL, Wasserstein RL, and Arnold MD. The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. *J Strength Cond Res* 11: 211-213, 1997.

137. Leveritt M, Abernethy PJ, Barry BK, and Logan PA. Concurrent strength and endurance training: A review. *Sports Med* 28: 413-427, 1999.

138. Liggins T, Yuhua L, Stephens L, and Qin L. Effects of summary knowledge of results and error estimation in motor learning: An EMG study. *J Sport Exerc Psychol* 29: S105-S105, 2007.

139. Magill RA. *Motor learning and Control: Concepts and Applications* New York: McGraw-Hill, 2011.

140. Magill RA and Wood CA. Knowledge of results precision as a learning variable in motor skill acquisition. *Res Q Exerc Sport* 57: 170-173, 1986.

141. Maio Alves JM, Rebelo AN, Abrantes C, and Sampaio J. Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. *J Strength Cond Res* 24: 936-941, 2010.

142. Majdell R and Alexander MJL. The effect of overspeed training on kinematic variables in sprinting. *J Hum Movement Stud* 21: 19-39, 1991.

143. Mangine GT, Ratamess NA, Hoffman JR, Faigenbaum AD, Kang J, and Chilakos A. The effects of combined ballistic and heavy resistance training on maximal lower- and upper-body strength in recreationally trained men. *J Strength Cond Res* 22: 132-139, 2008.

144. Mangus BC, Takahashi M, Mercer JA, Holcomb WR, McWhorter JW, and Sanchez R. Investigation of vertical jump performance after completing heavy squat exercises. *J Strength Cond Res* 20: 597-600, 2006.

145. Markovic G and Jaric S. Positive and negative loading and mechanical output in maximum vertical jumping. *Med Sci Sports Exerc* 39: 1757-1764, 2007.

146. Masuda K, Kikuhara N, Takahashi H, and Yamanaka K. The relationship between muscle cross-sectional area and strength in various isokinetic movements among soccer players. *J Sports Sci* 21: 851-858, 2003.

147. Matthews M, O'Conchuir C, and Comfort P. The acute effects of heavy and light resistances on the flight time of a basketball push-pass during upper body complex training. *J Strength Cond Res* 23: 1988-1995, 2009.

148. McBride JM, Triplett-McBride T, Davie A, and Newton RU. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res* 16: 75-82, 2002.

149. McGuigan MR, Cormack S, and Newton RU. Long-term power performance of elite Australian rules football players. *J Strength Cond Res* 23: 26-32, 2009.

150. McKay JM, Selig SE, Carlson JS, and Morris T. Psychophysiological stress in elite golfers during practice and competition. *Aust J Sci Med Sport* 29: 55-61, 1997.

151. McNair PJ, Depledge J, Brettkelly M, and Stanley SN. Verbal encouragement: effects on maximum effort voluntary muscle action. *Br J Sports Med* 30: 243-245, 1996.

152. Meir R, Colla P, and Milligan C. Impact of the 10-meter rule change on professional rugby league: Implications for training. *Strength Cond J* 23: 42-46, 2001.

153. Mero A and Komi PV. Force-, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. *Eur J Appl Physiol Occ Physiol* 55: 553-561, 1986.

154. Metzger JM, Greaser ML, and Moss RL. Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal muscle fibers. Implications for twitch potentiation in intact muscle. *J Gen Physiol* 93: 855-883, 1989.

155. Mihalik JP, Libby JJ, Battaglini CL, and McMurray RG. Comparing short-term complex and compound training programs on vertical jump height and power output. *J Strength Cond Res* 22: 47-53, 2008.

156. Moss BM, Refsnes PE, Abildgaard A, and Nicolaysen K. Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *Eur J Appl Physiol Occ Physiol* 75: 193-199, 1997.

157. Mota S, Brito J, Passos E, Marques E, Mota J, Seabra A, and Rebelo A. Variation of isokinetic strength and bone mineral density in youth portuguese soccer players with age. *Open Sports Sci J* 3: 49-51, 2010.

158. Naclerio F, Rodraguez G, and Colado JC. Application of a jump test with increasing weights to evaluate the relation between strength-speed and potency. *Fitness Perf J* 7: 295-300, 2008.

159. Newton RU and Kraemer WJ. Developing explosive muscular power: Implications for a mixed methods training strategy. *Strength Cond* 16: 20-31, 1994.

160. Newton RU, Kraemer WJ, and Hakkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. *Med Sci Sports Exerc* 31: 323-330, 1999.

161. Newton RU, Kraemer WJ, Hakkinen K, Humphries BJ, and Murphy AJ. Kinematics, kinetics, and muscle activation during explosive upper body movements. *J Appl Biomech* 12: 31-43, 1996.

