

**Methods of Assessing, Monitoring and Improving Strength
and Ballistic Performance in Highly Trained Rugby Union
Players**

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ATTESTATION OF AUTHORSHIP

“I hereby declare that this thesis 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 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.”



D. Travis Williams McMaster

Daniel Travis Williams McMaster

DEDICATION

This thesis is dedicated to the life and memory of

Dr. Melanie Morgan Williams

Mother, fighter and pioneer for veterinarian ophthalmology

25th of September, 1949 to 3rd of May, 2013

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LIST OF CO-AUTHORED PUBLICATIONS

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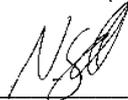
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ABSTRACT

Strength and ballistic qualities are vital to excelling in contact team sports, such as rugby. The assessment, development, retention and decay of these qualities are of great interest, as this information can be utilised by strength and conditioning coaches to better inform and guide the yearly training plan. The overall aim of this project was to develop innovative and effective strength and ballistic assessment batteries that provide an in depth athlete profile through novel analytical approaches to improve current methods of assessment, monitoring and programming in the semi-professional rugby union.

In study one, measurement system validation (Chapter 4) outcomes revealed an inconsistency between peak force (PF), peak velocity (PV) and peak power (PP) between the force plate and accelerometers (hip and bar attachments) during vertical jumps (VJ). Both accelerometer attachments were reliable for assessing PF (ICC = 0.80 – 0.83), but were low to moderately reliable for monitoring PV and PP (ICC = 0.35 – 0.77); therefore, subsequent studies in this PhD utilised force plate technology and linear position transducers as the primary means of assessing ballistic performance. In Chapter five, bench throw (BTH) and VJ incremental relative load (body mass-VJ, 15, 30, 45, 60 and 75% 1RM) profiles were also validated using a linear position transducer. The BTH (ICC > 0.80; CV < 11 %) and VJ (ICC > 0.75; CV < 11%) protocols described were relatively stable and reliable within and across testing sessions; and in turn deemed appropriate to monitor BTH and VJ PP, PF and PV adaptations in subsequent studies. The force-velocity profiling data was further analysed to predict maximum BTH and VJ force (F_{max}) and velocity (V_{max}) to provide a more holistic representation of these ballistic movements.

In chapters six and seven, the effects of strength and sprint ability on the previously validated BTH and VJ force-velocity-power profiles were assessed. The comparative statistical analysis illustrated that stronger players produced higher BTH P_{max} (14%) and F_{max} (17%) and higher VJ F_{max} (10%); whereas faster players

produced greater VJ Pmax (14%) and Vmax (11%). These findings could be useful to better inform programming of individual and group mechanical efficiencies and deficiencies.

The next three chapters used the major findings of these validation and comparative studies to assess the effects of training, detraining and a competitive season on the performance profile. Firstly, the five week complex training (Chapter 8) interventions (strength + heavy ballistic [SHB]; strength + light ballistic [SLB]) herein elicited positive adaptations in 1RM bench press (4 – 9 %) and 1RM squat (9 – 12 %); as well as reductions in 10, 20 and 30 m sprint times (-1 to -2%). SHB training caused positive shifts in Fmax (6 to 10%) and Pmax (12 to 46%); whereas the SLB training caused increases in Vmax (15 to 68%) and Pmax (15 to 36%). Findings indicate that acute SHB and SLB training can be implemented to elicit positive adaptations in strength, sprint ability and ballistic Fmax and Vmax capabilities, respectively. Secondly, the examination of six weeks of resistance detraining (Chapter 9) lead to small reductions in 1RM bench press (-1%) 1RM squat (-6%) and heavy load PF (2%); moderate and very large negative shifts in VJ Vmax (-35%) and Pmax (-14%); and large increases in sprint times over 10, 20 and 30 m (1-3%) were observed. The results suggest that decay rates using high velocity loads are greater than the high force loads.

Finally, the effects of a competitive season (Chapter 10) on VJ (PP, F@PP and V@PP) was monitored pre- (58 ± 2 hrs) and post- (41 ± 10 hrs) match to assess weekly ballistic recovery patterns. Decreases in post-match PP (-2%) in comparison to baseline, and increases in pre-match PP (4%) and V@PP (3%) in comparison to post-match were observed. Furthermore, a very large correlation was also observed between PP ($r = 0.72$) and the number of hours post-match jump testing took place, a trendline fitted to this data also suggests that PP may be reduced for up to 110 hrs. There were also increases in PP (2%) and V@PP (6%) from the first two weeks of competition to the last two weeks,

suggesting the mixed method strength and ballistic training performed 2 to 3 times per week throughout the competition period may be sufficient to maintain VJ PP. This information has provided a greater understanding of current in-season ballistic recovery patterns of rugby union competition; and in turn may allow for more informed planning (e.g. recovery modalities and weekly training load management) throughout future competitive seasons.

PREFACE

1.1 Rationale and Significance of Research

It is widely accepted that to excel at the elite level in rugby union, a player must possess a myriad of physical attributes, including high levels of strength and ballistic force, power, and velocity, to cope with the performance demands of this intense collision sport [1-11]. Current mechanical assessments of weight-room (i.e. pressing and squatting) and rugby specific movements (i.e. throwing, sprinting and jumping) through the use of performance technology (i.e. force plates, position transducers and accelerometers) have provided strength and conditioning coaches with the tools required to improve assessment methods and better inform programming. Mechanical assessments using innovative technology that allows for precise quantitative analysis of these physical attributes should inevitably lead to better strength and conditioning practice and as a result better athletes.

The technology used specifically to assess force, velocity and power in athletes has and will continue to evolve [12, 13]. Current equipment and methods used to measure and analyse these kinematic and kinetic outputs include: predictive equations based on an athlete's vertical jump height and body mass, force plates and linear position transducers that measure ground reaction force and displacement, respectively; and more recently wireless accelerometers that measure acceleration [14-26]. If wireless accelerometry is validated for assessing upper and lower body ballistic movements, performance monitoring and in field research will become more accessible and practical for coaches and practitioners alike.

There is an abundance of research examining power as the primary performance variable in rugby populations, however, such analysis/information only provides a partial representation of the athlete's true ballistic capabilities [27-36]. The inclusion of upper and lower body maximum predicted force (Fmax) and maximum predicted velocity (Vmax) and their contribution to the ballistic performance profile may provide a more holistic mechanical representation of the athlete's capabilities [37]. This may result in more

informative assessments, possibly leading to a better quality of programming. In rugby union it is paramount that players continue to improve strength, sprint ability and ballistic performance capabilities through the effective integration of strength, speed and power programming within the yearly training plan. A number of training studies have effectively improved strength and power in elite rugby-football code players ^[38-53], but there is minimal research that has attempted to shift Vmax and Fmax through acute complex strength and ballistic training methods. Small shifts in areas of focus due to specific programming combinations may allow for better individualisation when it comes to developing strength, speed, Pmax, Fmax and Vmax in athletes.

Few studies have assessed the acute and accumulative effects of a rugby competition on ballistic performance (VJ power) ^[54-58]; furthermore, no research has monitored the changes in the derivatives of peak power (PP [force at PP and velocity at PP]) and their contribution to the changes in ballistic performance. An investigation tracking the time course changes in ballistic performance the days following each rugby match as assessed throughout a competitive season may provide a greater understanding of ballistic (neuromuscular) recovery patterns; and in turn allow for more informed planning (e.g. recovery modalities and weekly training load management) throughout the competitive season.

Once performance gains have been made, the retention of these gains becomes critical given the physical demands of training and in-season of rugby union competition. Detraining data on elite athletes is scarce ^[59-63] and there is minimal research on the decay rates of ballistic performance in elite rugby codes. When training is ceased for an extended period, the decay rates in these performance variables (Pmax, Fmax and Vmax) are of great interest; therefore its investigation may allow us to determine the residual effects on these ballistic capabilities, strength and sprint performance. This information may in turn influence off-season programming and provide guidelines for off-season

strength and power training frequencies required to retain these qualities in elite rugby players. Also of interest to the practitioner are the effects of in-season competition on physical performance.

As a result of the exposed gaps in rugby research, this PhD thesis was designed to further improve and evolve physical performance assessment and monitoring techniques for the purpose of creating comprehensive player profiles to better inform programming in the elite rugby union environment.

1.2 Purpose of Research

The objectives of this thesis were to:

1. Validate wireless accelerometry for its practicality as an assessment tool.
2. Create detailed ballistic (bench throw and vertical jump) performance profiles to assess and monitor acute and chronic performance adaptations.
3. Investigate the effects of acute complex strength and ballistic (heavy vs light) training on strength and ballistic performance.
4. Assess the residual effects of off-season rest on strength and ballistic performance.
5. Monitor weekly recovery patterns and the accumulative effects of competition on ballistic performance.

The overall aim of this project was to develop innovative and effective upper and lower body assessment batteries that provide comprehensive athlete profiles. This was achieved by utilising novel analytical approaches to improve current methods of assessment, monitoring and programming in semi-professional rugby union.

1.3 Significance of Thesis

Strength, sprint ability and ballistic capabilities are linked to successful individual and team performance, and their regular assessment is important from a talent identification,

development and monitoring perspective. However, the utilisation of ballistic assessments to inform programming to positively effect ballistic adaptations remains unclear. Clarity and guidance in ballistic assessment and development is needed to create effective high performance resistance training programmes.

Accurate ballistic performance assessment and analysis strategies need to be established. To date, ballistic research in rugby union has over-utilised the importance of power profiling, neglecting to include force and velocity in the ballistic profile. Such analyses should provide a more holistic mechanical understanding of ballistic movement, improve athlete profiling and enhance programming strategies specific to rugby union.

Finally, the integration of strength, sprint running and novel ballistic assessment methodologies utilised within this thesis will add to the current rugby research knowledge base; which in turn will help improve and guide future programming. Subsequently the assessment, monitoring and programming strategies used in this research are of greatest relevance to New Zealand's provincial (semi-professional) rugby union structure, but information herein may also be applied to the southern and northern hemispheres' developmental, club level, regional and professional rugby union yearly training structure, along with other contact sports.

1.4 Structure of Thesis

This thesis is comprised of four main inter-linking sections (see Figure 1.1). The first section is comprised of two literature reviews, the first (Chapter 2) addressing strength and ballistic profiling methodologies. Chapter 3 is a systematic review of strength and power development, retention and decay in elite rugby-football code athletes. The second section investigates the use of wireless technology (i.e. wireless accelerometry) as a viable means of assessing and monitoring ballistic upper and lower body performance (Chapter 4). The third section focus' on developing valid and reliable protocols to assess ballistic upper (BTH) and lower body (VJ) force, velocity and power (Chapter 5) as well as create innovative athlete performance profiles through novel methods of manipulating and comparing individual and group data across a squad of semi-professional rugby union players (Chapters 6 and 7). The fourth and final section concentrated on utilising these newly designed testing protocols and innovative athlete profiles to assess the performance adaptations in strength, sprint running ability, BTH and VJ due to complex strength and ballistic (heavy vs. light) training interventions (Chapter 8) and off-season active rest (Chapter 9). A simplified VJ protocol was also used to quantify the weekly ballistic-neuromuscular recovery patterns across a competitive season (Chapter 10) in semi-professional rugby union players.

Methods of Assessing, Monitoring and Improving Strength and Ballistic Capabilities in Highly Trained Rugby Union Players

Chapter 1: Preface

Reviews of Literature

Chapter 2: A review of strength and ballistic profiling methodologies

Chapter 3: Systematic review: strength and power adaptations in rugby football codes

Validation of Equipment and Assessment Protocols

Chapter 4: Validation of wireless accelerometry

Chapter 5: Validation of ballistic upper and lower body assessment protocols

Analysis of Strength, Speed and Ballistic Capabilities

Chapter 6: Importance of strength to ballistic upper body performance

Chapter 7: Importance of strength and speed to ballistic lower body performance

Strength and Ballistic Monitoring and Training

Chapter 8: Effects of complex strength and ballistic (heavy and light) training on performance

Chapter 9: Effects of off-season rest on strength, sprint ability and ballistic performance

Chapter 10: In-season ballistic performance monitoring

Chapter 11: Summary

***A BRIEF REVIEW OF STRENGTH AND BALLISTIC PROFILING
METHODOLOGIES: A RUGBY-FOOTBALL CODE APPLICATION***

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McGuigan**

**Sports Medicine
Accepted (Appendix 4a)**

2.0 Lead Summary

Background and aim: An athletic profile should encompass the physiological, biomechanical, anthropometric and performance measures pertinent to the athlete's sport, position and/or discipline. The measurement systems and procedures used to assess these performance measures is constantly evolving and becoming more precise and practical for off-site and on-field assessments. This is a review of current strength and ballistic assessment methodologies utilised in the realm of sports science, a critique of current maximum strength (one-repetition maximum [1RM] and isometric strength) and ballistic performance [throw and jump ability] assessments for the purpose of informing practitioners and evolving current assessment methods.

Data analysis: The reliability of the various maximum strength and ballistic assessment protocols were reported in the form of intra-class correlation coefficients (ICC) and coefficient of variation (%CV). Mean differences ($Mdiff = \left[\frac{|X_{method1} - X_{method2}|}{(X_{method1} + X_{method2})} \right] \times 100$) and effect size ($ES = [X_{Method 2} - X_{Method 1}] \div SD_{Method1}$) calculations were used to assess the magnitude and spread of methodological differences for a given performance measure in the included studies. The studies were grouped and compared according to their respective performance measure and movement pattern.

Results: The various measurement systems (e.g. force plates, position transducers, accelerometers, jump mats, optical motion sensors and jump-and-reach devices) and assessment procedures (i.e. warm-up strategies, loading schemes and rest periods) currently utilised to assess maximum isometric squat and mid-thigh pull force production (intra-class correlation coefficient [ICC] > 0.95; coefficient of variation [CV] < 2.0%), one-repetition maximum (1RM) bench press, back squat and clean strength (ICC > 0.91; CV < 4.3%), and ballistic (vertical jump and bench throw) capabilities (ICC > 0.82; CV < 6.5%) were highly reliable. The measurement systems and assessment procedure

employed to assess maximum isometric strength (mean difference [MDiff] = 2 – 71%; effect size [ES] = 0.13 – 4.37), maximum dynamic strength (MDiff = 1 – 58%; ES = 0.01 – 5.43), vertical jump capabilities (MDiff = 2 – 57%; ES = 0.02 – 4.67) and bench throw capabilities (MDiff = 7 – 27%; ES = 0.49 – 2.77) had a range of trivial to very large effects on these respective performance measures. Highly trained rugby-football code athletes produced mean and peak forces (MF and PF) of 1400 to 2000 N and 2100 to 3500 N during the isometric squat and isometric mid-thigh pull. 1RM bench press, back squat and power clean values between 110 to 190 kg, 140 to 250 kg and 100 to 140 kg were also respectively reported. Vertical jump (body mass to 60% 1RM) and bench throw (20 and 60% 1RM) peak power (PP) outputs across the various loads ranged between 2500 to 9000 W and 500 to 1500 W, respectively.

Conclusion: The large variations in maximum strength and power can be attributed to the wide range in physical characteristics between different positions, training and chronological age as well as the different measurement systems of the included studies. The reliability and validity outcomes suggest that a number of measurement systems and testing procedures can be implemented to accurately assess maximum strength and ballistic performance in rugby-football codes. The reader needs to be cognisant of the inherent differences between the various assessment methodologies currently available, as selection will inevitably affect the outcome measure. The strength and conditioning practitioner should carefully consider the benefits and limitations of the various measurement systems (e.g. force plates, video, jump mats, optical sensors, linear position transducers and accelerometers), testing apparatus (bar type [free vs fixed]), measurement system attachment sites, movement patterns (e.g. direction of movement, contraction type, depth), loading parameters (e.g. no load, single load, absolute load, relative load, incremental loading), warm-up strategies, inter-trial rest periods, dependent variables of

interest (e.g. displacement, velocity, force, power) and data processing techniques (sampling frequency, filtering and smoothing options).

2.1 Introduction

A performance profile should encompass all physiological, biomechanical, anthropometric and performance measures pertinent to the athlete's discipline. The measures that comprise an athlete profile in rugby-football codes may include: aerobic capacity [3, 64-67], repeated sprint ability [68-77], maximum sprint ability (acceleration and maximum speed) [45, 78-95], agility [85, 88, 89, 96-102], maximum strength [1, 4, 11, 24, 49, 54, 78, 103-108], ballistic upper and lower body force, velocity and power production [27-32, 35, 36, 40, 44, 48, 52, 56, 104, 105, 109-117], throwing [6, 118-121] and kicking [122-126] abilities, muscle architecture [127-130], anthropometry [2, 4, 5, 7, 9, 10, 131-136], functional movement [137-140] and flexibility [141-145]. Combinations of the above variables are often used for talent identification, the creation of national standards and performance tracking for the underlying purpose of determining an athlete's ability to excel in a particular code of rugby-football (i.e. rugby union, rugby league, Australian Rules football, American football and European football) [1, 2, 4, 5, 11, 27, 49, 54, 56, 58, 146-153].

In order to evolve current strength and conditioning practice, physical performance assessments and athlete profiling must be improved and standardised, as this will inevitably allow for direct unbiased comparisons within and between athletes and squads of the same sport/athletic discipline. The type of strength, power, speed and conditioning an athlete is exposed to will undoubtedly cause specific neuromuscular and morphological adaptations, which in turn may improve certain rugby-football specific performance variables, such as scrummaging, blocking, tackling and fending force/power and sprint running ability. Strength and conditioning practitioners utilise a combination of speed, strength, hypertrophy, power, velocity and metabolic training phases to elicit position and individual specific adaptations. [41, 154-156].

The mechanical assessment and analysis of weight-room (i.e. pressing, pulling and squatting) and sport specific movements (i.e. throwing and jumping) through the use

of technology (i.e. force plates, position transducers, accelerometers and video capture devices) may provide strength and conditioning coaches with the tools required to improve assessment methods to create comprehensive athlete profiles that effectively influence programming. The overall objective of this review is to consolidate current maximum strength and ballistic assessment methodologies in sport and provide practical recommendations for the sport scientist and strength and conditioning coach. Subsequent discussion will provide further insight into the reliability, validity and primary differences between current measurement systems and procedures/methods utilised to assess ballistic upper and lower body capabilities and maximum strength.

2.2 Methods

2.2.1 Search Strategies

The following electronic data bases were searched multiple times between February 1, 2013 and November 1, 2013: MEDLINE, EBSCO Host, Google Scholar, IngentaConnect, Ovid LWW, ProQuest Central, PubMed Central, ScienceDirect Journals, SPORTDiscus and Wiley InterScience between the years of 1980 and 2013. The following keywords were used in various combinations during the electronic searches: ‘rugby’, ‘football’, ‘AFL’, ‘League’, ‘Union’ ‘elite’, ‘highly trained’, ‘athlete’, ‘sport’, ‘profile’, ‘physical’, ‘characteristics’, ‘maximum’, ‘strength’, ‘one-repetition’, ‘1RM’, ‘isometric’, ‘dynamic’, ‘ballistic’, ‘neuromuscular’, ‘performance’, ‘measure’, ‘capture’, ‘record’, ‘quantify’, ‘assess’, ‘evaluate’, ‘track’, ‘monitor’, ‘test’, ‘analyse’, ‘identify’, ‘develop’, ‘reliability’, ‘validity’, ‘human movement’, ‘jump’, ‘countermovement’, ‘bench’, ‘throw’, ‘squat’, ‘press’, ‘deadlift’, ‘clean’, ‘mid-thigh pull’, ‘measurement’, ‘system’, ‘technology’, ‘device’, ‘method’, ‘protocol’, ‘design’, ‘force plate’, ‘linear position transducer’, ‘rotary encoder’, ‘accelerometer’, ‘optical sensor’, ‘jump mat’, ‘video’, ‘Vertec’, ‘output’, ‘biomechanics’, ‘kinetics’, ‘kinematics’, ‘force’, ‘power’,

‘velocity’, ‘displacement’, ‘time’, ‘sampling frequency’, ‘rate’, ‘Nyquist theorem’, ‘cut-off’, ‘data processing’, ‘smooth’, ‘filter’.

2.2.2 Inclusion and Exclusion Criteria

Original research studies, technical notes, conference abstracts, book sections and online sources focusing on human movement measurement systems, maximum isometric strength, maximum dynamic strength and ballistic upper and lower body assessments were included in the initial screening phase. The studies were also required to be written in English, all others were excluded. During the final screening, selections were based on the relevance of the identified sources to the assessment of maximum strength and ballistic performance to recreational and elite athletes, alike.

2.2.3 Data Analysis

The reliability of the included studies was reported in the form of intra-class correlation coefficients (ICC) and coefficient of variation (%CV). Mean percent difference ($Mdiff = \left[\frac{X_{method1} - X_{method2}}{X_{method1} + X_{method2}} \right] \times 100$) and effect size ($ES = [X_{method2} - X_{method1}] \div SD_{Method1}$) calculations were used to assess the magnitude and spread of methodological differences for a given dependent variable. Where X represents the mean of each method (one or two) and SD represents the standard deviation of method one. The studies were grouped and compared according to their respective performance measure and movement pattern. The mean per cent difference calculations do not take into account the variance of the change within and between groups^[157], therefore effect size (ES) calculations were included to account for variance by standardizing the effects allowing for a more accurate comparison within and between measurement systems and movement patterns. Effect sizes have been classified into the following for highly trained rugby-football code athletes: trivial (< 0.25), small (0.25 – 0.50), moderate (0.50 -1.00) and large (> 1.00).