162. Norton K, Whittingham N, Carter L, Kerr D, Gore C, and Marfell-Jones M. Measurement techniques in anthropometry, in: *Anthropometrica* K Norton, T Olds, eds. Marrackville: UNSW Press., 1996, pp 25-75.

163. O'Connor DM and Crowe MJ. Effects of six weeks of β-hydroxy-β-methylbutyrate (HMB) and HMB/creatine supplementation on strength, power, and anthropometry of highly trained athletes. *J Strength Cond Res* 21: 419-423, 2007.

164. Obminski Z and Stupnicki R. Comparison of the testosterone-to-cortisol ratio values obtained from hormonal assays in saliva and serum. *J Sports Med Phys Fitness* 37: 50-55, 1997.

165. Passelergue P, Robert A, and Lac G. Salivary cortisol and testosterone variations during an official and a simulated weight-lifting competition. *Int J Sports Med* 16: 298-303, 1995.

166. Perini TA, de Oliveira GL, Ornellas JDS, and de Oliveira FP. Technical error of measurement in anthropometry (english version). *Revista Brasileira de Medicina do Esporte* 11: 86-90, 2005.

167. Peterson MD, Rhea MR, and Alvar BA. Applications of the dose-response for muscular strength development: A review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res* 19: 950-958, 2005.

168. Pucci AR, Griffin L, and Cafarelli E. Maximal motor unit firing rates during isometric resistance training in men. *Exp Physiol* 91: 171-178, 2006.

169. Quarrie KL and Hopkins WG. Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. *J Sports Sci* 25: 895-903, 2007.

170. Rahimi R, Arshadi P, Behpur N, Boroujerdi SS, and Rahimi M. Evaluation of plyometrics, weight training and their combination on angular velocity. *Phys Educ Sport* 4: 1-8, 2006.

171. Randell AD, Cronin JB, Gill ND, and Pedersen MC. Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport-specific performance tests. *J Strength Cond Res* 25: 87-93, 2011.

172. Rassier DE and Macintosh BR. Coexistence of potentiation and fatigue in skeletal muscle. *Braz J Med Biol Res* 33: 499-508, 2000.

173. Robbins DW. Postactivation potentiation and its practical applicability: a brief review. *J Strength Cond Res* 19: 453-458, 2005.

174. Robbins DW and Docherty D. Effect of loading on enhancement of power performance over three consecutive trials. *J Strength Cond Res* 19: 898-902, 2005.

175. Rogerson S, Riches CJ, Jennings C, Weatherby RP, Meir RA, and Marshall-Gradisnik SM. The effect of five weeks of tribulus terrestris supplementation on muscle strength and body composition during preseason training in elite rugby league athletes. *J Strength Cond Res* 21: 348-353, 2007.

176. Rousanoglou E, Nikolaidou M-E, and Boudolos K. Discrimination of youg women athletes and nonathletes based on anthropometric, jumping, and muscular strength measures. *Percept Motor Skills* 102: 881-895, 2006.

177. Santos EJAM and Janeira MAAS. Effects of complex training on explosive strength in adolescent male basketball players. *J Strength Cond Res* 22: 903-909, 2008.

178. Sapega AA. Muscle performance evaluation in orthopaedic practice. *J Bone Joint Surg Am* 72: 1562-1574, 1990.

179. Schachar R, Herzog W, and Leonard TR. Force enhancement above the initial isometric force on the descending limb of the force-length relationship. *J Biomech* 35: 1299, 2002.

180. Schmidtbleicher D. Training for power events, in: *Strength and power in sport*. PV Komi, ed. United Kingdom: Oxford, Blackwell Scientific Publications, 1992, pp 381-395.

181. Schneider V, Arnold B, Martin K, Bell D, and Crocker P. Detraining effects in college football players during the competitive season. *J Strength Cond Res* 12: 42-45, 1998.

182. Sheppard J, Hobson S, Barker M, Taylor K, Chapman D, McGuigan M, and Newton R. The effect of training with accentuated eccentric load counter-movement jumps on strength and power characteristics of high-performance volleyball players. *Int J Sport Sci Coaching* 3: 355-363, 2008.

183. Siegel JA, Gilders RM, Staron RS, and Hagerman FC. Human muscle power output during upper- and lower-body exercises. *J Strength Cond Res* 16: 173-178, 2002.

184. Sleivert G and Taingahue M. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol* 91: 46-52, 2004.

185. Smart DJ. Physical profiling of rugby union players: implications for talent development, in: *Division of Sport and Recreation*. Auckland: Auckland University of Technology, 2011.