2.3 Measurement Systems

Technology used to profile athletes is constantly evolving and becoming smaller, lighter and more practical. Equipment has been designed and created to assess the kinematics and kinetics of any and all isometric and dynamic athletic (e.g. sprinting, cutting, squatting, jumping, pressing, throwing and pulling) and rugby-football specific movements (e.g. scrummaging, tackling, passing and kicking) [3, 23, 24, 85, 96, 101, 102, 118, 119, 122, 123, 158-166]. Current measurement systems utilised to assess these athletic movements include: timing lights [68, 83, 89, 167-171], video devices [172, 173], optical motion sensors [174, 175], global positioning systems (GPS) [3, 20, 68, 176, 177], stop watches [89, 100], timing mats [172, 173, 175, 178], linear position transducers (LTP) [16, 35, 113, 179-181], force plates (FP) [15-17, 19, 26, 35, 173, 182-184], strain gauges, rotary encoders [113, 185], accelerometers [16, 18, 25, 180, 186-188], magnetometers and gyroscopes [3, 15, 19, 20, 25, 26, 30, 37, 85, 117, 118, 162, 187, 189-194]. These technologies have been validated to measure force, acceleration, displacement, sprint times, change in position and their respective integrated and derived variables.

This information may be used to, provide immediate performance feedback, assess the effectiveness of training and track changes over-time. Sports scientists have used many of the above motion analysis systems in controlled laboratory based settings; and more recently accelerometers have been employed to assess changes in force, velocity and power during the above movements, in order to assess the effectiveness of training interventions and monitor performance over time [16, 172, 174, 187, 195-198]. A shift to develop smaller, more practical wireless technologies (e.g. wireless accelerometers and GPS) may afford strength and conditioning coaches the opportunity and capability to assess performance changes in the various training environments [199, 200]. However, these commercially available devices (e.g. Myotest®, XC2®, G-Link-LXRS®, AmmSensor™) are still relatively untested in terms of measuring kinematics and kinetics during squatting, jumping, pushing and pulling type movements in high performance

environments [16, 18, 25, 180, 187, 188, 191]; these technologies therefore require further validation before being used as a monitoring tool in rugby-football codes.

2.3.1 Sampling, Filtering and Smoothing Techniques

The data collected during these movement patterns is often filtered, smoothed, differentiated and integrated to calculate and predict specific kinematic (displacement, speed and velocity) and kinetic (work, impulse, rate of force development and power) variables using built-in and customised software programmes [16, 19, 21, 35, 161, 177, 180, 186, 195, 201-204]. The sampling frequency, filtering and data smoothing techniques applied may also affect the resultant output. A broad range of sampling frequencies (25 to 1000 Hz) have been applied to collect and record kinematic and kinetic data across different measurement system (e.g. video, rotary encoders, position transducers, accelerometers and force plates [15, 17, 19, 27-29, 31, 35, 36, 40, 112, 113, 166, 179, 180, 186, 201, 203, 205-212]. Recommendations are based on the Nyquist-Shannon sampling theorem, which states that the critical sampling frequency must be a minimum of two times the highest frequency in the signal of interest to obtain the all information found in the original signal [213, 214]. The movement pattern assessed (e.g. jumping, throwing, pressing and squatting), dependent variables of interest (e.g. mean, peak and rate dependent variables) and measurement system determine the frequency of the signal and in turn the required sampling frequency. The required sampling frequency increases with increasing velocity; for example, in order to capture position changes of 5 mm for movements with velocities between 1.00 and 3.00 m/s, the subsequent measurement system must sample at rates between 20 and 60 Hz [215-218]. Sampling at rates below the critical frequency run the risk of aliasing (i.e. distorting the original signal) and losing vital pieces of the original signal (e.g. peak values) [213]. Hori et al. [203], found minimal differences in peak force (< 0.04%), peak velocity (< 0.05%) and peak power (< 1.3%) using FP sampling frequencies between 200

and 500 Hz (ICC > 0.91; CV < 4.2%). Regardless of the measurement system employed, it is recommended that the sampling frequency be at least five to ten times the frequency of the signal of interest (i.e. 50 Hz or more) for human movements to ensure peak values are not missed [203, 214]. However, when rate dependent variables are included (e.g. rate of force development) sampling frequencies should be much larger (1000 – 2500 Hz). Therefore, the sampling frequencies required to accurately capture maximum dynamic strength (e.g. squat, bench press and clean), maximum isometric strength (e.g. squat, bench press and mid-thigh pull) and ballistic (e.g. bench throws and jumps) movements range from low (100 Hz) to very high (2500 Hz), respectively.

A number of the kinematic and kinetic measurement systems have built in software programmes that convert the analog signal to digital, the time dependent data is then smoothed and filtered (between 0 and 100 Hz), which can often be adjusted to reduce noise and signal distortion [203, 211, 212, 214, 219-227]. Human movement occurs at relatively low frequencies (5 – 30 Hz), therefore low pass filters (4 to 10 Hz) are often used to remove the high frequency noise of the signal; whereas high pass filters are used to minimize signal distortion [214, 225]. Displacement, velocity, acceleration and force data are most commonly smoothed using polynomial (i.e. second and fourth order Butterworth filters), splines (i.e. cubic, rectangular and quintic splines), Fourier transforms, moving averages (3 to 15 data points) and digital filters (i.e. high pass, low pass and band pass) [15, 112, 203, 211, 212, 214, 224, 225, 227-240].

The filtered and smoothed data is then differentiated or integrated depending on the measurement system utilised to calculate other important variables of interest (e.g. impulse, work and power). As the number of calculations increases, so does the error. For example, position-time data from a linear position transducer must be differentiated and double differentiated to calculate velocity and acceleration; similarly force- and acceleration- time data from a force plate and accelerometer must be integrated to

calculate velocity and displacement. Both methods introducing more noise for each successive calculation.

2.4 Ballistic Profiling

Rugby-football codes are typified by a spectrum of match specific force-velocity-power governed actions, such as tackling, fending, jumping, sprinting, cutting, kicking and passing [3, 150, 151, 153, 212]. Explosive upper and lower body capabilities are generally quantified and assessed via FP and LPT technology during explosive pulling, pressing, squatting, jumping and throwing [15, 17, 28, 36, 56, 201, 205, 211, 212, 241-243]. Ballistic movements, such as jumping and throwing allow the athlete to accelerate the body/bar throughout the entire range of motion; producing greater velocity and power outputs than traditional non-ballistic movements [41, 244]. When designing vertical jump and bench throw profiling protocols, the sports scientist and strength and conditioning coach must carefully consider the measurement system (i.e. FP, LPT, jump mat, optical sensors and accelerometry), testing apparatus (bar type [free vs fixed]), movement patterns (i.e. countermovement, concentric-only, direction of movement, depth), loading parameters (single load, incremental loading, absolute load, relative load [%1RM vs %BM]), warm-up strategy and inter-trial rest periods. A number of different bench throw and vertical jump testing protocols have been implemented to reliably ($ICC \geq 0.83$; $CV \leq 6.4\%$) assess vertical displacement (jump and throw height), force, velocity and power across the various absolute and relative loads using the previously mentioned measurement systems [15, 17, 19, 27-29, 31, 40, 54, 112, 113, 163, 166, 179, 190, 196, 201, 203, 205, 207-210, 228, 245-247].

2.4.1 Ballistic Assessment Strategies

The measurement system used during ballistic assessments will affect the resultant kinematics and kinetics [15, 17, 21, 172, 173, 175, 201, 248-250]. Jump mats and photo-cells predict

jump height based on flight time; whereas the reach-and-jump apparatuses (e.g. Vertec) measure jump height directly based on the difference between reach height and the highest obtained jump. Based on jump height and body mass peak power can be predicted using previously developed regression equations. Video capture devices use anatomical landmarks to track movement of the centre-of-mass, which are converted to vertical and horizontal position coordinates via digitisation, jump height is calculated as the rise of the centre-of-mass. Velocity and acceleration are calculated through single and double differentiation of the digitized position-time data; subsequently force (mass x acceleration) and power (force x velocity) can be determined if the mass of the athlete is known. The force plate predicts jump height from take-off velocity using different methods that include integration of the acceleration-time curve, the impulse-momentum theorem and the work-energy theorem. The force plate calculates power from the ground reaction force and velocity of the centre of mass as integrated from the acceleration-time curve; whereas the position transducer calculates power from the system mass (body mass + external load) and velocity of the position transducer attachment point as differentiated from the position-time data. When these two devices are synchronized, power is calculated from the ground reaction force of the force plate and the velocity of position transducer. Based on the above descriptions inter-device differences are expected as the respective kinematics and kinetics are measured and calculated via different parameters.

A number of vertical jump studies have compared the kinematic and kinetic differences between measurement systems. Lara et al. ^[21] reported that vertical jump peak power predictive equations based on jump height and body mass developed by Sayers^[250], Harman^[249] and Canavan^[248] differed from the force plate by 9% (ES = 0.52), 21% (ES = 1.19) and 33% (ES = 1.76), respectively. Cormie et al. ^[15] also observed trivial to small non-significant differences in peak power (MDiff = 2 – 7%; ES = 0.03 – 0.27) between the FP (4247 – 6261 W), LPT (4403 – 6497 W) and FP+LPT (4093 - 6332 W) during

jump squats across a spectrum of loads (0 – 85% 1RM). Much larger CMJ peak power differences (MDiff = 8 – 22%; ES = 0.61 – 1.72) between the FP (3866 W), LPT (3567 W) and LPT+FP (4427 W) were reported by Hori et al. [210]. These studies demonstrate that peak power outputs using similar measurement systems and movement patterns may also differ between studies. Previous researchers utilising accelerometer found the bar attachment [16, 187, 251] to over-predict (3-8%) and the hip attachment [174, 247, 252] to under-predict (~2-6%) flight time, force and power, in comparison to FP technology. Jump height estimations also vary in direct relation to the measurement system utilised [172, 173, 175]. Garcia-Lopez et al. [175] reported predicted jump height difference of 4 to 20% (ES = 0.23 – 1.04) between a FP (33 cm), photo-cells (31 cm) and a jump mat (27 cm); Nuzzo et al. [172] also observed jump height estimation differences (MDiff = 8 – 22%; ES = 0.39 – 1.21) between a jump mat (55 cm), Vertec (48 cm) and an accelerometer attached to the hip (44 cm). Dias et al. [173] also found predicted jump height differences of 4 to 32% (ES = 0.20 – 1.38) between video (38 cm), FP (36 cm) and jump mat (28 cm) measurement systems. The different devices measure and predict jump height and power based on different parameters, therefore inter-device differences should be expected. Nonetheless, these devices were all deemed highly reliable (ICC > 0.92; CV < 5.6%) for estimating jump height within and across testing sessions. There were no definitive predicted jump height trends for any of the devices, as the largest jump heights were predicted by three different devices (jump mat, FP and video) across these studies.

Although less researched, inter-devices differences were also observed during bench throw and explosive bench press assessments. Gomez-Piriz et al. [253] found a wireless accelerometer (805 ± 242 W; 1.94 ± 0.50 m/s) to over-predict explosive bench press peak power and peak velocity by 20% (ES = 2.77) and 7% (ES = 1.05) using a 25 kg load, in comparison to a LPT (662 ± 52 W; 1.81 ± 0.13 m/s). The within subject standard deviations (SD) may also suggest that the accelerometer was more variable and

less stable than the LPT. Drinkwater et al. ^[113] reported a high criterion validity ($r \geq 0.97$) for optical rotary encoders in assessing mean and peak power during a 40 kg Smith machine bench throw in comparison to a digital video camera. A number of studies assessed criterion validity using a Pearson product correlation, while failing to report absolute or mean percentage differences between measurement systems, therefore only partially validating these respective systems ^[113, 197, 254]. Based on the above studies, the various measurement systems should not be used interchangeably to assess and monitor kinematic and kinetic changes in bench throw and vertical jump power and jump height due to the observed differences. Ballistic performance is not only affected by the measurement system and attachment site used to collect the data, but also by the apparatus (fixed vs. free) and movement pattern selected.

Vertical plane movements using free ^[15, 35, 166, 190, 203, 210, 212, 228] and fixed bar ^[27-30, 54, 112, 179, 205, 240] set-ups are most commonly used to assess jump and bench throw capabilities, as they are more easily evaluated using the various measurement systems; and incremental loading can be applied more effectively. Ballistic bench throw and vertical jump profiles have been created using incremental loading (i.e. absolute and relative [% 1RM or %BM] loads) ^[27-29, 31, 117, 166, 211, 212, 244, 255]. The logistics of these incremental loading schemes should be carefully considered when applied to team sports versus individual athletes, as absolute loading may be more practical (less time consuming) in team sport settings, where a large number of athletes are tested within a single session. The use of magnetic braking systems is often advised during heavy load trials as a safety precaution to reduce impact forces on landing ^[256-258]. Training experience and age should also be taken into consideration when selecting a loading scheme, as more experience athletes will have a greater tolerance to heavier external loads.

There are two similar, yet distinct bench throw and vertical jump movement patterns used to assess the kinematics and kinetics, the countermovement and concentric-only muscle actions; which are respectively used to assess the stretch-shortening cycle (SSC) and concentric only capabilities of the athlete [56, 166, 259]. The inclusion of both movements in a performance profile may help determine an athlete's level of SSC augmentation (i.e. ratio between countermovement and concentric-only performance) [259]. The eccentric displacement of these ballistic movements will influence the validity, reliability and subsequent kinematic and kinetic outputs, and therefore needs to be carefully controlled.

The depth of bench throw (e.g. bar-to-chest, 90⁰ elbow angle and self-selected depth) and vertical jump (e.g. self-selected, 90⁰ knee angle and parallel) assessments varies between studies [28, 29, 35, 54, 112, 113, 166, 179, 190, 203, 205, 212, 228, 240, 245, 260]. There are inherent benefits and limitations to utilising self-selected and fixed depths [261, 262]. Two studies investigating the effects of SJ and CMJ depth on performance found that as squat depth increased, peak force (MDiff = 16 – 57%; ES = 1.41 – 3.27) decreased and jump height increased (MDiff = 35 – 56%; ES = 2.08 – 4.67) . [261, 262]. Clark et al. [163] found that the full range (bar-to-chest) bench throw produced greater peak force (MDiff = 27%; ES = 2.38) and throw height (MDiff = 16%; ES = 0.49) in comparison to the half range bench throw utilising a load of 60 kg. It seems that increasing CMJ and SJ depth may improve jump height and reduce peak force; whereas increasing bench throw depth appears to increase throw height and peak force.

Other ballistic upper and lower body movements, such as horizontal and lateral jumps/throws have also been used to a lesser extent to assess performance in these respective planes [22, 116, 153, 263-270]. Horizontal and lateral jumps and throws may provide the strength and conditioning coach with information regarding the athletes' explosive horizontal and lateral capabilities that could transfer to sport specific qualities, such as

sprint acceleration and change in direction ability. Unilateral (e.g. single leg and single arm) ballistic movements have also been utilised to assess kinematic and kinetic asymmetries for preventative and rehabilitative purposes ^[62, 267, 271-276]. Horizontal, lateral and unilateral ballistic assessments in rugby-football codes have been under-utilised considering the sports specific application and relevance of these assessments.

Various warm-up and post-activation potentiation strategies (e.g. dynamic stretching, light ballistic loading, plyometric, heavy dynamic loading, isometric contractions, motivation, feedback) have also been implemented to improve ballistic upper and lower body performance (e.g. power, velocity and jump height) ^[110, 277-292]. Researchers have reported jump height increases of 3 to 5 cm (ES = 0.32 – 1.25) and peak power increases of 120 to 350 W (ES = 0.22 – 0.77) following heavy load back squats (1-5RM) ^[69, 279, 291, 293-295]. According to Kilduff and colleagues ^[278, 279, 291], it may take four to twelve minutes to significantly potentiate CMJ and bench throw peak power following a heavy set of back squats and/or bench presses. Implementing potentiation exercises as part of the standardised warm-up prior to assessing ballistic upper and lower body capabilities may be a worthwhile strategy. Traditional rest periods prescribed between sets range between two to five minutes across numerous ballistic upper and lower body profiling studies ^[15, 27-29, 54, 112, 113, 166, 179, 190, 201, 205, 211, 212, 240]; implementing longer inter-set rest periods (8-12 min) could also allow for optimal neuromuscular recovery and in turn an increase in ballistic performance. Given this information the reader needs to be cognisant of the inherent benefits and limitations of the various assessment strategies currently available, as they will inevitably affect the resultant kinematic and kinetic outputs.

2.4.2 Power Production in Rugby-Football Codes

Concentric power (peak power and mean power) and jump height are the two most commonly reported performance variables within rugby-football codes [1, 28, 31, 36, 40, 82, 115, 190, 212, 245, 277, 296-299]. Peak power can be defined as the maximum instantaneous value achieved during the concentric phase at a given load; whereas mean power is calculated as the area under the concentric portion of a power-time curve using a given load [300]. The load that maximises an athlete's power output is often referred to as the Pmax load; which is often predicted based on a polynomial equation applied to the individual power-load curve; and is expressed as mean or peak power [28, 30, 31, 34, 36, 41, 56, 201, 242, 256, 259, 277, 296, 301-307]. Pmax has been reported across a range of bench throw (30-60% 1RM; 35-70 kg) [28, 30-32, 39, 54, 205, 246, 296, 308] and vertical jump loads (0-60% 1RM) [15, 17, 27, 31, 35, 166, 201], which is dependent on the measurement system and the group or individual being assessed.

Peak power in highly trained rugby union, rugby league and Australian Rules football players can range between 500 to 1500 W during the bench throw using relative loads between 20 and 60% 1RM (40 – 80 kg) [31, 32, 42, 54, 205, 297]; and between 2500 to 9000 W during vertical jump using loads between body mass (no external load) and 60% 1RM (0 – 140 kg) [1, 27, 28, 31, 32, 35, 36, 56, 57, 206, 212]. Large variations in peak power can be attributed to the full spectrum of loads utilised and the wide range in physical characteristics between the various rugby-football code athletes and subsequent positional demands. Many of these studies have reported Pmax in their assessments, while failing to report other equally important variables across the loading spectrum [27-29, 31, 32, 39, 166, 205]. Kinematic and kinetic variables, such as force and velocity should also be included to provide a greater mechanical understanding of these ballistic movements [37, 112, 203, 228, 280]. The addition of maximum force (Fmax) and maximum velocity (Vmax) as assessed during throwing and jumping may provide a more holistic representation of

ballistic performance ^[37]. Fmax (velocity = 0 m/s) and Vmax (force = 0 N) encompass the entire force-velocity spectrum, as they are hypothetical maximums produced at extreme ends of the force-velocity curve and could provide valuable prognostic information for athlete profiling and programming, but such a contention requires further validation. This is especially so given the spectrum of force-velocity-power activities rugby-football players engage in.

2.5 Maximum Strength

Maximum strength can be defined as the maximum amount of force (dynamic or isometric) an athlete can produce against an external load during a given movement ^[309]. Maximum strength is an integral part of rugby, specifically in scrumming, mauling and tackling. The following factors need to be considered as they will inevitably affect the maximum strength measure: testing equipment, measurement system, movement pattern, contraction type (i.e. eccentric-concentric, concentric-only and isometric), range of motion (eccentric depth), warm-up strategy, 1RM loading scheme. The various maximum dynamic ^[27, 179, 186, 245, 310-315] and isometric ^[276, 312, 316, 317] strength testing methodologies have been deemed highly reliable (ICC > 0.91; CV < 4.5%) and are subsequently discussed.

2.5.1 Maximum Dynamic Strength Assessment Strategies

The 1RM bench press, back squat and clean are the most common methods of assessing maximum strength in highly trained rugby-football codes ^[38, 44, 46-48, 54, 78, 82, 115, 205, 210, 242, 296, 312, 315, 318-320]. The required squat depth (i.e. quarter, half, parallel and full) and knee angle (70 to 110⁰) varies between studies, in turn affecting the resultant 1RM ^[54, 179, 190, 205, 242, 245, 312, 313, 316, 321]; whereas bench press depth was not always identified, but a bar-to-chest depth is required by the International Powerlifting Federation ^[322] and a handful

of studies [179, 186, 190, 245, 312, 323, 324]. As expected, shallower depths resulted in greater 1RM outputs (MDiff = 49 - 58%; ES = 4.24 - 5.43) [185, 316]. The use of a fixed lifting apparatus (e.g. Smith machine) versus free-weights also appeared to affect the resultant 1RM squat (MDiff = 2%; ES = 0.09) and 1RM bench/chest press (MDiff = 8 - 13%; ES = 0.35 - 0.70) [325, 326]. Submaximal strength tests have also been implemented to accurately predict 1RM; mean differences of 0 to 4% (ES = 0.00 - 0.13) have been reported between true 1RM and predicted 1RM bench press and back squat [186, 314, 327, 328]. This information may be useful in determining the athletes 1RM without subjecting them to maximum external loads during testing. The Clean (full clean and power clean) instructions were similar between studies: lift the bar explosively in the vertical plane from the floor (1st pull) past the knees, followed by an explosive (Vmax) triple extension of the knees, hips and ankles (2nd pull), scoop under and catch the bar on the shoulders with the elbows high in a front quarter/full squat position [115, 154, 181, 315, 329].

Previous researchers have implemented many different warm-up strategies, such as the cycle ergometer (5 to 10 min) [115, 212, 242, 260, 316], dynamic stretching and potentiation exercises to maximize strength [115, 286, 287, 330-335]. Squat, bench press and leg press strength increases of 2 to 4% (ES = 0.07 - 0.21) have been reported following various potentiation strategies (e.g. drop jumps, plyometric push-ups and dynamic warm-ups) [331, 333, 334, 336]. Other studies have also found maximum strength increases of 8 to 12% (ES = 0.50 - 0.64) using various motivational strategies [337-339]. In general, loading patterns progressed from light to heavy (30 to 100% 1RM) across three to seven successive sets of two to ten repetitions prior to reaching 1RM with three to five minutes rest given following each set [27, 54, 115, 179, 181, 186, 190, 205, 245, 312, 313, 332]. Based on the above information, different methods of potentiation strategies may be a beneficial warm-up strategy to further increase upper and lower body 1RM outputs during testing. The

isometric squat and mid-thigh pull are also being implemented in the laboratory setting to assess maximum strength in athletes.

2.5.2 Maximum Isometric Strength Assessment Strategies

Maximum isometric strength tests are less accessible and therefore less popular than the 1RM, as a force measurement system (e.g. FP or strain gauge) is required to assess these strength qualities (i.e. peak force, mean force and rate of force development) [1, 24, 107, 184, 242, 260, 311, 312, 340]. A number of investigations have reported strong correlations ($r = 0.76$ to 0.97) between maximum dynamic strength and isometric force production during similar movement patterns [316, 317, 341, 342]. When converted to mass, the peak force produced during isometric squats and mid-thigh pulls were larger (MDiff = 6 - 71%; ES = 0.26 - 4.37) than the external load lifted during a 1RM squat; these differences were much less substantial (MDiff = 2 - 32% ; ES = 0.13 - 3.40) when compared to the 1RM system mass (external 1RM load + body mass) [107, 242, 312, 316, 341]. This information may prove useful for assessing isometric to dynamic strength deficits. The isometric squat (90 to 140°) and isometric mid-thigh pull (120 to 145°) knee angles, contraction durations (3 to 6 sec), inter-trial rest intervals (2 to 5 min) and force plate sampling frequencies (500 to 1000 Hz) vary between studies [107, 184, 242, 260, 276, 311, 312, 316, 317, 343-347]. It appears that force capabilities during the isometric squat and leg press increased (MDiff = 1 to 70%; ES = 0.05 - 1.67) when the knee angle was extended position beyond 110° [316, 340, 345, 346]. Isometric squat (3500 N) and isometric mid-thigh pull (3150 N) peak force differences of 11% (ES = 0.61) have been reported [242].

The isometric bench press has also been assessed at a number of positions relative to the chest (i.e. 2 to 50 cm from the chest) and elbow angles (90 to 135°) using strain gauges and force plates [184, 265, 292, 348]. No other upper body studies to date have compared or reported differences in isometric force production between the various isometric joint angles; but based on the force-position analysis of the heavy dynamic bench press, it

would appear that the greatest amount of force (acceleration) is produced during the initial concentric acceleration phase ($60^{\circ} - 90^{\circ}$) when the athlete is attempting to overcome the inertia of the external load [349-352].

2.5.3 Maximum Strength in Rugby-Football Codes

Maximum strength varies greatly within and between rugby-football codes depending on anthropometry, morphology, chronological age, training age and experience. The 1RM bench press, back squat and power clean in highly trained rugby-football players can range from 110 to 190 kg, 140 to 250 kg and 100 to 140 kg, respectively [15, 29-31, 34, 42, 46-48, 54, 78, 85, 115, 153, 205, 212, 242, 297, 312, 315, 318, 319, 353, 354]. In rugby union, forwards typically have superior maximum upper and lower body strength qualities in comparison to backs due to body mass, increased strength demands of scrumming, mauling and tackling from a stationary position [319, 353]. Mean and peak forces of 1400 to 2000 N and 2100 to 3500 N have been reported in highly trained rugby and American football players during isometric back squat and mid-thigh pull movement patterns [1, 24, 107, 312]. The large ranges in maximum dynamic and isometric strength may be a result of the various testing methodologies and large variations in somatotype within and between codes. Anthropometric and morphological differences within rugby-football code populations can be off-set by scaling maximum strength to body mass, or by allometrically scaling to a ratio of body mass (0.44 – 0.67) to allow for an unbiased comparison between players [103, 111, 179, 355].

Isometric and dynamic strength tests can be used to assess and monitor maximum strength adaptations as well as effectively inform weight-room specific programming; but may not necessarily provide a true representation of the required rugby specific isometric/dynamic strength qualities [1, 24]. Rugby-football code specific strength tests have also been developed to quantify individual tackling capabilities [106] and scrum forces [23, 24, 356]; however, their diagnostic value to strength and conditioning practice

remains inconclusive. Individual tackling forces of 1400 N (non-dominant shoulder) to 2100 N (dominant shoulder) and scrum forces between 1000 to 1700 N have been reported in highly trained rugby union players [23, 24, 106, 108, 356, 357]. Large differences in maximum strength exist due to the wide range of physical characteristics and demands of each position.

2.6 Conclusion

Maximum strength and ballistic qualities vary widely within and across rugby-football codes due to the large range in sport and position specific requirements and subsequent physical characteristics (Table 2.1).

Table 2.1 A summary of strength and ballistic performance measures in highly trained rugby-football codes

Category	Movement Pattern	Variable	Output
Ballistic performance	CMJ and SJ	PP	3500 – 9000 W
	CMBT and COBT	PP	500 – 1500 W
Dynamic strength	Bench press	1RM	110 - 190 kg
	Squat	1RM	140 - 250 kg
	Power clean	1RM	100 - 140 kg
Isometric strength	Squat and MTP	PF	2100 - 3500 N
		MF	1400 - 2000 N

CMBT = countermovement bench throw; **CMJ** = countermovement jump; **COBT** = concentric only bench throw; **MF** = mean force; **MTP** = mid-thigh pull; **PF** = peak force; **PP** = peak power; **SJ** = squat jump; **1RM** = one repetition maximum.

When creating a performance profile, the strength and conditioning practitioner needs to carefully consider the benefits and limitations of the various measurement systems (i.e. force plates, video, jump mats, optical sensors, linear position transducers and accelerometers), testing apparatus's (bar type [free vs fixed]), measurement system attachment sites, movement patterns (i.e. run, jump, throw, squat, clean, pull, the direction of movement, contraction type, movement dept), loading parameters (single load, absolute load, relative load, incremental loading), warm-up strategies (i.e. cycling,

dynamic, static, post-activation potentiation, motivation), rest periods, dependent variables of interest (e.g. displacement, velocity, force, strength, power) and data processing techniques (sampling frequency, filtering and smoothing options).

Table 2.2 Summary of strength and ballistic lower and upper body assessment methodologies

Movement Pattern	Measurement System	Equipment	Depth	Variables	ICC (%CV)
CMJ	LPT	FW	Self-select	PF/MF	0.83-0.99
SJ	FP	Smith	90 ⁰ knee	PV/MV	(<6.5%)
	Video	LR		PP/MP	
	Accelerometer	BS		JH	
		Goniometer			
CMBT	LPT	FW	Bar-to-chest	PF/MF	0.86-0.99
COBT	FP	Smith	90 ⁰ elbow	PV/MV	(<6.5%)
	Video	LR		PP/MP	
	Accelerometer	BS		TH	
		Goniometer			
Squat	FW	FW	Full to 1/4	1RM	0.91-0.99 (<4.3%)
	FP	Smith	70-140 ⁰ knee		
		LR			
		Goniometer			
BP	FW	FW	Bar-to-chest	1RM	0.91-0.99 (<4.3%)
	FP	Smith	90 ⁰ elbow		
		LR			
		Goniometer			
Clean	FW	FW	Hang	1RM	0.91-0.99 (<4.3%)
	FP	Platform	Power	PF, PV,	
	LPT		Full	PP RFD	
Iso-BP	FP	Barbell	90 ⁰ elbow	PF	0.95-1.00 (<2.0%)
	Strain gauge	LR	5cm-chest	MF	
		Goniometer		RFD	
Iso-squat	FP	Barbell	90-140 ⁰ knee	PF	0.95-1.00
Iso-MTP	Strain gauge	LR		MF	(<2.0%)
		Goniometer		RFD	

BP = bench press; **BS** = breaking system; **CMBT** = countermovement bench throw; **CMJ** = countermovement jump; **COBT** = concentric only bench throw; **FP** = force plate; **FW** = free weights: barbell + weight plates; **Iso-BP** = isometric bench press; **Iso-squat** = isometric back squat; **Iso-MTP** = isometric mid-thigh pull; **JH** = jump height; **LPT** = linear position transducer; **LR** = lifting rack; **MF** = mean force (N); **MP** = mean power (W); **MV** = mean velocity (m/s); **NA** = not applicable; **PF** = peak force (N); **PP** = peak power (W); **PV** = peak velocity (m/s); **RFD** = rate of force development (N·s); **SJ** = squat jump; **Smith** = Smith machine; **TH** = throw height.

Based on current reliability findings (Table 2.2), all of the reviewed maximum strength and ballistic assessment methodologies may be implemented to measure their respective measures. The evolution of wireless measurement systems is broadening the scope of current biomechanical assessment batteries by transporting laboratory based assessments into the field. The most accurate and reliable methods are not always the most practical, therefore sport specific and environmental factors should also be considered when selecting a battery of performance tests for assessment and monitoring purposes. Given the methodological differences, comparisons of the same performance measure between research studies was difficult. Therefore, the reader needs to be cognisant of the benefits and limitations of the different assessment methodologies currently available, as this will inevitably affect the outcome measure. Current physical performance assessments are utilised to create national standards and develop athlete performance profiles to better inform programming. Athlete performance profiles can be further improved by assessing sport (e.g. rugby and football codes) specific tasks/activities covering the entire force-velocity-power spectrum, such as passing, throwing and kicking velocities, fending and tackling power outputs, and scrummaging, mauling and blocking forces.

***A SYSTEMATIC REVIEW OF LITERATURE: THE DEVELOPMENT,
RETENTION AND DECAY RATES OF STRENGTH AND POWER IN
ELITE RUGBY UNION, RUGBY LEAGUE AND AMERICAN
FOOTBALL***

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Sports Medicine
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3.0 Lead Summary

Background and aim: Strength and power are crucial components to excelling in all contact sports; and understanding how a player's strength and power levels fluctuate in response to various resistance training loads is of great interest, as it will inevitably dictate the loading parameters throughout a competitive season. This is a systematic review of training, maintenance and detraining studies, focusing on the development, retention and decay rates of strength and power measures in elite rugby union, rugby league and American football players.

Search strategies: A literature search using MEDLINE, EBSCO Host, Google Scholar, IngentaConnect, Ovid LWW, ProQuest Central, ScienceDirect Journals, SPORTDiscus and Wiley InterScience was conducted. References were also identified from other review articles and relevant textbooks. From 300 articles, twenty-seven met the inclusion criteria and were retained for further analysis.

Study quality: Study quality was assessed via a modified twenty-point scale created to evaluate research conducted in athletic based training environments. The mean quality rating of the included studies was 16.2 ± 1.9 ; the rating system revealed that the quality of future studies can be improved by randomly allocating subjects to training groups, providing greater description and detail of the interventions, and include control groups where possible.

Data analysis: Percent change, effect size ($ES = [\text{Post } X_{\text{mean}} - \text{Pre } X_{\text{mean}}] \div \text{PreSD}$) calculations and standard deviations (SD) were used to assess the magnitude and spread of strength and power changes in the included studies. The studies were grouped according to i) mean intensity relative volume ($IRV = \text{sets} \times \text{repetitions} \times \text{intensity}$) ii) weekly training frequency per muscle group and iii) detraining duration. IRV is the product of the number of sets, repetitions and intensity performed during a training set and session. The effects of weekly training frequencies were assessed by normalising the

percent change values to represent the weekly changes in strength and power. During the IRV analysis, the percent change values were normalised to represent the percent change per training session. The long term periodised training effects (12, 24 and 48 months) on strength and power were also investigated.

Results: Across the twenty-seven studies ($n = 1015$), 234 percent change and 230 ES calculations were performed. IRVs of eleven to thirty (i.e. 3-6 sets of 4-10 reps at 74-88% one-repetition maximum [1RM]) elicited strength and power increases of 0.42 and 0.07 % per training session, respectively. The following weekly strength changes were observed for two, three and four training sessions per muscle region/week: 0.9, 1.8 and 1.3 %, respectively. Similarly, the weekly power changes for two, three and four training sessions per muscle group/week were 0.1, 0.3 and 0.7 %, respectively. Mean decreases of 14.5 (ES = -0.64) and 0.4 (ES = - 0.10) % were observed in strength and power across mean detraining periods of 7.2 ± 5.8 and 7.6 ± 5.1 weeks, respectively. The long term training studies found strength increases of 7.1 ± 1.0 (ES = 0.55), 8.5 ± 3.3 (ES = 0.81) and 12.5 ± 6.8 (ES = 1.39) % over 12, 24 and 48 months, respectively; they also found power increases of 14.6 (ES = 1.30) and 12.2 (ES = 1.06) % at 24 and 48 months.

Conclusion: Based on current findings, training frequencies of two to four resistance training sessions per muscle group/week can be prescribed to develop upper and lower body strength and power. IRV's ranging from eleven to thirty (i.e. 3-6 sets of 4-10 reps of 70 to 88 % one-repetition maximum [1RM]) can be prescribed in a periodised manner to retain power and develop strength in the upper and lower body. Strength levels can be maintained for up to three weeks of detraining, but decay rates will increase thereafter (i.e. 5 to 16 weeks). The effect of explosive-ballistic training and detraining on pure power development and decay in elite rugby and American football players remain inconclusive. The long term effects of periodised resistance training programmes on

strength and power seem to follow the law of diminishing returns, as training exposure increases beyond 12-24 months, adaptation rates are reduced.

3.1 Introduction

An athlete's strength, speed, power and endurance will fluctuate in direct relation to the mode (i.e. hypertrophy, strength, speed, power and endurance) and quantity (i.e. frequency, intensity, volume and duration) of the training dose. Therefore, all of these factors must be considered when designing the various phases in an athlete's training program. This review examines this contention but will focus solely on strength and power fluctuations. The combination of training modalities, quantity, tempo and rest periods prescribed during strength and power development (i.e. off-season and pre-season), maintenance (in-season) and detraining (immediate off-season) vary and are dependent on the specific goals at a particular point in time. The dose required to develop, retain and decay strength and power are high, moderate and minimal, respectively [154, 156, 358]. The dosage required to develop strength is generally described as high frequency (3-5 weekly sessions per muscle group), moderate volume (3-6 sets x 2-6 repetitions [reps] x load mass) and high intensity (85-100% one-repetition maximum [1RM]) with a slower movement tempo due to the high intensity loading and non-ballistic nature of strength training exercises; while power differs mainly in the intensity (20-70% 1RM) and movement tempo (i.e. explosive-ballistic) [28, 154, 156, 296, 358-360]. Strength and power maintenance (i.e. retention) is much less investigated in elite rugby and American football, but generally the intensity and session volume are held constant and frequency is reduced (1-2 weekly sessions per muscle group) [361]. Muscle groups within this paper are divided into upper, lower and whole body; encompassing both single (i.e. elbow and knee flexion and extension) and multi-joint (i.e. squatting, jumping, press, throwing and pulling) movements. During detraining (i.e. no structured training), the weekly decay rates of strength and power are of great interest, as they allow us to determine the minimum and maximum durations training can be ceased before another training stimulus is required. Studies utilising resistance trained and untrained individuals indicate that

large losses in strength occur in the first one to four weeks of training cessation; while there is almost no research on detraining and its effect on power ^[362, 363].

The manner in which the neuromuscular and musculoskeletal systems adapt to the dose (stimulus) is sometimes referred to as the “response”, which has a direct effect on the changes in strength and power ^[364]. The neuromuscular and morphological changes due to a training stimulus (i.e. development and maintenance) or lack thereof (i.e. detraining) will inevitably effect change in strength and power of the sport/training specific movements (i.e. squats, bench press, vertical and horizontal jumps) ^{[365] [366]}. When an athlete is exposed to a new stimulus (i.e. a new exercise, training method, a change in frequency, intensity and/or volume) the body will initially (two to four weeks) undergo a number of neuromuscular changes with minimal morphological change^[363, 366]. Changes may include: an increase or decrease in inter-muscular coordination, muscle fibre activation, muscle fibre recruitment and firing frequency. These changes may also be accompanied with an increased or decreased synchronisation of action potentials and a decrease or increase in antagonist co-activation leading to an improvement or reduction in dynamic force (i.e. strength) and power production ^[363, 366].

Morphological adaptations may occur thereafter (i.e. two to sixteen or more weeks) and changes may include: increases/decreases in cross-sectional area, myofibrillar size, muscle size (hypertrophy/atrophy), muscle fibre pennation angle, musculotendinous stiffness and tendon thickness possibly leading to increased/decreased strength and power production ^[127, 363, 365-368]. A large body of literature has focused on the above neuromuscular and morphological adaptations and their influence on the development and decay of strength and power due to resistance training in non-athletes, recreational athletes and resistance trained individuals ^[363, 365, 366, 369-373]. But there is a lack of research investigating the training, maintenance and detraining doses and their effects (i.e. development, retention and decay) on strength and power in elite athletes and more

specifically rugby league, rugby union and American football. Numerous critical, narrative and meta-analytical reviews have also been written on the development, maintenance and decay of strength, power and muscle architecture, for detailed descriptions refer to the following sources: [127, 130, 308, 361-363, 365-367, 369, 371, 374-386]. To date no review has systematically assessed the effects of development, maintenance and detraining based studies on strength and power of elite football code athletes. Therefore, the purpose of this study was to systematically review and assess the magnitude of the treatment effects (i.e. resistance training dosage) of resistance training, maintenance and detraining programs on the changes in upper and lower body strength and power of American football players and elite rugby union and rugby league players.

3.2 Methods

3.2.1 Definition of Terms

Highly trained athletes are those whom have been resistance training for three plus years and are currently participating in collegiate level, state level, semi-professional and professional sport [157]. Studies utilising these elite athletic populations were included in this review, all others were excluded.

Muscular strength can be assessed during concentric, eccentric and/or isometric contractions. Strength has been defined as the ability to overcome an external resistance via muscular effort, also known as maximum dynamic force production [309]. 1RM is the most common method of assessing dynamic strength in athletes. 1RM tests are generally used to assess maximum strength in the bench press, squat, deadlift, power clean, clean and jerk and the snatch. Strength has also been assessed via isokinetic dynamometers (i.e. elbow and knee flexion and extension) and force plates (i.e. isometric squat, mid-thigh pull and bench press); these methods are most often used in controlled laboratory based settings.

Muscular power can be defined as the product of force and velocity or the amount of work produced per unit time. Power is generally assessed during explosive movements, such as the bench press throw, medicine ball throws, countermovement jumps (vertical and horizontal), drop jumps and/or squat jumps utilising tape measures, accelerometers, jump mats, linear position transducers and/or force plates.

Frequency can be defined as the number of training sessions completed in a given time period (i.e. sessions per day, per week, per month and per year). However for the purpose of this review, frequency has been reported as the number of resistance training sessions per muscle group (upper vs. lower body) completed each week.

Intensity is often based on RM load or a percentage of 1RM; the greater the percent 1RM utilised during training, the greater the intensity. For example, 30, 65 and 90 % 1RM loads would be considered low, moderate and high intensities, respectively.

Volume describes the total amount of work performed in a training session. Absolute (e.g. sets x reps x load) and relative (e.g. sets x reps x intensity) measures are commonly used throughout the literature.

Intensity relative volume (IRV) is represented by arbitrary units, as the product of the number of sets, repetitions and intensity (% 1RM) performed during a training set and/or session ^[156, 378, 387]. For studies not including percent 1RM values, a standard conversion table by Baechle et al. ^[11] was used to estimate the % 1RM. For example, the IRV for four sets of five repetitions using an 85% 1RM load would be 17 units (IRV = 4 x 5 x 0.85). To put the values into perspective, in general strength training IRVs may range from thirteen to twenty-five units (i.e. 3-6 sets of 2-6 reps at 85-100 % 1RM); while power IRVs may range from four to fifteen units (i.e. 3-5 sets of 2-5 reps of 30-60 % 1RM) ^[154, 156, 388].

3.2.2 Search Strategies

The following electronic data bases were searched multiple times between June 15, 2011 and December 15, 2011: MEDLINE, EBSCO Host, Google Scholar, IngentaConnect, Ovid LWW, ProQuest Central, PubMed Central, ScienceDirect Journals, SPORTDiscus and Wiley InterScience between the years of 1950 and 2011. The following keywords were used in various combinations during the electronic searches: ‘rugby’, ‘rugby union’, ‘rugby league’, ‘Australian football’, ‘American football’, ‘gridiron’, ‘athletes’, ‘elite’, ‘strength’, ‘force’, ‘power’, ‘jump’, ‘resistance training’, ‘plyometrics’, ‘detrain’, ‘maintenance’, ‘frequency’, ‘volume’, ‘periodisation’, ‘development’, ‘decay’, ‘dose’, ‘response’, ‘in-season’, ‘off-season’, and ‘taper’. References were also identified from textbooks of sports science, strength and power, and resistance training. The identified articles, manuscripts and theses reference sections were also scanned to identify further studies.

3.2.3 Search Summary

The searches identified 1475 potentially relevant articles and an additional 31 articles were identified through reference lists. Following a review of titles and abstracts, the total was cut to 300. Of these articles, 27 met the selection criteria (Figure 3.1).