186. Smilios I, Pilianidis T, Sotiropoulos K, Antonakis M, and Tokmakidis SP. Short-term effects of selected exercise and load in contrast training on vertical jump performance. *J Strength Cond Res* 19: 135-139, 2005.

187. Snowling NJ and Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients: a meta-analysis. *Diabetes Care* 29: 2518-2527, 2006.

188. Stone MH, Moir G, Glaister M, and Sanders R. How much strength in necessary? *Phys Ther* 3: 88-96, 2002.

189. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, and Schilling B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. *J Strength Cond Res* 17: 140-147, 2003.

190. Suter E, Herzog W, and Huber A. Extent of motor unit activation in the quadriceps muscles of healthy subjects. *Muscle Nerve* 19: 1046-1048, 1996.

191. Sweeney HL and Kushmerick MJ. Myosin phosphorylation in permeabilized rabbit psoas fibers. *Am J Physiol* 249: C362-C365, 1985.

192. Taylor J. Sport training quality: Enhancing physical, technical, and psychological development. Presented at Workshop presented at the annual meeting for the

Association for the Advancement of Applied Sport Psychology, Banff, Canada, 1999.

193. Thompsen AG, Kackley T, Palumbo MA, and Faigenbaum AD. Acute effects of different warm-up protocols with and without a weighted vest on jumping performance in athletic women. *J Strength Cond Res* 21: 52-56, 2007.

194. Tod DA, Iredale KF, McGuigan MR, Strange DEO, and Gill N. "Psyching-up" enhances force production during the bench press exercise. *J Strength Cond Res* 19: 599-603, 2005.

195. Tod DA, Thatcher R, McGuigan M, and Thatcher J. Effects of instructional and motivational self-talk on the vertical jump. *J Strength Cond Res* 23: 196-202, 2009.

196. Tong RJ and Mayers R. The effect of pre-season training on the physiological characteristics of international rugby players, in: *Science and Football*. T Reilly, J Bangsbo, M Hughes, eds. London: E & FN Spon, 1997, pp 98-102.

197. Toumi H, Best TM, Martin A, and Poumarat G. Muscle plasticity after weight and combined (weight + jump) training. *Med Sci Sports Exerc* 36: 1580-1588, 2004.

198. Van Cutsem M, Duchateau J, and Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 513 (Pt 1): 295-305, 1998.

199. van Herp G and Shah A. The effects of feedback in isokinetic dynamometry. *S Afr J Physiotherapy* 52: 88-90, 1996.

200. Vervoorn C, Quist AM, Vermulst LJ, Erich WB, de Vries WR, and Thijssen JH. The behaviour of the plasma free testosterone/cortisol ratio during a season of elite rowing training. *Int J Sports Med* 12: 257-263, 1991.

201. Vescovi JD and McGuigan MR. Relationships between sprinting, agility, and jump ability in female athletes. *J Sports Sci* 26: 97-107, 2008.

202. Vining RF and McGinley RA. The measurement of hormones in saliva: possibilities and pitfalls. *J Steriod Biochem* 27: 81-94, 1987.

203. Vining RF, McGinley RA, and Symons RG. Hormones in saliva: Mode of entry and consequent implications for clinical interpretation. *Clin Chem* 29: 1752-1756, 1983.

204. Walker S, Ahtiainen JP, and Hakkinen K. Acute neuromuscular and hormonal responses during contrast loading: effect of 11 weeks of contrast training. *Scand J Med Sci Sports* 20: 226-234, 2010.

205. Weber KR, Brown LE, Coburn JW, and Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. *J Strength Cond Res* 22: 726-730, 2008.

206. Weinberg R, Jackson A, and Seaboune T. The effects of specific vs nonspecific mental preparation strategies on strength and endurance performance. *J Sport Behav* 7: 175-180, 1985.

207. Wilson GJ, Newton RU, Murphy AJ, and Humphries BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25: 1279-1286, 1993.

208. Withers RT, Craig NP, Bourdon PC, and Norton KI. Relative body fat and anthropometric prediction of body density of male athletes. *Eur J Appl Physiol Occ Physiol* 56: 191-200, 1987.

209. Wulf G and Dufek JS. Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *J Motor Behav* 41: 401-409, 2009.

210. Wulf G, Dufek JS, Lozano L, and Pettigrew C. Increased jump height and reduced EMG activity with an external focus. *Hum Mov Sci* 29: 440-448, 2010.

211. Wulf G, Shea C, and Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ* 44: 75-84, 2010.

212. Wulf G, Zachry T, Granados C, and Dufek JS. Increases in jump-andreach height through an external focus of attention. *Int J Sport Sci Coaching* 2: 275-284, 2007.

213. Young WB, Jenner A, and Griffiths K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res* 12: 82-84, 1998.

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