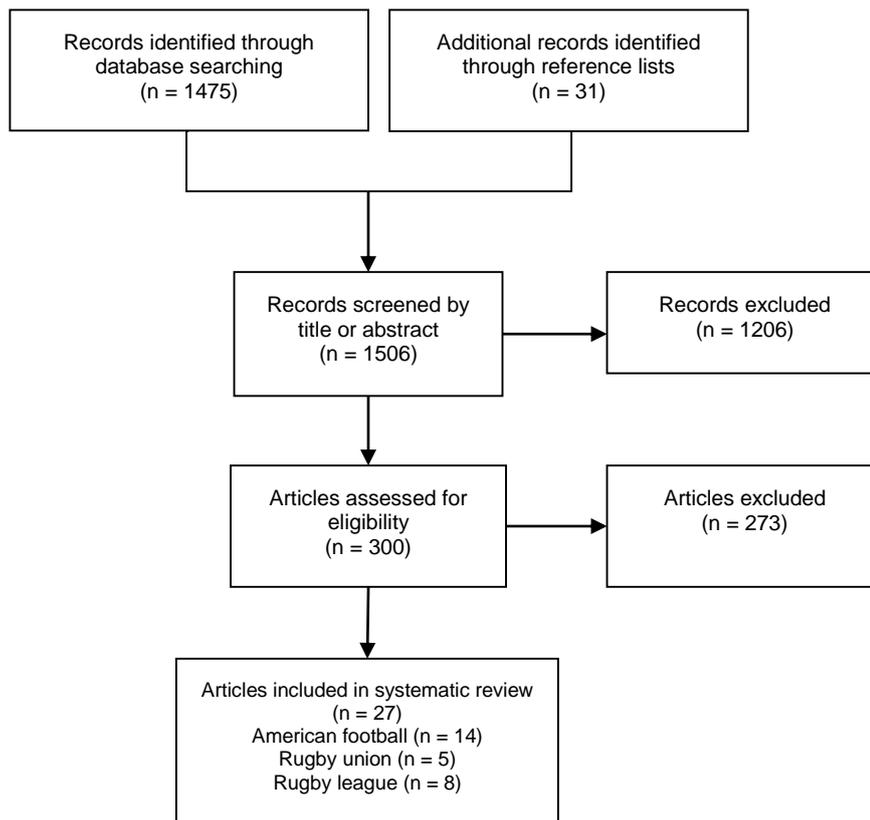


Figure 3.1. Flow chart of the study selection process

3.2.4 Inclusion and Exclusion Criteria

Studies investigating the effects of resistance training, tapering, maintenance and detraining on strength and power in American football, rugby union and rugby league were included in the initial screening phase ($n_{\text{articles}} = 300$). The studies were also required to be written in English, all others were excluded. Final selections were based on training status, as described previously ^[157]; where studies ($n_{\text{articles}} = 27$) investigating elite male American football, rugby union and rugby league players were selected for further analysis.

3.2.5 Study Quality

The quality of the included research studies was assessed based on a modified version of currently established scales used in sport science, health care and rehabilitation (i.e.

Cochrane, Coleman, Delphi and PEDRO) to evaluate research conducted in athletic based training environments. The current scale (Table 3.1) was adapted from a recent review by Brughelli et al. ^[160], where study quality was based on ten items (two points per item) with a score of zero (no), one (maybe) or two (yes) given for each item. This results in a total scoring range between zero and twenty.

Table 3.1. Study quality scoring system*

No.	Item	Score
1	Inclusion criteria stated	0-2
2	Subjects assigned appropriately (random/equal baseline)	0-2
3	Intervention described	0-2
4	Control group	0-2
5	Dependent variables defined	0-2
6	Assessments practical	0-2
7	Training duration practical (acute vs. long term)	0-2
8	Statistics appropriate (variability, repeated measures)	0-2
9	Results detailed (mean, SD, % change, effect size)	0-2
10	Conclusions insightful (clear concise, future directions)	0-2
	Total	0-20

*Adapted from Brughelli et al. ^[160]

A total of 1015 athletes participating in American football, rugby union and rugby league were investigated ^[38, 39, 46-48, 50, 54, 59, 245, 296, 354, 383, 389-403]. The mean quality rating of the included studies was 16.2 (\pm 1.9) out of 20.0 (Table 3.2). Discrepancies in study quality were largely affected by the inclusion or exclusion of items two, three and four in table 1: ii) subjects assigned appropriately, iii) intervention described, and iv) a control group included ^[160]. These items were the most decisive factors in separating the high quality from the low quality studies. Eight of the twenty-five studies assigned the subjects to training groups appropriately, by randomised allocation or by similar baseline measures (i.e. group equalisation); eight of the studies provided insufficient descriptions of their training interventions. Eight of the twenty-seven studies included control groups, as it is generally impractical to use control groups during training of elite athletes. From

these results, it would appear that to improve the quality of future studies, investigators should allocate subjects to various training groups randomly or through group equalization, provide greater description and detail of the intervention and include a control or comparative training group where possible.

Table 3.2. Study quality ratings

Author	Year	N	Age (mean \pm SD or range)	Training Status	QS
Allen ^[389]	1969	64	16.0-18.0	A – American football	16
Ableby et al ^[383]	2012	20	25.4 \pm 6.8	E – Rugby union	17
Argus et al ^[38]	2010	33	24.8 \pm 2.4	E – Rugby union	16
Argus et al ^[54]	2009	32	24.4 \pm 2.7	E – Rugby union	16
Babault et al ^[50]	2007	25	22.0 \pm 1.0	E – Rugby union	20
Baker and Newton ^[296]	2006	12	20.2 \pm 1.6	E – Rugby league	16
Baker ^[28]	2001	31	18.2-24.5	E – Rugby league	15
Brechue et al ^[390]	2009	58	18.9-19.7	A – D2 American football	17
Chilibeck et al ^[391]	2007	18	26.8 \pm 2.9	A – Rugby union	17
Coutts et al ^[245]	2007	7	25.7 \pm 2.6	A – Rugby league	16
Coutts et al ^[392]	2004	42	16.7 \pm 1.1	A – Rugby league	18
Gabbett ^[393]	2006	41	23.6-27.3	A – Rugby league	17
Gabbett ^[394]	2006	69	22.2 \pm 0.9	A – Rugby league	17
Ghigiarelli et al ^[395]	2009	36	20.0 \pm 1.0	A – D1 American football	16
Hoffman et al ^[396]	1990	61	19.9 \pm 1.3	A – D1 American football	14
Hoffman et al ^[397]	2003	52	19.7 \pm 1.4	A - D3 American Football	17
Hoffman et al ^[46]	2004	20	19.1 \pm 1.3	A – D3 American football	16
Hoffman et al ^[48]	2005	47	19.7 \pm 1.2	A – D3 American football	16
Hoffman et al ^[47]	2009	51	19.7 \pm 1.1	A – D1 American football	15
Hortobagyi et al ^[59]	1993	12	24.4 \pm 0.7	E - D1 American football	16
Jones et al ^[398]	1999	40	20.0 \pm 0.9	A – D1 American football	18
Legg and Burnham ^[399]	1999	59	18.0-22.0	A – Canadian football	13
O’ Connor et al ^[400]	2007	30	24.8 \pm 1.3	E –Rugby league	17
Rogerson et al ^[354]	2007	22	19.8 \pm 2.9	E – Rugby league	19
Schneider et al ^[401]	1998	28	Unknown	A – Canadian football	13
Stone et al ^[402]	1999	42	18.4 \pm 0.5	A – D1 American football	19
Wenzel et al ^[403]	1992	65	19.6 \pm 1.2	A – American football	11

QS = quality score; **N** = number of subjects; **A** = high school/collegiate athletes/junior elite; **E** = professional athletes; **D1** = division one; **D2** = division two; **D3** = division three

3.2.6 Data Analysis

To evaluate the magnitude of the dosage effects, percent change $[(\text{Post } X_{\text{mean}} - \text{Pre } X_{\text{mean}}) \div \text{Pre } X_{\text{mean}} \times 100]$ and effect size $[(\text{Post } X_{\text{mean}} - \text{Pre } X_{\text{mean}}) \div \text{PreSD}]$ were calculated for each dependent variable for each study. Percent change was used to estimate the magnitude of change in strength and power training, maintenance and detraining studies. The percent change values were then normalised via two methods to allow for comparisons between studies prescribing varying training frequencies, durations and IRVs. Training frequencies were compared by dividing the pre-post percent change values by the study duration to represent the weekly changes in strength and power. Differences in the prescribed IRVs of the included studies were normalised by dividing the pre-post percent change values by the product of the training frequency and duration to represent the percent change per training session. The studies were then grouped into three categories according to prescribed IRV (0-10 vs. 11-20 vs. 21-30), to allow for direct comparisons. Percent change calculations do not take into account the variance of the change within and between groups ^[157], therefore effect size (ES) calculations were included to account for variance by standardizing the training effects allowing for a more accurate comparison within and between training groups ^[157]. The magnitude of an ES varies based on the training status of the athlete, which have been classified into: trivial (< 0.25), small ($0.25 - 0.50$), moderate ($0.51 - 1.0$) and large (> 1.0) effects; as the adaptive response to training is larger in recreationally and elite junior versus highly trained and elite senior athletes^[374].

3.3 Results

The magnitude of the treatment effects (i.e. IRV, frequency and detraining duration dosage) of resistance training, maintenance and detraining programmes on upper and lower body strength and power of elite rugby union, rugby league and American football

players was conducted. The various training loads were quantified via percent change and ES calculations and compared based on i) IRV, ii) weekly training frequency and iii) detraining duration. Mean and SD were also presented where appropriate.

Subject characteristics were as follows: age = 21.2 ± 2.8 years; mass = 94.3 ± 6.8 kg; height = 182.2 ± 3.8 cm; 1RM bench press = 126 ± 21 kg; 1RM squat = 169 ± 22 kg. A summary of the twenty-seven studies ($n = 1015$) assessing changes in strength, power and jump height is presented in table three. A meta-analysis of upper and lower body strength of the included training studies ($n = 549$) revealed a moderate ($ES = 0.53$) mean percent increase of $10 \pm 7\%$ over a mean training duration of 8.7 ± 4.0 weeks, a mean frequency of 2.7 ± 0.6 sessions per week and mean IRV of 19.4 ± 7.4 (3.6 ± 1.1 sets x 7.2 ± 2.6 reps x $80 \pm 7\%$ 1RM) units, respectively (Tables 3.3 and 3.4). A second meta-analysis was conducted for the upper and lower body power studies ($n = 357$), which also showed a small ($ES = 0.42$) mean percent increase of $2.0 \pm 4.3\%$ over a mean training duration of 9.7 ± 4.3 weeks, a mean frequency of 2.5 ± 0.6 sessions per week and a mean IRV of 19.3 ± 6.6 (3.8 ± 0.8 sets x 6.4 ± 2.0 reps x $81 \pm 5\%$ 1RM) units.

Table 3.3. American football and rugby strength and power training studies

Author	Group	Training type	Number of RT sessions (F x D)	Mean IRV (sets x reps x intensity)	Dependent variables → percent change (effect size)
Allen ^[42]	1	Hypertrophy	6 (2 x 3)	15.0 (2.0 x 10.0 x 0.75)	1RM BP, 1RM LP → 1.2 (0.07), 0.2 (0.01)
	2	Strength	6 (2 x 3)	1.0 (1.0 x 1.0 x 1.00)	1RM BP, 1RM LP → 1.3 (0.09), 1.1 (0.09)
	4	Detrain	0 (0 x 3)	0	1RM BP, 1RM LP → -0.5 (-0.04), -1.6 (-0.09)
Appleby et al ^[67]	1	Pre-season	40 (4 x 10)	? (15-25 x 1-15 x 0.50-1.00)	2007-2008: 1RM BP, 1RM squat → 6.4 (0.65), 7.8 (0.44)
		Pre-competition	5-10 (1-2 x 5)	? (15-20 x 1-10 x 0.75-1.00)	2007-2009: 1RM BP, 1RM squat → 9.7 (1.02), 8.1 (0.46)
		In-season	14-28 (1-2 x 14)	? (20-25 x 3-12 x 0.80-1.00)	2008-2009: 1RM BP, 1RM squat → 3.5 (0.41), 0.3 (0.02)
Argus et al ^[43]	1	Strength-power	20 (5 x 4)	19.0 (4.0 x 6.3 x 0.80)	1RM BP, 1RM Box squat → 9.9 (0.71), 10.2 (0.68) PP BT, JS → -6.5 (-0.33), -5.5 (-0.45)
Argus et al ^[44]	1	Maintenance	26 (2.2 x 13)	17.5 (5.0 x 4.0 x 0.875)	1RM BP and BS → -1.2 (trivial) and 8.35 (small) PP BT and JS → -3.5 (trivial) and -3.4 (small)
Babault et al ^[66]	1a	Control-detrain	0 (0 x 6)	0	SJ, CMJ, DJ → -3.0 (-0.23), -1.2 (-0.1), -2.7 (-0.26)
	1b	Control-detrain	0 (0 x 12)	0	SJ, CMJ, DJ → 0.5 (0.04), 1.2 (0.1), 5.0 (0.51)
Baker and Newton ^[5]	1	General prep	8-16 (2 x 4-8)	? (3-4 x 8-10 x ?)	1998-2000: 1RM BP, PP BT: 8.1 (0.75), 14.6 (1.3)
		Specific prep	12-20 (2 x 6-10)	? (3-4 x 2-6 x ?)	1998-2002: 1RM BP, PP BT: 12.5 (1.21), 12.2 (1.06)
		In-season	48-64 (2 x 24-32)	? (3 x 1-10 x ?)	2002-2004: 1RM BP, PP BT: 4.8 (0.46), -2.7 (-0.23)
Baker ^[4]	1	Periodised (NRL)	58 (2 x 29)	?	1RM BP, PP BT, PP JS → -1.2 (-0.12), -0.3 (-0.03), -1.4 (-0.09)
	2	Periodised (SRL)	38 (2 x 19)	?	1RM BP, PP BT, PP JS → 3.2 (0.22), 1.9 (0.11), 3.9 (0.41)
Brechue et al ^[46]	1	LP	24 (2 x 12)	15.2 (5.5 x 3.3 x 0.83)	1RM BP → 7.6 (0.57)
Chilibeck et al ^[47]	1	Creatine ME	16 (2 x 8)	?	Max Rep 75% BP and LP → 17.3 (3.29) and 23.8 (2.94)
	2	Control ME	16 (2 x 8)	?	Max Rep 75% BP and LP → -4.6 (-0.36) and 9.8 (0.70)
Coutts et al ^[48]	1	Overreach and taper	18 (2.6 x 7)	20.5 (4.3 x 6.0 x 0.79)	3RM BP, squat, MaxCU and CMJ → 0(0), 1.7 (0.11), 2.5 (0.21) and 1.1 (0.07)

Table 3.3. American football and rugby strength and power training studies continued....

Coutts et al ^[49]	1	Unsupervised LP	36 (3 x 12)	18.5 (2.6 x 9.6 x 0.74)	3RM BP, squat, MaxCU, CMJ → 12.8 (0.78), 18.7 (0.91), 25.8 (0.74), 6.0 (0.46)
	2	Supervised LP	36 (3 x 12)	18.5 (2.6 x 9.6 x 0.74)	3RM BP, squat, MaxCU, CMJ → 22.5 (1.83), 27.1 (1.69), 38.4 (1.02), 8.3 (0.70)
Gabbett ^[50]	1	Speed-power	28 (2 x 14)	?	CMJ → 4.5 (0.96)
Gabbett ^[51]	1	Speed-power	18 (2 x 9)	?	CMJ → -5.4 (-4.43)
	2	Skill-speed	18 (2 x 9)	?	CMJ → 4.5 (2.45)
Ghigiarelli et al ^[52]	1	Strength + bands	14 (2 x 7)	?(6.0 x 3.0 x ?)	1RM BP, PP speed bench → 7.3 (0.40), 2.8 (0.13)
	2	Strength + chains	14 (2 x 7)	?(6.0 x 3.0 x ?)	1RM BP, PP speed bench → 6.6 (0.61), -1.0 (-0.06)
	3	Strength only	14 (2 x 7)	?(5.5 x 4.0 x ?)	1RM BP, PP speed bench → 5.2 (0.33), 0.9 (0.06)
Hoffman et al ^[54]	1	Strength-size	30 (3 x 10)	27.1 (4.8 x 6.8 x 0.83)	1RM BP, 1RM squat, VJ → 1.7 (0.16), 5.0 (0.39), 1.3 (0.12)
	2	Strength-size	20 (2 x 10)	27.1 (4.8 x 6.8 x 0.83)	1RM BP, 1RM squat, VJ → 3.4 (0.32), 6.8 (0.35), 0.2 (0.01)
	3	Strength-size	30 (3 x 10)	27.1 (4.8 x 6.8 x 0.83)	1RM BP, 1RM squat, VJ → 3.1 (0.21), 7.0 (0.66), 2.3 (0.17)
	4	Strength-size	40 (4 x 10)	27.1 (4.8 x 6.8 x 0.83)	1RM BP, 1RM squat, VJ (cm) → 3.9 (0.48), 6.1 (0.36), 4.2 (0.39)
Hoffman et al ^[56]	1	In season	22 (2 x 11)	19.2 (4.0 x 6.0 x 0.80)	1RM BP, 1RM squat → -0.7 (-0.04), 5.1 (0.26)
Hoffman et al ^[53]	1	Olympic lifting	45 (3 x 15)	25.0 (4.3 x 7.0 x 0.83)	1RM BP, 1RM squat, PP CMJ, VJ → 4.3 (0.39), 11.4 (1.07), 7.6 (0.88), 13.3 (3.18)
	2	Power lifting	30 (2 x 15)	25.0 (4.3 x 7.0 x 0.83)	1RM BP, 1RM squat, PP VJ, VJ → 8.8 (0.68), 11.3 (0.73), 14.0 (0.76), 1.2 (0.06)
Hoffman et al ^[57]	1	Strength +CJ	30 (2 x 15)	25.4 (4.3 x 7.25 x 0.83)	1RM squat, VJ → 12.0 (0.76), 5.4 (0.49)
	2	Strength +CEJ	30 (2 x 15)	25.4 (4.3 x 7.25 x 0.83)	1RM squat, VJ → 16.7 (0.86), 3.6 (0.20)
	3	Strength only	30 (2 x 15)	25.4 (4.3 x 7.25 x 0.83)	1RM squat, VJ → 7.3 (0.55), 6.1 (0.36)
Hoffman et al ^[55]	1	Non-periodised	30 (2 x 15)	23.2 (4.0 x 7.0 x 0.83)	1RM squat, 1RMBP, PP-VJ, MBT → 16.9 (1.99), 8.0 (0.89), -0.3 (-0.03), 1.9 (0.21)
	2	Linear-periodised	30 (2 x 15)	27.6 (4.0 x 9.0 x 0.77)	1RM squat, 1RMBP, PP-VJ, MBT → 17.2 (1.24), 7.2 (0.50), 1.4 (0.11), 5.79 (0.67)
	3	Non linear	30 (2 x 15)	23.5 (4.0 x 7.3 x 0.81)	1RM squat, 1RMBP, PP-VJ, MBT → 10.0 (0.79), 7.7 (0.41), -9.8 (-0.48), 3.5 (0.27)

Table 3.3. American football and rugby strength and power training studies continued....

Hortobagyi et al ^[5a]	1	Detrain	0 (0 x 2)	0	1RM BP, 1RM squat, CMJ, SJ → -1.8 (-0.12), -0.9 (-0.05), 3.2 (0.20), -3.8 (-0.24)
Jones et al ^[5b]	1	Traditional	28 (2 x 14)	15.7 (4.4 x 4.9 x 0.74)	1RM BP, MBT, MP push up → 3.7 (0.27), 2.5 (0.40), 3.7 (0.15)
	2	High velocity	28 (2 x 14)	15.7 (4.4 x 4.9 x 0.74)	1RM BP, MBT, MP push up → 8.6 (0.63), 8.8 (1.75), 12.2 (0.63)
Legg and Burnham ^[60]	1	In season-detrain	0 (0 x 10)	0	Isometric shoulder abduction: right, left → -38.9 (-1.04), -40.1 (-0.98)
O' Connor et al ^[61]	1	Control	18 (3 x 6)	? (3-6 x 2-6 x 0.80-0.95)	3RM BP, 3RM DL, PP cycle → 3.4 (0.93), 9.9 (3.89), 6.4 (1.09)
	2	HMB+CR	18 (3 x 6)	? (3-6 x 2-6 x 0.80-0.95)	3RM BP, 3RM DL, PP cycle → 3.4 (0.93), 9.7 (2.78), 4.0 (1.34)
	3	HMB only	18 (3 x 6)	? (3-6 x 2-6 x 0.80-0.95)	3RM BP, 3RM DL, PP cycle → 4.8 (1.42), 11.6 (4.02), 4.4 (1.24)
Rogerson et al ^[62]	1	TT	13 (2.6 x 5)	? (4 x 2-8 x ?)	2RM BP, 2RM LP, 2RM DL → 12.6 (1.12), 22.3 (2.91), 17.3 (1.82)
	2	Placebo	13 (2.6 x 5)	? (4 x 2-8 x ?)	2RM BP, 2RM LP, 2RM DL → 9.8 (0.91), 20.1 (1.68), 14.8 (1.10)
Schneider et al ^[63]	1	In-season	32 (2 x 16)	?	1RM BP, VJ, U → -6.9 (-0.38), -4.8 (-0.48), -1.2 (-0.19)
	2	In-season	32 (2 x 16)	?	1RM BP, VJ, U → -8.4 (-2.99), -2.9 (-0.27), -0.4 (-0.07)
Stone et al ^[64]	1	CR	18 (3 x 6)	10.7 (3.0 x 4.2 x 0.85)	1RM squat, 1RM BP, CMJ, SJ → 10.4 (1.92), 9.1 (1.97), -0.3 (-0.07), 3.1 (0.67)
	2	Placebo	18 (3 x 6)	10.7 (3.0 x 4.2 x 0.85)	1RM squat, 1RM BP, CMJ, SJ → 7.6 (1.12), 3.7 (0.89), -0.9 (-0.19), -1.3 (-0.29)
	3	Ca-P	18 (3 x 6)	10.7 (3.0 x 4.2 x 0.85) 10.7	1RM squat, 1RM BP, CMJ, SJ → 6.8 (1.77), 2.6 (0.47), -1.8 (-0.38), 0.4 (0.08)
	4	CR-P	18 (3 x 6)	(3.0 x 4.2 x 0.85)	1RM squat, 1RM BP, CMJ, SJ → 8.1 (1.57), 9.3 (1.71), -2.4 (-0.84), 1.8 (0.42)
Wenzel et al ^[65]	1	Squat	15 (3 x 5)	? (3.0 x 6-12 x ?)	1RM squat, VJ, MK power → 13.3 (0.76), 1.8 (0.14), 3.3 (0.26)
	2	Hip sled	15 (3 x 5)	? (3.0 x 6-12 x ?)	1RM squat, VJ, MK power → 9.1 (0.45), 3.6 (0.29), 6.6 (0.44)

RT = resistance training; F = weekly training frequency; D = duration in weeks; IRV = intensity relative volume; 1RM = 1-repetition maximum; BP = bench press; LP = leg press; BS = box squat; PP = peak power; BT = bench throw; JS = jump squat; CMJ = countermovement jump; DJ = drop jump; SJ = squat jump; RM = repetition maximum; ? = unknown; NRL = National Rugby League players; SRL = State Rugby League players; ME = muscular endurance training; Max rep 75% = maximum number of repetitions performed at 75% of 1RM; MaxCU = maximum number of chin-ups performed; VJ = vertical jump height; strength+CJ = strength training plus concentric jumps; strength+CEJ = strength training + concentric-eccentric jumps; MBT = medicine ball throw; MP push up = mean power produced during an explosive push up; HMB + CR = resistance training supplemented with β -hydroxy- β -methylbutyrate + creatine; CR = creatine supplementation; DL = dead lift; PP cycle = 10 second maximal cycle ergometer test; TT = *Tribulus terrestris* supplementation; Ca-P = calcium pyruvate supplementation; CR-P = creatine pyruvate supplementation; MK power = Margaria-Kalamen power test.

3.3.1 Intensity Relative Volume

When prescribing resistance training loads, intensity (% 1RM) and volume (no. of sets x no. of repetitions) are inversely related and fluctuate accordingly, where an increase in one generally causes a decrease in the other. Calculating IRVs may allow for simplified-direct comparisons between studies. The literature currently recommends that IRVs ranging anywhere from 6 to 25 units (i.e. 3-5 sets of 2-6 repetitions at 80 to 98% of 1RM) and 3 to 18 units (i.e. 2-5 sets of 1-6 repetitions at 30-60% of 1RM) should be prescribed in a periodised manner to improve upper and lower body strength and power, respectively [30, 41, 154, 156, 163, 358, 360, 404]. However, the optimal training dose to develop strength and power in elite athletes is widely debated and remains inconclusive. Examining the current IRVs utilised to develop and retain strength and power in elite rugby league, rugby union and American football players may therefore provide some clarity and precision to the current strength and power prescription guidelines. The IRV analysis entailed normalising the pre- and post-training percent changes in strength and power to represent the percent change per training session (Figures 3.2 and 3.3).

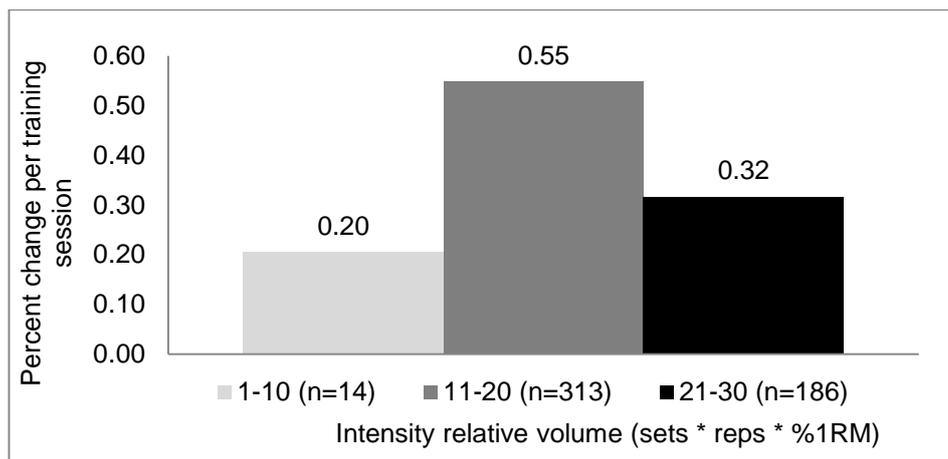


Figure 3.2. Intensity relative volume effects on upper and lower body strength represented as percent changes per training session in elite American football, rugby league and rugby union players.

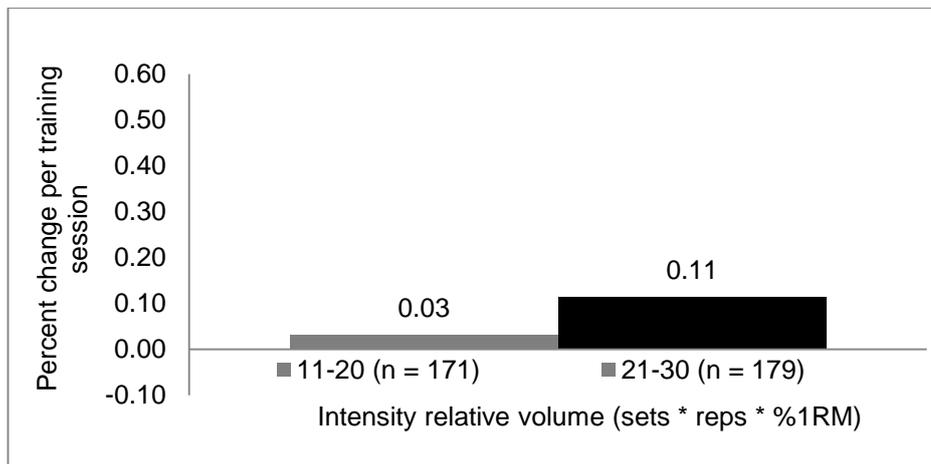


Figure 3.3. Intensity relative volume effects on upper and lower body power and its derivatives (medicine ball throw distance and vertical jump height) represented as percent changes per training session in elite American football, rugby league and rugby union players.

3.3.2 Intensity Relative Volume Effects on Strength

These calculations established that IRVs ranging from eleven to twenty (3.4 ± 1.2 sets of 6.5 ± 3.3 reps at $77 \pm 7\%$ 1RM) provided the largest sessional increases in strength (0.55 % per training session), followed by IRVs between twenty-one and thirty (25.4 ± 2.0 sets of 7.1 ± 0.7 reps at $82 \pm 2\%$ 1RM), which elicited slightly lower sessional strength increases (0.35 % per training session). IRVs of less than ten (1 set of 1 rep at 100% 1RM) provided considerably lower sessional strength increases (0.20 % per training session). Of the included studies, 61 % of the athletes ($n = 313$) trained with IRV loads between 11 and 20 units. The pooled mean IRV of these studies was 15 ± 3.2 units (3.4 ± 1.2 sets of 6.5 ± 3.3 reps at $77 \pm 7\%$ 1RM), which was typical of resistance training doses utilised to develop strength and more specifically hypertrophy in elite athletes [38, 50, 54, 389, 397, 404]. 36 % of the athletes ($n = 186$) trained with IRV loads between 21 and 30 units, using a pooled mean IRV of 25.4 ± 2.0 units (4.4 ± 0.3 sets of 7.1 ± 0.7 reps at $82 \pm 2\%$ 1RM); which would also be considered a standard training dose for developing strength and muscle mass in American football and rugby players [46-48, 245, 396]. Only one study [389] prescribed an IRV of less than ten units [one unit (1 set of 1 rep at 100% 1RM)], which comprised the remaining 3% of the included players ($n = 14$). They found that bench press

and leg press strength increased by 0.22 and 0.19 % per training session in elite American high school football players (age = 16-18 yrs). These outcomes indicate that low IRVs may be adequate for maintaining bench press and leg press strength in junior level athletes, but these findings may not be transferrable to elite level senior athletes (age > 18 years), as a greater training dose (i.e. IRV > 10 units) may be needed to elude similar effects.

3.3.3 Intensity Relative Volume Effects on Power

The current recommendations to develop upper and lower body power vary greatly depending on the source. For the included studies there was a linear relationship between the prescribed IRV and increasing power measures; but this trend may only be applicable to the included studies of this review (figure 3). The greatest gains (0.20 % per training session) in power and its derivatives occurred whilst training with IRVs between twenty-one and thirty units (4.3 ± 0.3 sets of 7.0 ± 0.9 reps at 81 ± 2 %), while lower gains (0.03 % per training session) were evident using IRVs between eleven and twenty (3.4 ± 1.3 sets of 6.9 ± 3.5 reps at 77 ± 8 %). It must be noted that according to current recommendations the mean training doses (number of sets x number of repetitions x % 1RM) used in the above studies are more specific to increasing strength and muscle mass than to improving power [154, 156, 358, 360, 366]. These training loads are in agreement with McBride et al. [405], Poprawski [117], Schmitdbliecher [406] and Wilson [307], whom argue that heavy loads (i.e. 4 sets of 3-6 reps at 70-90% 1RM squats) should be used to improve power production by increasing the force component. The findings reveal positive correlations between strength development and power production, specifically with strength trained athletes [92, 117, 307, 405, 406]. The basis for the prescription of heavy loads is related to hypertrophic adaptations and motor unit recruitment, in that near maximal force production is needed

to recruit and fully activate the fast-twitch muscle fibres; which are responsible for producing upper and lower body power. [307, 405]

Other researchers [30, 41, 154, 156, 163, 404, 407] have suggested that lower training doses and lighter loads be utilised to optimise upper and lower body power due to the high movement velocities and power outputs associated with lighter training loads. Current power prescription guidelines span an IRV spectrum of 1 and 15 units (2-5 sets of 3-5 reps at 20-60 % of 1RM). It is believed that a lower training dose and lighter loads may elicit greater neuromuscular adaptations, including increased synchronization and firing frequency of motor units. [302, 364, 379, 407, 408]

3.3.4 Frequency

There has been much debate in regards to the optimal weekly training frequency required to develop and retain strength and power [361, 378]. Most of the comparative research in this area has been conducted on recreational athletes [166, 255, 409]. The meta-analysis here-in allowed for cross-over comparisons between studies utilising different frequencies. Since the percent change values were divided by the study durations, the weekly frequency effects on strength and power could be observed (Figures 3.4 and 3.5).

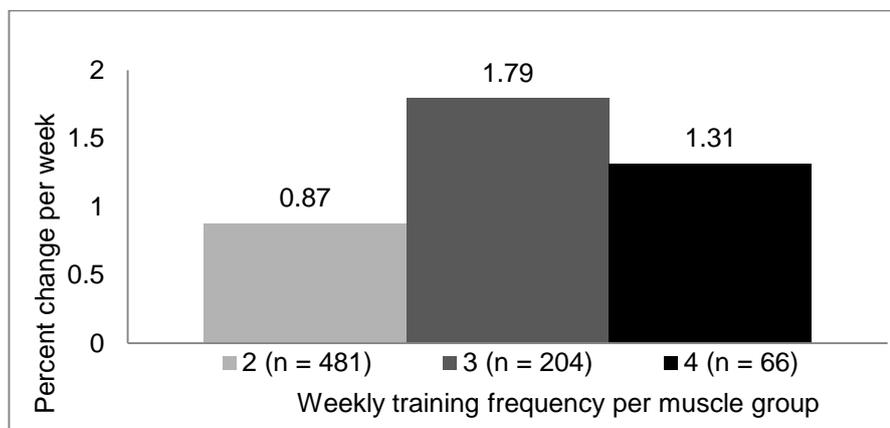


Figure 3.4. Frequency effects on upper and lower body strength represented as percent changes per week in elite American football, rugby league and rugby union players

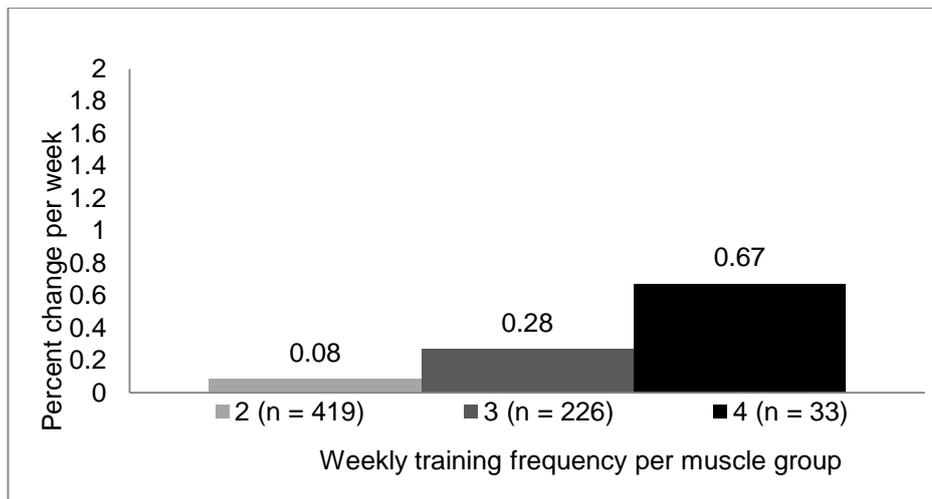


Figure 3.5. Frequency effects on upper and lower body power and its derivatives (medicine ball throw distance and vertical jump height) represented as percent changes per week in elite American football, rugby league and rugby union players

3.3.5 Frequency Effects on Strength

Athletes that resistance trained each muscle group (i.e. upper or lower body) two, three and four times per week obtained mean weekly strength increases of 0.9, 1.8 and 1.3 %, respectively (Figure 3.4). The strength outcomes established from the groups using weekly training frequencies of two (n = 506) and three (n = 229) were more representative of the total population than those using training frequencies of one (n = 25) and four (n = 66), as illustrated by the large range in sample sizes between groups. The mean training volumes and intensities prescribed in the included studies were typical to induce hypertrophic adaptations (i.e. 3.5 sets of 7.2 reps at 79% of 1RM); yet a wide range of volumes and intensities (i.e. 2-7 sets of 2-16 reps at 55-94% 1RM) were prescribed to establish the current weekly training frequency guidelines to retain and develop strength. These volume and intensity ranges may elicit numerous neural and musculoskeletal adaptations, including changes in fibre type recruitment and development, muscle architecture, muscle size, muscular endurance and strength^[38, 48, 54, 60, 97, 245, 283, 392-394, 397, 402, 404, 410-413].

Studies ^[38, 46, 396, 400] that prescribed four weekly training sessions per muscle group utilised a range of training methods (i.e. mixed, linear and non-linear) and durations

(four to fifteen weeks) to improve strength capabilities in their athletes. Argus et al.^[38] prescribed a four week mixed training programme to elite rugby union players, where athletes completed four different resistance training sessions per week: hypertrophy (4 sets of 8-12RM), strength (3-7 sets of 2-6RM), power (3 sets of 4-6 reps at 50-70% 1RM) and muscular endurance (i.e. 10 exercise circuit of 6-12 reps/exercise). Over the short-term, this mixed training method elicited large weekly bench press (2.5%/week) and box squat (2.6%/week) strength gains. These strength increases may be in-part due to the high training volume, increased muscle cross-sectional area and changes in muscle architecture (i.e. fibre composition and pennation angle changes) ^[38, 361, 366, 368]. Another short-term intervention^[400] (6 weeks) prescribing four weekly sessions applied a non-linear strength training loading scheme (25-30 sets/session of 2-6 at 80-95% 1RM) with a leucine metabolite and creatine supplementation to elite rugby league players; and found moderate weekly improvements in bench press (0.6-0.8%/week) and deadlift (1.6-1.9%/week) strength. In a single training week these athletes performed three whole body strength training sessions and one power session; the results indicate that the strength gains were due to the high training frequency, volume and intensity utilised and not the ingested supplementations ^[400].

A ten week intervention study^[396] that assigned six training sessions per week (four sessions per muscle group) in a linear fashion (i.e. increasing from 4-5 sets of 8 at 80%, to 4-5 set of 2 reps at 95% 1RM from the first to final week) found moderate weekly gains in bench press (0.4%/week) and squat (0.6%/week) strength. This long term high-volume training intervention may have caused some overtraining effects within its athletes; hence the reduced weekly strength gains in comparison to the short-term interventions. The discrepancies in weekly strength gains between the short (4 and 6 weeks) and long term (10 weeks) training interventions were also partially caused by the frequency normalisation calculations, where the overall strength improvements of the

four (strength increases of 9.9 - 10.2%), six (strength increases of 3.3 - 11.5%) and ten (strength increases of 1.4 - 7.0%) week interventions were divided by their corresponding durations to allow for comparisons of weekly strength changes between studies [38, 396, 400].

Studies prescribing three weekly training sessions per muscle group [392, 396, 402, 403] also utilised a wide range of volumes (3.5 ± 1.2 sets of 7.7 ± 3.0 reps) and intensities ($78 \pm 7\%$) to elicit their weekly strength gains. Stone et al. [402] prescribed three whole body sessions to elite American college football players utilising a block method of strength training over five weeks with a creatine monohydrate supplementation (i.e. weeks 1-2 used 3 sets of 6RM; weeks 3-5 used 3 sets of 3RM) and found weekly squat and bench press increases of 2.1 and 1.8%, respectively. These weekly strength increases may be attributed to a combination of neuromuscular and hypertrophic adaptations caused by the strength training loads as well as the creatine supplementation dose [402]. Coutts et al. [392] also found similar weekly squat (2.6-3.8%) and bench press (1.8-2.3%) strength gains in elite junior rugby league players with three whole body training sessions utilising a traditional-linear training model for a duration of twelve weeks. The linear model in this study [392] progressed from muscular endurance (i.e. 12-16 reps at 55-70% 1RM) to hypertrophy (i.e. 6-12 reps at 70-84% 1RM) to maximum strength (i.e. 4-5 reps at 85-89% 1RM) training loads across the training weeks. The large weekly strength increases may be attributed a combination of training adaptations related to the junior level training status of the athletes; which may include enhanced neural adaptations (i.e. increased recruitment, firing rates and synchronisation of motor units), increased neuromuscular coordination (i.e. lifting technique) and larger hypertrophic adaptations [363, 366, 392]. Lower weekly upper (-0.19 to 1.9%/week) and lower body (0.5 to 1.9%/week) strength gains were observed in studies utilising two weekly training sessions per muscle group [47, 48, 54, 389, 390, 397, 398, 402] when prescribing similar training volume and intensity ranges

in relation to studies utilising three and four weekly training frequencies [38, 39, 46, 392, 395, 396, 400, 402, 403].

This information suggests that training frequencies of two to four weekly resistance training sessions per muscle group can be prescribed to improve upper and lower body strength in elite rugby league, rugby union and American football players. Similar to previous findings it can be stated that if session volume and intensity are unchanged that increasing or decreasing weekly resistance training frequencies will provide greater or lesser gains in strength [361]. It should also be noted that lower body strength increased at a mean weekly rate of 1.7 times greater than upper body strength when utilising the same weekly training frequencies (i.e. two, three and four), indicating that the lower body may have greater neuromuscular adaptations and response rates to resistance training [363, 366]. Possible explanations include an increased activation, recruitment and synchronisation of motor units, due to the number of muscle groups involved, resulting in a larger amount of testosterone being released and therefore greater anabolic effects overtime [366, 367, 414]. Based on findings utilising traditional strength training loads in recreational athletes [409], it may be possible to maintain and even develop strength levels with as little as one to two weekly resistance training sessions per muscle group [54, 60, 389, 397, 410]; but due to the scarcity of research utilising elite rugby league, rugby union and American football players, this notion warrants further investigation.

3.3.6 Frequency Effects on Power

Athletes that resistance trained two, three and four times per week obtained weekly power increases of 0.1, 0.3 and 0.7 %, respectively (Figure 3.5). The training volumes and intensities prescribed in the included studies were typical of strength, muscular endurance and hypertrophy (i.e. 2-7 sets of 2-16 reps at 65-95% of 1RM) and not power development loads. Therefore the guidelines for prescribing specific weekly training frequencies to

develop upper and lower body power output are representative of the volume and intensity ranges utilised in the included studies and not necessarily of the training loads and movement velocities that optimise power output. [38, 48, 54, 60, 97, 245, 283, 392-394, 397, 404, 410-413].

In order to improve upper and lower body power utilising strength and hypertrophy loads training frequency must remain high (3-4 sessions/week). Five studies [46, 392, 396, 402, 403] assessed the changes in vertical jump height (VJH) using three to four weekly training sessions; and found mean weekly improvements of 0.5 %. These studies [46, 400, 402, 403] also investigated high frequency training and its effects on mechanical leg power; and found that power increased at a mean rate of 0.4 % per week. These outcomes confirm current IRV findings and previous research, suggesting that near maximal force production is required to optimise motor unit recruitment and activate the majority of fast-twitch fibres responsible for producing and possibly developing lower body power [307, 405]. The effects of high weekly training frequencies (three to four) on upper body power adaptations were not investigated due to the scarcity of literature.

Based on our findings, upper and lower body power output can be maintained with two training sessions per muscle group/week. Studies prescribing two resistance training sessions per muscle group/week [46-48, 393, 394, 397] also found that VJH could also be maintained and even improved by 0.1 to 0.9 % per week with various types of resistance training interventions (i.e. non-linear, linear, non-periodised, strength, Olympic style weightlifting and power-lifting). Other studies prescribing two training sessions per muscle group/week, [38, 39, 47, 54, 404] elicited a range of upper body power decrements and improvements (-1.6 to 0.6% per week). The three studies [38, 54, 394] showing decrements in upper body power output utilised mixed training methods, where the players performed hypertrophy (i.e. 4 sets of 8-12RM), strength (i.e. 3-7 sets of 4-6RM) and power (i.e. 3 sets of 4-6 reps at 50-70% 1RM) training sessions, as well as two aerobic/anaerobic training sessions within a training week. The high volume and

concurrent strength, hypertrophy, power and aerobic training in the above studies may have had an interference effect that negatively affected upper body power production. Past research [38, 39, 54] also suggests that high training volumes can increase neuromuscular fatigue and consequently reduce power output.

One study [39] induced minor upper body power improvements (0.1- 0.2%/week) in college level rugby league athletes with a periodised concurrent strength (one training session per muscle group/week), power (one training session per muscle group/week) and aerobic training programme. The positive power outcomes of this study may be attributed to the timing of training and testing sessions within the periodised plan, as the strength and power-training sessions were performed before and/or on alternate days to the aerobic sessions, which may have reduced the concurrent training effects. The upper body power testing was conducted the week following a low volume training week when neuromuscular fatigue was lowest and power capacity was highest [39]. Hoffman et al. [47] also reported improvements in upper body power when prescribing two resistance training sessions per muscle group/week to elite American football players utilising linear and non-linear methods. The linear group increased the resistance training intensity and decreased the volume (i.e. from 4 sets of 9-12 reps to 5 sets of 3-5 reps) across 15 weeks; while the non-linear group alternated between low volume-high intensity (5 sets of 3-5 reps) to high volume-low intensity (4 sets of 9-12 reps) dosages each training session for a duration of 15 weeks. [47]. The hypertrophic and strength training loads prescribed above appeared to elicit a positive effect on upper body power output. The use of explosive Olympic style lifts (i.e. power cleans, power shrugs, high pulls and push press) may have also contributed to increased neuromuscular activation and in turn power output [47].

The current findings based on frequency, indicate that elite rugby league, rugby union and American football players will inevitably improve their power capabilities when utilising strength and hypertrophy training loads as long as a high weekly training

frequency is sustained. Yet, these elite player may only need to perform two whole body or two resistance training sessions per muscle group/week to retain upper and lower body power levels throughout a competitive season. The effects of training frequency on power development when utilising loads specific to improving power remain inconclusive.

3.3.7 Long Term Training Effects

The majority of studies included in this review have investigated the short term (< 12 months) effects of resistance training on strength and power changes without considering the long term (>12 months) effects. Previous research has found that as an athlete's training age and experience increases, strength and power adaptation rates diminish and begin to plateau. [296, 366, 380, 383]

It has been shown that the magnitude of strength improvement is greater in weaker less experienced players. Longitudinal (i.e. 12 to 48 months) studies tracking changes in strength and power in elite rugby players have found moderate (ES = 0.55) improvements during the first 12 months and diminished returns thereafter (i.e. 24-48 months). [296, 383]

The two studies (n = 32) investigating the longitudinal changes in strength found increases of 7.1 ± 1.0 (ES = 0.55), 8.5 ± 3.3 (ES = 0.81) and 12.5 ± 6.8 (ES = 1.39) % over 12, 24 and 48 months, respectively in elite senior (age = 22.8 ± 3.7 years) rugby players. [296, 383]

In these studies, resistance training was performed two times per week on average throughout the training year (off-season, pre-season and in-season), which is in agreement with the maintenance guidelines (i.e. 1-2 resistance training session per muscle group/week) previously discussed. Both studies utilised a classical linear model of periodisation during the pre-season phase progressing from a hypertrophy-strength focus for 3-4 weeks (i.e. general preparation) to a strength-power focus for 3-4 weeks (specific preparation). The in-season phases were designed to maintain strength, muscle mass and power. [296, 383]

Appleby et al. [383] provided minimal detail on how they programmed during

this period; while Baker and Newton^[296] utilised a wave like progression repeating 2 blocks of 4 weeks throughout the season. The first block was focused on developing base strength and hypertrophy, the second block was geared towards maximum strength and power. Off-season lengths were 4-6 weeks to allow for physical and mental restoration. These three phases (pre-season, in-season and off-season) were repeated each year in similar fashion. As expected, once the players attained a certain level of strength (i.e. after the first 12-24 months of training), adaptation rates diminished (3.6 ± 2.8 %; ES = 0.34).

Long-term power adaptations are less investigated, but logically should follow a similar adaptation pattern over time. Baker and Newton^[296] investigated the changes in upper body power in elite rugby league players over a four year period and found a large increase in power (14.5 %; ES = 1.30) after the first two years and a small decrease in power between the second and fourth year (-2.7%; ES = -0.23). These findings reinforce the notion of diminishing returns, as well as suggest that power development and decay rates may be greater than that of strength. The majority of power adaptations are caused by neuromuscular changes (i.e. an increase/decrease in inter-muscular coordination, muscle fibre activation, muscle fibre recruitment and firing frequency), whereas the majority of strength adaptations are due morphological changes (i.e. an increase/decrease in cross-sectional area, myofibrillar size, muscle size, muscle fibre pennation angle, musculotendinous stiffness and tendon thickness); thus the discrepancies in development and decay rates between power and strength. Issurin^[380] suggests that maximal strength can be retained for up to 30 ± 5 days post-training and that maximal speed can only be retained for 5 ± 3 days post-training, highlighting the need to re-consider current periodisation strategies. Maximal speed and maximal power production utilise the same energy system (alactic) and require similar neuromuscular activation processes (i.e. motor unit recruitment and firing frequencies), therefore should have similar adaptations to detraining.

3.3.8 Detraining

When resistance training is ceased for an extended period, the decay rates in strength and power over time are of great interest, as they may allow us to determine the minimum and maximum duration strength and power training can be ceased before another training stimulus is required, which in turn may allow us to periodise training programmes more effectively. A residual effect is the maximum detraining duration in which an athlete can retain his or her strength or power; while the decay rate is a measure of the speed at which strength and power is lost over time ^[415]. Previous research investigating the detraining effects on strength and power elite rugby league, rugby union and American football players was scarce; but some inferences can be drawn. A total of five studies ^[50, 59, 389, 399, 401] investigated the detraining effects on strength and power in rugby union and American/Canadian football players.

3.3.9 Detraining Effects on Strength

A mean decrease in strength of 14.5 ± 14.3 % was found when players ($n = 155$) ceased strength training for a mean duration of 7.2 ± 5.8 weeks. The 7.2 weeks of detraining produced a moderate negative effect ($ES = -0.64$) on the strength levels in these players. Based on the outcomes of the included studies, ^[59, 61, 389, 416-418] the detrained athletes were able to maintain the majority of their pre-season strength levels (mean = -1.2 %; $ES = -0.08$) with no resistance training over detraining periods of two to three weeks. A study by Allen ^[389] found that three weeks of no resistance training caused trivial reductions in upper (0.5% decrease; $ES = -0.04$) and lower body (1.6% decrease; $ES = -0.09$) strength in American football players. It should be note that the players in the above study ^[389] continued to practice during these periods of resistance detraining, which may have provided a sufficient stimulus to maintain strength throughout the unloading phase. Another study by Hortobagyi et al. ^[59] found that two weeks of detraining also lead to

trivial reductions in upper (1.7% decrease; ES = -0.12) and lower body (0.9% decrease; ES = - 0.05) strength in power trained athletes (i.e. American football players and Olympic-weightlifters). These two studies indicate that trained athletes can retain the majority of their strength over short periods of detraining (i.e. two to three weeks). Other researchers [309, 363, 369, 380] have also suggested that elite athletes may be able to retain maximum strength gains for up to thirty days (3-4 weeks) days after training has ceased.

As expected the two studies [399, 401] utilising longer detraining periods (10 and 16 weeks) showed much larger losses in strength (mean = 19%; ES = 1.06). Both studies found large decrements in shoulder abduction strength (- 40 and - 13%) and less substantial losses in bench press (-6.9 to - 8.4%) strength in American (Canadian) football players throughout a competitive season. Shoulder abduction strength was used to assess fatigue, injury and readiness to return to play, as it appears to be more susceptible to the effects of detraining in comparison to other strength measures (i.e. bench press, squats and leg extensions) [399, 401]. Based on the above outcomes and past literature, [59, 60, 362, 363, 365, 369, 380, 389, 399, 401] it can be speculated that maximum strength levels can be maintained for up to three weeks without resistance training, but decay rates will increase thereafter (5 to 16 weeks).

3.3.10 Detraining Effects on Power

The detraining power studies included in this systematic review [50, 59, 401] investigated the changes in VJH of elite rugby union and American football players over detraining periods of 2, 6, 12 and 16 weeks. VJH is a common and practical measure used to monitor neuromuscular fatigue and recovery of the lower body within a competitive season, as well as the effectiveness of plyometric and ballistic training programs [56, 59, 61, 97, 417, 418]. A trivial (ES = -0.10) mean decrease in VJH ($- 0.4 \pm 3.2$ %) was found when players (n = 57) ceased resistance training for an average of 7.6 ± 5.1 weeks. Hortobagyi et al. [59]

found that countermovement and drop jump height improved by 3.2 (ES = 0.20) and 4.5 % (ES = 0.26) with two weeks of detraining; while static squat jump height decreased by 3.8 % (ES = -0.24). Based on the above study it appears that a two-week taper can induce non-significant improvements in countermovement vertical jump performance (3.2%). On the other hand, it seems that short term detraining may be detrimental to static vertical jumps (-4.5%) that rely on concentric only muscle contractions. Due to the small sample size (n=12), further investigation is required to confirm these results.

A second study by Babault et al. ^[50] found that vertical jump performance (i.e. countermovement, drop and static squat jump height) could be maintained (0.5 to 5.0%) in elite French rugby union players (n = 10) that participated in five rugby practices weekly with no resistance or power training for six to twelve weeks. This may indicate that the physical nature of on-field rugby practices provides an adequate in-season stimulus to maintain vertical jump performance and possibly power. However, Schneider et al. ^[40] found contradictory results, in that VJH decreased (-4.8 to -2.9%) in Canadian football players (n = 20) across a sixteen week competitive season; therefore it can be inferred that the in-season football training stimulus was inadequate for maintaining jump performance and possibly lower body power. It has been inferred that reductions in VJH will in turn cause corresponding decreases in power production based on high correlations ($r = 0.91$) between the two variables. But VJH is not a direct measure of power and changes in VJH do not necessarily transfer to equivalent changes power output ^[82]. As evident above, the effects of detraining on power output in elite rugby union, rugby league and American football players remains inconclusive, hence the need to conduct further research in this area.

3.4 Discussion

The systematic evaluations of i) IRV, ii) training frequency, iii) short term training effects and iv) detraining duration on strength and power adaptations have been compiled to provide clear and concise future research directions and training dose recommendations to develop/retain strength and power in elite rugby union, rugby league and American football players (Table 3.4).

Table 3.4 Meta-analysis of dose-response variables: forecasting changes in strength and power overtime based on intensity relative volume

	Volume x Intensity					Overall					Percent change forecast				
	IRV	Sets	Reps	% IRM	Duration (weeks)	Frequency (x/week)	Percent Change (ES)	One	Five	Ten	Twenty				
Strength (n = 549)	19.4 ± 7.4	3.8 ± 1.0	6.7 ± 2.2	80 ± 5	10.4 ± 4.3	2.5 ± 0.7	9.5 ± 7.3 (0.53)	0.42	2.1	4.2	8.4				
Power (n = 357)	19.3 ± 6.6	3.8 ± 0.8	6.4 ± 2.0	81 ± 5	9.7 ± 4.3	2.5 ± 0.6	2.0 ± 4.3 (0.42)	0.07	0.4	0.8	1.5				

All values are represented as pooled means and standard deviations. **IRV** = intensity relative volume of all included strength or power measures; **%IRM** = percentage of one-repetition maximum utilized; **One** = mean percent change in strength or power per training session; **Five, ten, twenty** = forecasted percent changes in strength and power across 5, 10 and 20 training sessions based on "One"; **ES** = mean effect size in strength and power

In terms of training loads to develop strength, IRVs ranging from eleven to thirty (3-5 sets of 4-10 reps of 70 to 88 % 1RM) should be prescribed in a periodised manner (fluctuating volume and intensity over time) utilising weekly training frequencies of two to four times per muscle group to elicit marked strength increases (mean increase of 9 %) in elite rugby union, rugby league and American football players. Although power was not the primary focus of many of these studies, the loads used to increase strength also impacted on the power measures. Given this information it seems power (i.e. VJH) can be improved (mean increase of 3 %) utilising IRVs between twenty-one and thirty (i.e. 4-5 sets of 7-9 reps at 77-83% 1RM), as long as a high weekly training frequency is sustained (3-4 sessions/week). These recommended training doses (i.e. a combination of IRV and training frequency) are typical of off-season and pre-season training loads and should be prescribed accordingly. The effect of ballistic/explosive load training doses on power remains uncertain and requires further investigation.

With regards to maintaining/retaining strength and power in American football and rugby codes, where competition periods are lengthy (i.e. 18 to 24 weeks), the retention of these qualities is of great importance for preventing injuries and maintaining consistent performance throughout the season. From the research reviewed, it seems that strength and power levels can be maintained with as little as one to two resistance training sessions/week if session IRV (i.e. 12-26 [3-5 sets of 4-6 reps at 75-85% 1RM]) is maintained. There is also some evidence to suggest that IRVs of less than ten (i.e. 1-6 sets of 1-6 reps at 85-100% 1RM) may be adequate for retaining strength and power in junior level players, but these findings are not necessarily transferrable to elite level senior athletes, as a greater training dose (IRV > 10 units) is most likely needed to induce similar effects. It can also be speculated that strength levels can be retained for up to three weeks of detraining (no resistance training), but decay rates will increase thereafter (5 to 16 weeks). Some of the research implies that VJH (a substitute for power output) can be

adequately maintained for up to eight weeks (i.e. 2-12 weeks) of resistance detraining^[50, 59], while others state that a stimulus (i.e. plyometrics, power training, strength training or speed training) must be provided every 5-8 days to retain power and speed.^[380] As evident from the above statement, the effects of detraining on power production in elite athletes as a primary measure remain inconclusive.

The long term effects of periodised training programmes on strength and power appear to follow the law of diminishing returns; as training experience increases, adaptation rates decrease. There is some evidence to suggest that elite athletes immersed in a high performance training environment will have marked improvements in strength and power during the first 12 months and minimal improvements thereafter (i.e. 2-4 years); this notion warrants further investigation of elite rugby and American football training environments.

A variety of strength (i.e. isokinetic torque, isometric force and maximum dynamic strength) and power (peak and mean vertical power, jump height, medicine ball throw distance) measures; as well as multiple movement patterns (i.e. single joint movements and multi-joint maximum strength movements) were combined to calculate the dosage effects (IRV and frequency) and percent changes in strength and power. It must be noted that across the included training studies there was a wide range in strength and power levels due to the differences in physical requirements of the included sports and on-field playing positions. For example, 1RM squat means ranged from 147 to 204 kg (mean = 174 ± 16 kg) for American football players and 105 to 194 kg (mean = 156 ± 30 kg) for rugby union and rugby league players; while 1RM bench press means ranged from 73 to 150 kg (mean = 119 ± 25 kg) for American football players and 85 to 143 kg (mean = 127 ± 15 kg) for elite male rugby league and union players. It must be also noted that inclusion of elite junior level (age < 18 years) along with elite professional and semi-

professional athletes may have skewed the pooled strength results, hence the large variance in the strength and power values.

3.5 Future Directions

As evident in the loading parameters discussed throughout, there is some conjecture within the literature in terms of the optimal training dose to develop and retain strength and power; therefore further investigations on a wide spectrum of training doses (i.e. varying intensity [%1RM], volume and frequency and training durations), movement velocities and movement patterns are required. Determining the minimal and optimal training doses to retain and develop strength and power in elite American football and rugby players is of utmost importance; as it will have a direct influence on off-season, pre-season and in-season loading parameters. The effects of detraining on specific upper and lower body strength and power measures over time is also of value, as it will inevitably affect the length of in-season and off-season unloading phases and cycles; due to the scarcity of research investigating various detraining durations on strength and power decay rates in these elite populations, future research is warranted.

***VALIDATION OF WIRELESS ACCELEROMETRY:
IS WIRELESS ACCELEROMETRY A VIABLE MEASUREMENT
SYSTEM FOR ASSESSING VERTICAL JUMP PERFORMANCE?***

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McGuigan

Sports Technology
Accepted (Appendix 4c)

Sports Performance Research Institute New Zealand Conference
Poster Presentation (Appendix 4c)

4.0 Prelude

For a measurement system to be implemented into a practical setting it must be reliable and the validity established against a “gold standard” system. The Review of Literature in Chapter 2 evaluated the methodological differences of the various measurement systems and ballistic movement patterns. The evolution of sports performance technology was highlighted in the review, which has led to the emergence of micro-electromechanical devices, such as the accelerometer. Of interest to this chapter was the utilisation of wireless accelerometry in accurately assessing ballistic performance, due to the practicality of this measurement system over other laboratory-based systems (e.g. force plates and linear position transducers). The aim of this study was to examine the differences (validity) in eccentric and concentric force, velocity and power, calculated from hip acceleration (accelerometer attached to the hip), bar acceleration (accelerometer attached to bar-bell) and centre of mass acceleration (force plate) during vertical countermovement jumps (CMJ). Furthermore the reliability of each methodological procedure was quantified.

4.1 Introduction

Motion analysis technology is constantly evolving and becoming smaller, lighter and more practical, which has led to the emergence and development of micro-electromechanical systems and devices [13]. These devices have been designed to assess the kinematics and kinetics of most athletic movements (e.g. running, sprinting, jumping, rotation, kicking, punching, throwing and catching) [158]. In many sports, performance changes are assessed and monitored during explosive movements performed primarily in the vertical plane, such as squatting, jumping, pushing and pulling via kinematic and kinetic measurement systems [16, 18, 25, 187, 195, 419]. Video, force plates, linear position transducers, rotary encoders, magnetometers, gyroscopes, laboratory constructed accelerometers and more recently commercially designed wireless accelerometers have been employed to assess and monitor changes in upper and lower body kinematics and kinetics. Of interest to this research is the utilisation of wireless accelerometry in assessing vertical jump performance due to the practicality of this measurement system.

The majority of research investigating the mechanics of the vertical jump has employed force plates (gold standard) and/or linear position transducers as the primary measurement system(s) [15, 17, 28, 36, 56, 201, 241-243]. When a force plate is used in isolation, measurements are based solely on ground reaction force and in turn acceleration of the centre of mass, a virtual point that changes in response to the changing positioning of body segments during movement. When a linear position transducer is used in isolation, measurements are calculated based on changes in velocity at the attachment point (i.e. bar-bell). Both systems are considered reliable and valid for assessing the kinematics and kinetics of vertical jumping, and have been previously compared to one another [15, 17, 183, 420, 421]. The most apparent differences between the two systems are that the force plate underestimates velocity of the centre-of-mass, as it uses inverse dynamics to calculate velocity from ground reaction forces and cannot account for bar velocity; while the linear

position transducer overestimates velocity and acceleration and in turn power due to the derived velocity and acceleration through single and double differentiation of bar displacement ^[15]. Wireless accelerometers operate in a similar fashion to linear position transducers in that they measure acceleration of a specific point or attachment site (i.e. hip or bar); and therefore both systems are governed by this inherent limitation.

Past research utilising wireless accelerometry has investigated the validity of a multitude of concentric phase kinematic and kinetic variables during following movements: the loaded and unloaded squat and countermovement jump, drop jump, back squat, high pull, bench press and bench throw ^[16, 18, 25, 174, 187, 188, 191, 195, 196, 204, 251, 252, 419, 422]. The concentric (phase) variables investigated include: peak displacement (PD), flight time, acceleration, peak force (PF), peak power (PP), peak velocity (PV) and rate of force development. During the above movements the wireless accelerometer was validated against either video, timing mats, force plates, linear position transducers or a combination of the force plate and linear position transducer. The attachment site of the accelerometer varied between bar (i.e. loaded and unloaded bar-bells and light weight wooden and plastic dowels) and hip placements depending on the movement patterns and protocols utilised in the above studies.

Current research has reported large kinematic and kinetic differences between accelerometer attachment sites (hip vs. bar), therefore it is important to determine, which attachment site is most appropriate for measuring and assessing a given movement pattern. The majority of accelerometry research selected a bar attachment site; this set-up would be of benefit during loaded pressing, pulling and possibly squatting, where movement at the bar is most important ^[16, 25, 187, 251, 419]. Many of the loaded and unloaded vertical jumping studies also utilised a bar attachment, when it can be argued that the hip attachment and/or movement of the centre-of-mass may be more appropriate for measuring the kinematics and kinetics of this movement. The few studies that utilised the

hip attachment, investigated the reliability of PD (jump height), flight time, PV, PF and PP as measured using wireless accelerometry during squat and countermovement jumps [174, 188, 195, 196, 204, 252, 422]; but only Feldmann et al. (2011) and Houel et al. (2010) validated their outputs against a force plate. To date no studies have compared the kinematics and kinetics measured with wireless accelerometry at the hip and bar in relation to the force plate (centre of mass). Furthermore, no research has investigated the eccentric phase variables using wireless accelerometry. Therefore, the aim of this study was to assess the i) the consistency of and ii) the kinematic and kinetic differences and relationships between three measurement systems: hip acceleration (accelerometer attached to the hip), bar acceleration (accelerometer attached to bar) and centre of mass acceleration (force plate) during vertical countermovement jumps (CMJ).

4.2 Methods

4.2.1 Subjects

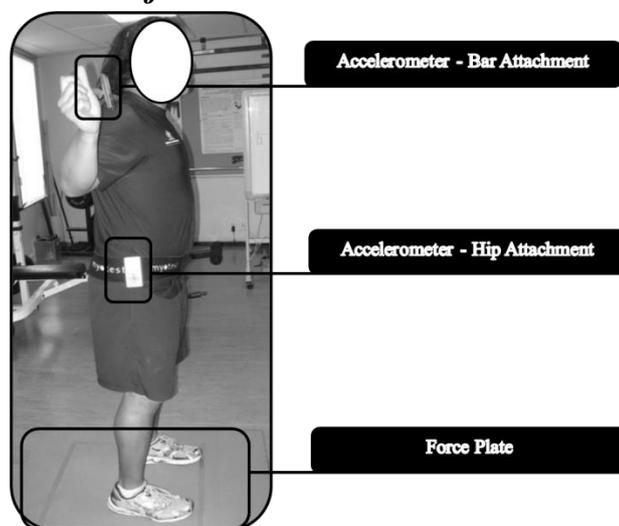


Figure 4.1. Vertical jump testing set-up. Two wireless accelerometers and one portable tri-axial force plate.



Figure 4.2. Accelerometer bar and hip attachments

Study approval was granted by the AUT University Ethics Committee and written informed consent was obtained from each participant prior to partaking in the study. The participants ($n = 18$; age = 21.6 ± 2.9 yrs; body mass = 101.5 ± 14.0 kg; height = 1.86 ± 0.07 m) were comprised of eighteen semi-professional rugby union players (1RM parallel back squat = 169 ± 21 kg; peak power = 5664 ± 770 W) participating in New Zealand's provincial rugby competition.

4.2.2 Instrumentation

Two tri-axial wireless accelerometers (Myotest©, Sion, Switzerland) and a tri-axial force plate (Advanced Mechanical Technology Inc. Acupower, Watertown, MA) were used during data collection; sampling frequencies of 200 and 400 Hz were pre-set for the accelerometers and force plate, respectively.

4.2.3 Procedures

The participants were tested on two separate occasions with six days rest between testing sessions: Monday week one and Monday week two (Table 4.1). Participants also completed one familiarization session prior to the two testing sessions, where they were introduced to the equipment and CMJ testing protocol in order to minimize the learning effects and increase the reliability of the test results. During testing, one accelerometer was attached to the athlete via a Velcro band which was wrapped around the hips and placed on the neck of the femur (hip acceleration – Figure 4.2), a second accelerometer

was attached (placed mid-way between the shoulder and hand) to a light weight wooden bar (<1 kg) via a plastic C-clamp (bar acceleration – Figure 4.2). The athletes were instructed to stand on the force plate with their feet shoulder width apart, while holding the bar firmly against the upper trapezius (Figure 4.1). The movement instructions for the countermovement jump (CMJ) were as follows; i) lift bar off rack, ii) stand erect and wait still for a “beep” from the accelerometer; and iii) on the beep perform one CMJ as explosively as possible using a self-selected depth; iv) wait still for a second “beep”; v) on the beep perform a second countermovement jump as explosively as possible; vi) wait still for a “double beep” to signal that the data has been collected. Data was collected during the eccentric and concentric phases of the CMJ; all data were saved in designated files for analysis.

Table 4.1. Countermovement jump testing protocol

Movement pattern	Volume: sets x distance/reps
<i>Warm-up</i>	
Light jog	1 x 200 m
Ankling (toe flicks)	2 x 40 m
A Skips	2 x 40 m
C Skips	2 x 20 m
Leg swings	2 x 8 each leg
Vertical hops	1 x 20 reps
~ 50% CMJ effort	1 x 5 reps
~ 75% CMJ effort	1 x 5 reps
100% CMJ effort	1 x 3 reps
Rest	1 x 3 min
<i>Testing</i>	
Acyclic CMJ	1 x 2 reps

CMJ = countermovement jumps; **m** = meters; **reps** = repetitions

4.2.4 Data Analysis

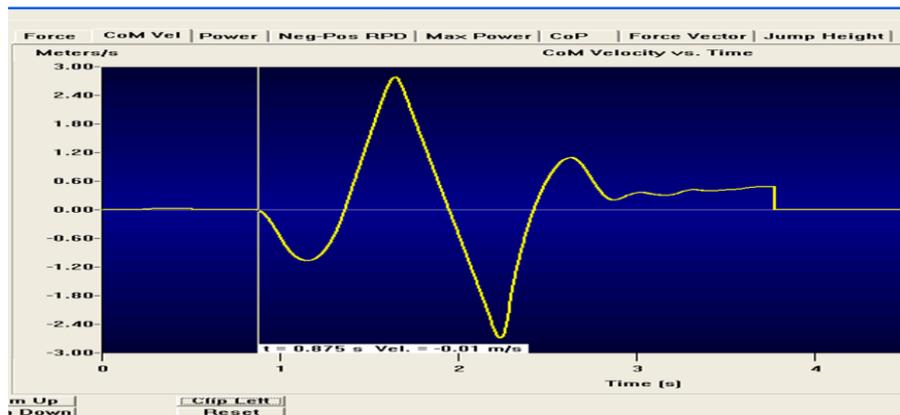


Figure 4.3. Accupower vertical jump analysis software: the start of the eccentric phase based on velocity of less than -0.01 m/s. The X axis is time in seconds. The Y axis is velocity of the centre of mass.

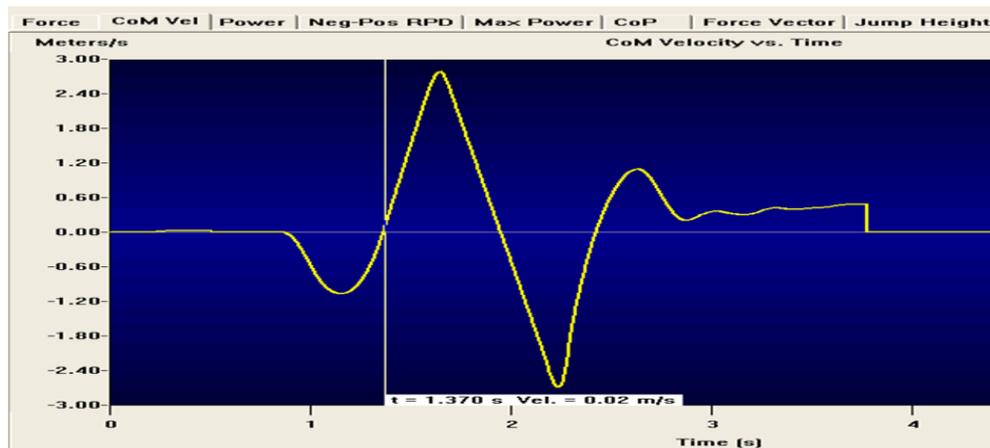


Figure 4.4. Accupower vertical jump analysis software: the start of the concentric phase based on velocity equal to or greater than 0.01 m/s. The X axis is time in seconds. The Y axis is velocity of the centre of mass.

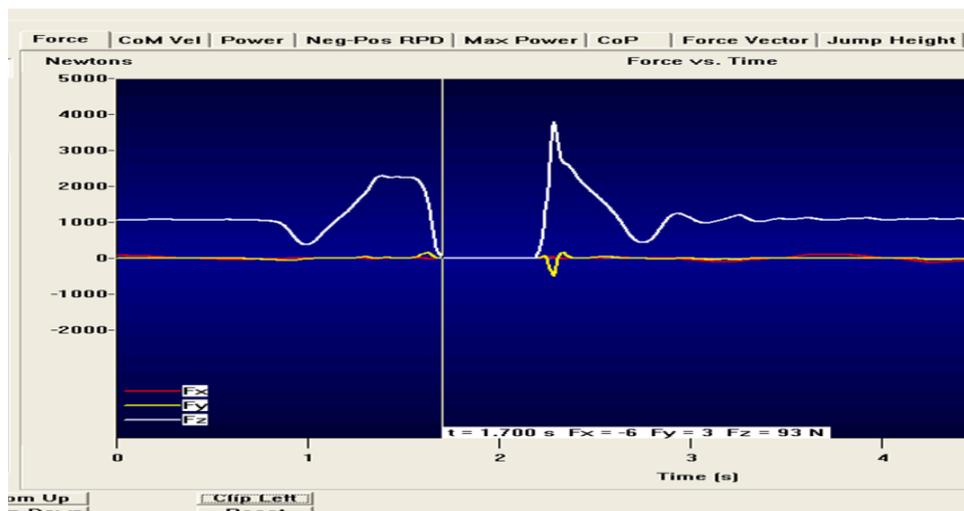


Figure 4.5. Accupower vertical jump analysis software: end of concentric phase based on force of less than 5% of body weight. The X axis is time in seconds. The Y axis is ground reaction force in Newton's.

The eccentric and concentric phases of movement were divided for the kinematic and kinetic analysis as follows; the eccentric phase (downward movement) began when velocity became negative (velocity < -0.01 m/s – Figure 4.3) and finished when velocity returned back to zero; the subsequent concentric phase (upward movement) began when velocity became positive (velocity > 0.01 – Figure 4.4) and finished when the subject left the ground (force < 5% of body weight, as determined by the vertical ground reaction force – Figure 4.5). The acceleration-time data from the accelerometer was integrated to calculate velocity and displacement. The force was calculated by multiplying the acceleration by the known mass of the subject; power was then calculated by multiplying the force by the integrated velocity-time data. The vertical ground reaction forces from the force plate were divided by the mass of the participant at each time point to determine acceleration of the centre of mass. Acceleration due to gravity was subtracted from the calculated acceleration; acceleration-time curves obtained from the force–time data were integrated using the Simpson method to calculate to velocity and displacement ^[423]. The derived velocity data were multiplied by the original force values to calculate power. The PF, PV and PP outputs occurring in the eccentric and concentric phases were recorded for further statistical analysis. The power absorption ratio (PAR [ratio between peak concentric and peak eccentric power]) was also calculated in order to further explore jump performance ^[424].

4.2.5 Statistical Analysis

Means and standard deviations were used to represent centrality and spread of the data. The reliability of the measures was assessed using intraclass correlation coefficients (ICC), percent standard error of measurement (%SEM) and Cohen's effect size (ES). Intraclass correlation coefficients and percent standard errors of measurements were considered acceptable if the scores were > 0.70 and < 10 %, respectively ^[425-427]. Effect

sizes were interpreted as < 0.1 as trivial, 0.1-0.3 as small, 0.3-0.6 as moderate, and > 0.6 as large [428]. Reliability was interpreted as good when the aforementioned criteria was met, moderate when two of the criteria ($ICC > 0.70$; $\%SEM < 10\%$; $ES < 0.3$) were met, or was categorised as poor when two or more criteria were breached.

Repeated measures analyses of variance (ANOVA) with Holm-Sidak post hoc contrasts, percent differences in mean scores and Pearson product correlations (r) were used to determine the criterion validity of the accelerometers (hip and bar) [15, 114]. An alpha value of 0.05 was used to assess statistical significance between devices for each kinematic and kinetic variable. Mean difference scores of $< 5\%$ and r values of > 0.70 were also set as the acceptable validity thresholds [425, 428]. The measurement system and variable were classified as valid if all criteria were met, partially valid if two of the criteria were met or invalid if two or more of the criteria were breached. The statistical analyses were performed using SPSS Statistics 17.0 (SPSS Inc., Chicago, IL).

4.3 Results

The differences and correlations between the three systems were quantified and displayed in Tables 4.2 and 4.3. When compared to the force plate (centre of mass acceleration), the hip accelerometer under-predicted (average mean % difference = 20.5%) and the bar accelerometer over-predicted (average mean % difference = 31.3%) the majority of eccentric and concentric phase kinematic and kinetic variables. For the eccentric phase variables all data sets differed significantly between the three measurement systems. Greater ($p < 0.05$) concentric PV and PP were found for the centre of mass (force plate) and bar (accelerometer) as compared to the hip (accelerometer). However, lower ($p < 0.05$) peak forces were associated with the centre of mass and hip in comparison to the bar.

Table 4.2 Comparison of the kinematics and kinetics measured using two wireless accelerometers and a portable force plate during vertical countermovement jumps

Variable	A _{hip}	A _{bar}	FP	Significance (p < 0.05)
Eccentric				
PP (W)	-986 ± 305 W	-2676 ± 898 W	-1473 ± 435 W	All devices differed significantly.
PV (m•s ⁻¹)	-0.84 ± 0.18 m•s ⁻¹	-1.60 ± 0.36 m•s ⁻¹	-1.13 ± 0.21 m•s ⁻¹	All devices differed significantly
Concentric				
PP (W)	4352 ± 878 W	5794 ± 1449 W	5664 ± 758 W	FP and A _{bar} significantly greater than A _{hip}
PF (N)	2345 ± 284 N	2849 ± 424 N	2305 ± 249 N	A _{hip} and FP significantly less than A _{bar}
PV (m•s ⁻¹)	2.28 ± 0.30 m•s ⁻¹	2.93 ± 0.44 m•s ⁻¹	2.88 ± 0.23 m•s ⁻¹	A _{bar} and FP were significantly greater than A _{hip}

*Day 1 and day 2 data were pooled for the statistical analyses; **A_{hip}** = Accelerometer attached to the hip; **A_{bar}** = Accelerometer attached to the bar; **FP** = force plate; **PP** = peak power; **PV** = peak velocity

There were low to moderate correlations ($r = 0.05$ to 0.62) between the three sets of data indicating that there was very little shared variance ($r^2 = 1-36\%$) between the hip, bar and centre of mass measures during the CMJ (Table 4.3).

Table 4.3. Correlation matrix between kinematics and kinetics measured using wireless accelerometry and a portable force plate during vertical countermovement jumps

Variable	Eccentric Peak Power			Eccentric Peak Velocity			Concentric Peak Force			Concentric Peak Power			Concentric Peak Velocity		
	A _{hip}	A _{bar}	FP	A _{hip}	A _{bar}	FP	A _{hip}	A _{bar}	FP	A _{hip}	A _{bar}	FP	A _{hip}	A _{bar}	FP
System															
A _{hip}	1	0.50	0.47	1	0.33	0.46	1	0.62	0.62	1	0.23	0.34	1	0.39	0.05
A _{bar}		1	0.43		1	0.30		1	0.59		1	0.38		1	0.33
FP			1			1			1			1			1

A_{hip} = accelerometer attached to the hip; **A_{bar}** = accelerometer attached to the bar; **FP** = portable force plate

All inter-trial and inter-day reliability measures can be observed in Tables 4.4 and 4.5, respectively.

Table 4.4 Inter-trial device reliability in assessing the kinematics and kinetics during the countermovement jump

Variable	Device	Day 1						Day 2							
		Trial 1			Trial 2			Trial 1			Trial 2				
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	%Mdiff	ICC	%SEM	
Eccentric	A_{hip}	-792	307	-1100	330	38.9	0.58	24	-955	379	-1093	299	14.4	0.80	16
	A_{bar}	-2357	872	-3035	1496	28.8	0.71	21	-2320	793	-2834	993	22.1	0.63	22
	FP	1307	353	1422	493	8.8	0.80	14	1270	424	1312	448	3.3	0.81	16
	A_{hip}	-0.69	0.24	-0.91	0.23	31.2	0.58	21	-0.81	0.21	-0.91	0.18	12.9	0.64	14
	A_{bar}	-1.28	0.91	-1.76	0.47	36.9	0.17	45	-1.55	0.28	-1.81	0.57	16.9	0.52	19
Concentric	FP	-1.05	0.21	-1.08	0.40	3.2	0.77	11	-1.02	0.23	-1.04	0.42	1.7	0.80	9
	A_{hip}	2436	345	2303	265	5.4	0.71	7	2316	291	2287	313	1.3	0.89	4
	A_{bar}	2916	686	2933	618	0.6	0.80	10	2901	573	3115	712	7.4	0.79	10
$PF(N)$	FP	2476	430	2214	581	10.6	0.71	6	2230	236	2102	585	5.7	0.90	5
	A_{hip}	4483	815	4462	859	0.5	0.73	10	4168	882	4302	1150	3.2	0.71	13
	A_{bar}	5706	1561	5400	1505	5.4	0.73	20	5980	1454	5773	1644	3.5	0.80	19
$PP(W)$	FP	5935	865	5585	1568	5.9	0.97	2	5461	749	5247	1501	3.9	0.94	3
	A_{hip}	2.31	0.28	2.36	0.29	2.0	0.75	6	2.21	0.33	2.29	0.42	3.6	0.60	11
	A_{bar}	2.92	0.52	2.85	0.51	2.6	0.29	16	3.03	0.45	2.91	0.59	3.9	0.84	9
FP	2.96	0.30	2.91	0.80	1.6	0.98	2	2.91	0.36	2.87	0.82	1.6	0.97	2	

A_{hip} = Accelerometer attached to the hip; A_{bar} = Accelerometer attached to the bar; FP = force plate; %Mdiff = inter-trial difference in mean score as a percentage; ICC = intra-class correlation coefficient; %SEM = standard error of measurement as a percentage.

Table 4.5 Inter-day device reliability of the vertical countermovement jump kinematics and kinetics

Variable	Device	Day 1		Day 2		Reliability Measures				
		Mean	SD	Mean	SD	%Mdiff	ICC	ES	ES	%SEM
Eccentric	A_{hip}	-946	283	-1027	330	8.5	0.69	0.29	Small	20
	A_{bar}	-2776	996	-2577	811	7.2	0.67	0.20	Small	19
	FP	-1366	388	-1543	510	13.0	0.81	0.46	Moderate	17
$PV (m\cdot s^{-1})$	A_{hip}	-0.80	0.21	-0.85	0.18	6.1	0.61	0.23	Small	16
	A_{bar}	-1.52	0.58	-1.65	0.40	8.0	0.35	0.21	Small	14
	FP	-1.08	0.21	-1.18	0.21	8.6	0.79	0.45	Moderate	9
Concentric	A_{hip}	2369	284	2321	290	2.0	0.80	0.17	Small	5
	A_{bar}	2978	602	3079	655	3.4	0.80	0.17	Small	13
	FP	2364	370	2338	361	1.1	0.81	0.07	Trivial	4
$PP (W)$	A_{hip}	4472	778	4232	976	5.4	0.72	0.31	Moderate	15
	A_{bar}	5512	1380	6075	1513	10.2	0.77	0.41	Moderate	23
	FP	5635	769	5631	773	0.1	0.96	0.00	Trivial	5
$PV (m\cdot s^{-1})$	A_{hip}	2.33	0.27	2.23	0.33	4.5	0.68	0.39	Moderate	11
	A_{bar}	2.89	0.42	2.97	0.48	2.8	0.57	0.19	Small	15
	FP	2.95	0.38	2.95	0.36	0.1	0.98	0.01	Trivial	3

*Trial 1 and trial 2 data on their respective days were pooled for the statistical analyses; A_{hip} = accelerometer attached to the hip; A_{bar} = accelerometer attached to the bar; FP = force plate; %Mdiff = inter-day difference in mean score as a percentage; ICC = intra-class correlation coefficient; ES = Cohen's inter-day effect size; %SEM = standard error of measurement as a percentage; PP = peak power; PV = peak velocity.

As expected, the force plate (gold standard) was found to be very stable within and across testing sessions for the concentric phase variables (%Mdiff \leq 1.1%, ICC \geq 0.81, %SEM \leq 5%, ES \leq 0.07). Whereas, the hip (%Mdiff \leq 6.1%, ICC \geq 0.68, %SEM \leq 15%, ES \leq 0.39) and bar (%Mdiff \leq 10.2%, ICC \geq 0.57, %SEM \leq 23%, ES \leq 0.41) accelerometer attachments were less consistent within and between testing sessions for the concentric phase variables. Of the three concentric phase variables measured using wireless accelerometry, PF seems to be the most reliable (%Mdiff $<$ 3.5%, ICC \geq 0.80, %SEM \leq 13% ES = trivial to small) and PP (%Mdiff $<$ 10.2%, ICC \geq 0.72, %SEM \leq 23% ES = moderate) the least. Overall however, it would seem that there would be very little difference in inter-day stability of the concentric measures using the hip and bar attachment sites.

With regards to the eccentric phase, for the most part the three measurement systems were unstable within and across testing sessions, as at least one of the reliability criteria were breached (ICC $>$ 0.69, SEM $<$ 10.1%, ES $<$ 0.31). The force plate breached the percent SEM (11 – 20%) and effect size (ES = 0.46) reliability criteria; while the hip (ICC = 0.58 – 0.80, %SEM = 14 – 24%) and bar (ICC = 0.17 – 0.80, %SEM = 14 – 45%) accelerometers breached the ICC and percent SEM criteria. When summarising all the stability measures, it would seem once more that there is very little difference between the two sets of accelerometer data when assessing eccentric performance.

4.4 Discussion

The aim of this study was to quantify the differences in and assess the stability of the eccentric and concentric kinematics and kinetics as measured using two accelerometer systems (hip accelerometer and bar accelerometer) during a vertical jump whilst simultaneously jumping on a force plate (centre of mass). It must be noted, that each device measured changes in acceleration at different locations and of different movement

paths, therefore it can be expected that the variables measured by each device to differ. That is, the force plate detects changes in ground reaction force, which are directly related to the changes in acceleration of the centre-of-mass; while the wireless accelerometers detect changes in acceleration at their point of attachment (i.e. bar and hip). These are intrinsic limitations of the respective measurement systems and comparisons between the three movement paths/locations within this study were conducted to determine the magnitude of differences in mean values; as well as the linear relationships (correlations) between kinematics and kinetics as measured by the three systems.

In terms of validity the main findings were: i) no devices were similar when measuring the eccentric phase variables; ii) the centre of mass (force plate) and bar accelerometer were similar when measuring concentric PP and concentric PV, while the hip accelerometer under predicted these two measures; and, iii) the force plate and hip accelerometer were similar when measuring PF, whereas the bar accelerometer over predicted this measure. With regards to reliability, the main findings from the analysis were that; i) the force plate was moderate to highly reliable when measuring the concentric (phase) variables, but poor when measuring the eccentric (phase) variables; and, ii) similarly, both accelerometer placements (bar and hip) were moderate to highly reliable when measuring the concentric variables, yet poor when measuring the eccentric variables.

When measuring the eccentric variables all systems (devices) were found to be unreliable and differed significantly from each other. This can be attributed to the large amount of within trial and between testing session eccentric movement variability of the subjects (biological error). Since the concentric variables were much more stable, subsequent discussion will focus solely on these variables.

Force plate technology is thought to be the “gold standard” in force measurement and the reference to which other devices are compared and validated against. As expected,

the concentric variables assessed using the force plate were stable between testing occasions ($\%M_{diff} \leq 1.1\%$, $ICC \geq 0.81$, $\%SEM \leq 5\%$ and trivial inter-day differences). These results were similar to previous kinematic and kinetic research on the reliability of squat and CMJ measures [17, 19, 36, 128, 208].

When comparing concentric PP and PV between devices, the force plate (centre of mass) and bar accelerometer were similar ($MDiff = 2\%$); whereas, the hip accelerometer greatly under predicted ($MDiff = 21-24\%$) these two measures in comparison to the force plate and bar accelerometer. Based on these findings, the bar accelerometer placement could possibly be used as a substitute to the force plate when measuring these two variables. However, due to the low reliability ($ICC = 0.58 - 0.77$; $ES =$ small to moderate; $\%SEM = 15-23\%$) of the bar accelerometer, caution is advised when utilising this set-up to monitor changes in concentric peak power and peak velocity. Even though the hip accelerometer was found to be invalid, this placement was moderately reliable ($ICC = 0.68 - 0.72$; $ES =$ Moderate; $\%SEM = 11 - 15\%$) when measuring concentric PP and PV. This finding reiterates the difference in movement paths followed by these two systems (centre-of-mass vs. hip) during the CMJ.

Previous research utilising the bar accelerometer placement has also found this set-up to slightly over-predict concentric velocity and power (5 to 8%) in comparison to the force plate [16, 187, 251]. These studies produced moderate to high correlations ($r = 0.66$ to 0.97) between devices, which is contradictory to our low/moderate correlations ($r = 0.33$ to 0.59). Previous studies also found the hip accelerometer to under-predict the concentric phase variables, which is in agreement with our findings [174, 196, 252]. However, Houel et al. (2010) and Roig et al. (2008) reported high correlations between devices (hip accelerometer and force plate; $r = 0.81$ and 0.91) possibly due to the similar movement paths followed by the hip and centre of mass during vertical jumping. These findings differ to our low/moderate correlations ($r = 0.05$ and 0.34); correlational discrepancies

may be attributed to a number of technological and biological factors. Correlations can be affected by small changes in performance especially if the sample is homogeneous. Also correlational analyses using one subject jumping multiple times (Roig et al., 2008) are likely to artificially inflate the r value as compared to a multiple subject design, such as ours. Furthermore, a host of other variables will likely affect the magnitude of the correlation, such as the use of a controlled laboratory based environment, the sample size (e.g. Houel et al. 2010, $n = 9$), the type of subjects, the method/location of accelerometer attachment, the model of accelerometer/force plate, the sampling frequency and the integration methods utilised.

As expected PF was the most stable measure ($ICC \geq 0.80$; %MDiff = 1.1 – 3.4%; %SEM = 4 - 13%) for all devices, these findings were similar to those reported by other researchers ^[187, 196]. The force plate and hip accelerometer were similar (Mdiff = 2%) when measuring PF, while the bar accelerometer greatly over predicted PF (Mdiff = 24%). These results indicate that the hip accelerometer could possibly be used as a substitute to the force plate for assessing PF. Previous research utilising the bar accelerometer attachment, found this set-up to significantly over-predict concentric force in comparison to the force plate ^[16, 187, 251]. These studies also revealed moderate to high correlations ($r = 0.66$ to 0.97) between devices, which is aligned with our moderate correlations ($r = 0.59$ to 0.62). There is minimal research investigating the validity and reliability of PF outputs using the hip accelerometer placement, therefore no comparisons were made with previous research.

4.5 Practical Applications

The findings from this study and previous research lead us to conclude that the device (i.e. force plate, accelerometer and linear position transducer), attachment site (i.e. barbell, hip, sacrum and centre-of-mass), contraction type (eccentric vs concentric) and set-up utilised (loaded vs unloaded and fixed bar vs. free bar vs. no bar) for CMJ assessment

and monitoring must be carefully selected [16, 18, 191, 196, 204, 252]. The differences between concentric phase measures from the force plate (centre of mass), hip accelerometer and bar accelerometer can be attributed to the movement path of (acceleration-time data collected at) each system (i.e. attachment site/centre-of-mass).

The two accelerometer set-ups should not be used interchangeably due to the large differences in the outcome measures of interest. The only accelerometer variable we found partially valid and stable was PF measured at the hip. Given this information the reader needs to be cognisant of the limitations of assessment using accelerometry and especially wary when comparing data between laboratories and/or studies.

***QUANTIFYING MECHANICAL VARIABILITY ACROSS UPPER
AND LOWER BODY BALLISTIC MOVEMENTS***

**Daniel Travis McMaster, Nicholas Gill, John Cronin and Michael
McGuigan**

**Journal of Sports Science and Medicine
In Review (Appendix 4d)**

5.0 Prelude

The accuracy of the measurement system utilised in ballistic assessments has been discussed (Chapter 4), similarly, before a ballistic profiling protocol is used as an assessment tool it must also prove to be valid and reliable. This chapter employed linear position transducer technology over force plate technology and wireless accelerometry due to the high validity and practicality of the device for the purpose of assessing and monitoring the changes in ballistic performance. Force, velocity and power profiling of BTH and VJ is used to provide the scientist and strength coach with detailed information regarding the ballistic qualities of the athlete. This chapter addresses the reliability of force, velocity and power as discussed previously (Chapters 4). The purpose of this study was to measure the mechanical reliability associated with the VJ and BTH across a spectrum of relative loads (0 – 75% 1RM) with the intention of utilising these respective protocols to assess and monitor acute and longitudinal performance changes in semi-professional rugby union players.

5.1 Introduction

Kinematic and kinetic profiling of ballistic lower and upper body movements is used to provide the scientist and coach with detailed information regarding the mechanical outputs produced by the athlete. Vertical jumps and bench throws are commonly used to assess and develop lower and upper body force, velocity and power [41, 128, 244, 308, 381, 429]. Ballistic movements allow the athlete to accelerate the bar throughout the entire range of motion; producing greater velocity and power outputs than traditional non-ballistic movements [41, 244]. Increasing the force, velocity and power capabilities of the lower and upper body may in turn improve performance in combat and contact sports and athletic events, such as mixed martial arts, rugby, shot put, hammer throw and high jump.

Ballistic kinematic and kinetic profiles have been created using incremental loading (i.e. absolute and relative-one repetition maximum [1RM] loads); which allows for the creation of load-power, load-velocity and load-force curves [27-29, 31, 117, 244, 255]. Based on individual load-curves, force, velocity and power loads can then be prescribed to shift various portions of these respective curves and possibly elicit specific neuromuscular adaptations [296, 308, 379]. Previous studies have developed protocols to assess stretch-shorten cycle (SSC) and concentric only performance of the lower and upper body within a single session; but there is minimal research devoted to assessing and comparing the kinematics and kinetics of these two contraction types across testing sessions, which is pertinent if the protocol is to be used for ballistic monitoring and performance tracking [27, 28, 31, 32, 36, 39, 166, 190, 208, 244, 296, 430-433]. Many of these studies have reported the reliability and usefulness of maximal power in their assessments, while failing to report/include other equally important variables across the loading spectrum [27-29, 31, 32, 39, 166]. Therefore, the purpose of this study was to assess the mechanical (i.e. force, velocity and power) variability of countermovement and concentric-only upper and lower body ballistic assessment protocols in highly trained rugby union players.

5.2 Methods

5.2.1 Subjects

Twenty semi-professional male rugby union players (age = 21.2 ± 3.0 years; mass = 94.9 ± 9.7 kg; 1RM squat = 158.9 ± 22.8 kg; 1RM bench press = 121.5 ± 21.8 kg) were recruited for this study, which was approved by the university's ethics committee. Written informed consent was obtained prior to study participation.

5.2.2 Procedures

The participants partook in the following nine testing sessions: a 1RM testing session, four vertical jump sessions, and four bench throw sessions. Session one was dedicated to determining the 1RM for the parallel back squat and bench press, which was validated for this group of elite rugby union players using the following protocol based on estimated 1RM: 8 repetitions at ~50% of 1RM (2 min rest), 3-4 repetitions at ~ 70% 1RM (3 min rest), 1-2 repetitions at ~ 80% 1RM (3-5 min rest), 1 repetition at ~ 90% 1RM (3-5 min rest), 1 repetition at 95-100% 1RM (3-5 min rest), 1 repetition at 100-105% 1RM ^[162]. Vertical jump performance was then assessed across six relative loads (0, 15, 30, 45, 60 and 75% 1RM) during two countermovement jump sessions (CMJ) and two static squat jump sessions (SJ). Bench throw performance was also assessed across five relative 1RM loads (15, 30, 45, 60 and 75% 1RM) during two countermovement bench throw (CMBT) and two concentric only bench throw (COBT) sessions.

The vertical jump and bench throw testing sessions were performed in a power cage (Fitness Technology: FT700 power cage, Adelaide, South Australia) utilising a free-weight barbell (a light weight wooden dowel was used for the body mass/0% 1RM load). A single linear position transducer (Celesco PT5A-150, Chatsworth, CA) was securely fixed to the top of the power cage, the displacement cord was then attached to the bar

directly above the subjects left acromioclavicular joint during the vertical jump testing (Figure 5.1), and directly above the pectoralis major during the bench throw testing (Figure 5.2). The position transducer was connected to a computer interface (Fitness Technology: Ballistic Measurement Systems, Adelaide, South Australia) and sampled at a frequency of 400 Hz. A braking system and a spotter positioned directly behind the subject were also used as safety precautions to decelerate the load once the bar was projected into the air. Prior to testing, the athletes underwent a five week complex strength and power training programme to improve their neuromuscular capabilities and musculoskeletal qualities, which in turn familiarized the athletes with the various loads and movement patterns used during testing.



Figure 5.1 Countermovement and static jump testing apparatus



Figure 5.2 Countermovement and concentric-only bench throw testing apparatus

The four vertical jump sessions assessed the inter-session reliability of countermovement jump (CMJ) and static squat jump (SJ) protocols (using relative loads of 0, 15, 30, 45, 60 and 75% of the athlete's 1RM parallel back squat); two sessions were dedicated to assessing each movement pattern. The CMJ utilised the SSC, where the subjects performed an initial eccentric contraction to a self-selected depth (~ 120 degree knee angle), immediately followed by an explosive concentric (upward movement) contraction and subsequent flight phase. The SJ was a concentric only contraction, where the athlete initially squatted down to a self-selected depth (~120 degrees), followed by a three second pause, which was immediately followed by an explosively concentric contraction and subsequent flight phase. SJ trials containing a countermovement prior to the concentric phase were deemed ineligible and re-tested.

The four bench throw sessions assessed the inter-session reliability of the CMBT and COBT protocols (using relative loads of 15, 30, 45, 60 and 75% of the athlete's 1RM bench press); two sessions were dedicated to assess each movement pattern. The CMBT utilised the SSC, where the subjects performed an initial eccentric (downward movement of the bar) contraction until the bar lightly touched the subject's chest, immediately followed by an explosive concentric (upward movement of the bar) contraction and subsequent flight phase. The COBT was a concentric only contraction, where the bar was initially lowered to the subject's chest with the aid of a spotter, followed by a three second

pause, which was immediately followed by an explosive concentric contraction and subsequent flight phase. COBT trials containing a countermovement prior to the concentric phase were deemed ineligible and re-tested.

Two repetitions were performed at each relative load across all vertical jump and bench throw testing sessions; three min rest was given between sets. Vertical jump (CMJ and SJ) and bench throw (CMBT and COBT) loading progressed from low (body weight for the vertical jumps and 15% 1RM for the bench throws) to high intensity (75% 1RM) for all testing sessions; and session order was randomised to minimize the learning effects. 72 hours rest was allocated between testing sessions.

5.2.3 Data Analysis

The use of position transducers in ballistic upper and lower body assessments have been previously validated with a high level of precision ($<1.2\%$; $ICC > 0.99$) for the measured (i.e. displacement) and the derived variables (i.e. velocity, force and power) ^[17, 434]. The displacement-time data were filtered using a second order Butterworth filter (low pass) with a cut off frequency of 5 Hz. The displacement data was then single and double differentiated to determine the velocity and acceleration, respectively. Force was calculated as the sum of the system weight ($[\text{body mass} + \text{external load}] \times \text{gravity}$) and the system mass multiplied by the acceleration of the athlete-load during jump testing ^[36]. Body mass was removed from the formula when calculating force from the bench throw data. Power was calculated as the product of force and velocity. The concentric and eccentric phases were determined based on velocity and force thresholds. The eccentric phase was initiated when velocity dropped below -0.01 m/s and terminated when velocity returned back to zero (i.e. at the bottom of the movement); the subsequent concentric phase was initiated when velocity increased above 0.01 m/s and terminated force was less than 5% of the system weight. The kinematic and kinetic variables of interest included:

Eccentric mean and peak force in N

Eccentric peak velocity in m/s

Eccentric mean power in W

Concentric mean and peak force in N

Concentric peak velocity in m/s

Concentric mean and peak power in W

5.2.4 Statistical Analysis

The interday reliability of the vertical jump and bench throw sessions were determined using intraclass correlation coefficients (ICC), coefficients of variation (CV%), standard error of measurement (SEM) in SI units, and Cohen's effect size (ES). ICC and CV assess the variability between two sets of data, be it intertrial or interday comparisons. ICC examines the reproducibility of the subject rank order for a specific dependent variable between trials/sessions; while CV calculates the typical error (i.e. measure of within each subject variation) between the means of two or more trials for a given variable expressed as a percentage ^[435]. ES detects the magnitude of differences of the means between two trials ^[436].

ICC and CV reliability classifications were as follows: high (ICC = 0.70 – 1.00; CV < 10.0%), moderate (ICC = 0.50 – 0.70; CV 10 – 20 %) and low (ICC < 0.50; CV > 20%) ^[427, 437]. Effect sizes were interpreted as follows: < 0.1 as trivial, 0.1-0.3 as small, 0.3-0.6 as moderate, and > 0.6 as large ^[438]. Overall reliability was interpreted as good when the following criteria was met (i.e. high ICC, low CV and low ES), moderate when only two criteria were met, or categorized as poor when only one criteria was met: ICC > 0.70; CV < 10%; ES < 0.3 ^[427, 439].

5.3 Results

The 1RM parallel back squat and bench press testing protocols had high inter-day reliability (ICC = 1.00; CV < 1.3%; SEM < 1.5 kg). The vertical jump (Tables 5.1 and 5.2) and bench throw (Tables 5.3 and 5.4) kinematic and kinetic variables across the relative loads and four movement patterns (CMJ, SJ, CMB and COB) produced highly reliable inter-day outcomes (ICC = 0.80 – 1.00; CV = 0.3 – 10.5%; ES = 0.001 – 0.72) during the concentric phase; whereas the eccentric variables across the same loads and movements were more variable and slightly less reliable (ICC = 0.50 – 1.00; CV = 0.3 – 17.1%; ES = 0.01 – 0.73). Based on the inter-day SEM calculations, the lower and upper body ballistic protocols could be used to monitor and/or assess concentric force, velocity and power if the observed changes are greater than 98 N, 0.13 m/s and 224 W, respectively. The SEM for the eccentric phase were slightly less than the concentric counterpart for force (66 N) and power (102 W) and similar for velocity (0.12 m/s).

5.3.1 Lower Body Kinematics and Kinetics

Vertical jump mean and peak force (ICC > 0.86; CV < 0.6%; ES < 0.33), peak velocity (ICC > 0.86 CV < 5.0%; ES < 0.36), mean and peak power (ICC > 0.72; CV < 6.5%; ES < 0.36) and total impulse (ICC > 0.88; CV < 9.2%; ES < 0.25) were highly reliable across all loads and movement patterns (CMJ and SJ) during the concentric phase; with the exception of body mass (0% 1RM) CMJ mean power (CV = 7.3%; ES = 0.62) and 30% 1RM SJ mean power (CV = 7.4%; ES = 0.47). Force (mean and peak) and peak velocity during the eccentric phase of the CMJ were moderate to highly reliable across the load spectrum (ICC > 0.84; CV < 11.6%; ES < 0.46). The reliability of eccentric mean power was poor at 15, 30 and 45% 1RM (ICC = 0.50 – 0.70; CV = 8.0 – 11.4; SEM = 68 – 102 W; ES = 0.26 – 0.61), moderate at body mass (ICC = 0.70; CV = 7.7%; SEM = 63 W; ES

= 0.73) and high at 60 and 75% 1RM (ICC > 0.72; CV < 8.3%; SEM = 67 – 75 W; ES < 0.13).

Table 5.1 Variability of countermovement jump kinematics and kinetics*

Dependent variables	SEM	ICC	CV%	ES	Overall reliability
<i>Eccentric</i>					
Peak velocity (m/s)	0.07-0.12	0.89-0.95	5.6-14.6	0.12-0.27	Moderate-Good
Peak force (N)	37-66	0.84-0.99	1.3-3.2	0.01-0.46	Moderate-Good
Mean force (N)	9-14	0.97-1.00	0.6-1.4	0.00-0.21	Good
Mean power (W)	63-102	0.50-0.76	7.7-11.4	0.12-0.73	Poor-Moderate
<i>Concentric</i>					
Peak velocity (m/s)	0.05-0.13	0.86-0.96	3.5-5.0	0.03-0.36	Moderate-Good
Peak force (N)	41-98	0.93-0.98	1.8-3.6	0.03-0.19	Good
Peak power (W)	143-224	0.92-0.97	3.7-5.5	0.05-0.24	Good
Mean force (N)	25-38	0.94-0.98	1.3-1.7	0.01-0.33	Moderate-Good
Mean power (W)	98-179	0.79-0.96	4.7-7.3	0.05-0.62	Moderate

*The subjects jumped with the following six relative 1RM loads: body mass/0% - 15% - 30% - 45% - 60% - 75% 1RM. *Overall reliability was assessed based on ICC > 0.70, CV < 10% and ES < 0.30 across the entire loading spectrum for a given variable; **SEM** = standard error of measurement in SI units; **ICC** = intra-class correlation coefficient; **CV%** = coefficient of variation as a percentage; **ES** = Cohen's effect size.

Table 5.2 Variability of static squat jump kinematics and kinetics*

Dependent variables	SEM	ICC	CV%	ES	Overall reliability
Peak velocity (m/s)	0.05-0.10	0.88-0.94	2.4-4.0	0.003-0.18	Good
Peak force (N)	40-66	0.97-0.99	1.6-2.4	0.002-0.06	Good
Peak power (W)	109-206	0.90-0.98	3.0-6.5	0.01-0.14	Good
Mean force (N)	19-42	0.95-0.99	0.8-1.8	0.03-0.22	Good
Mean power (W)	65-174	0.80-0.98	4.1-10.5	0.01-0.47	Moderate

*The subjects jumped with the following six relative 1RM loads: body mass/0% - 15% - 30% - 45% - 60% - 75% 1RM. *Overall reliability was assessed based on ICC > 0.70, CV < 10% and ES < 0.30 across entire loading spectrum for a given variable. **ICC** = intra-class correlation coefficient; **SEM** = standard error of measurement in SI units; **CV%** = coefficient of variation as a percentage; **ES** = Cohen's effect size.

5.3.2 Upper Body Kinematics and Kinetics

Bench throw mean and peak force (ICC > 0.91; CV < 3.4%; SEM = 2 – 40 N; ES < 0.13), peak velocity (ICC > 0.81; CV < 11.0%; SEM = 0.04 – 0.07 m/s ; ES < 0.33) and mean and peak power (ICC > 0.90; CV < 7.9%; SEM = 15 – 45 W; ES < 0.42) were highly reliable across all loads and movement patterns (CMB and COB) during the concentric phase, with the exception of COB mean power (ICC = 0.86; CV = 8.6%; SEM = 35 W; ES = 0.72) using the 75% 1RM load. The eccentric variables during the CMB were also highly reliable, with the exception of peak velocity at 45% 1RM (ICC = 0.73; CV =

13.0%; SEM = 0.13 m/s; ES = 0.10) and mean power at 30% 1RM (ICC = 0.85; CV = 12.4%; SEM = 28 W; 6.3%; ES = 0.01).

Table 5.3 Variability of countermovement bench throw kinematics and kinetics*

Dependent variables	SEM	ICC	CV%	ES	Overall reliability
<i>Eccentric</i>					
Peak velocity (m/s)	0.06-0.11	0.86-0.96	6.7-13.0	0.04-0.28	Moderate-Good
Peak force (N)	10-35	0.97-0.99	2.3-3.6	0.01-0.13	Good
Mean force (N)	2-4	1.00	0.3-1.1	0.001-0.02	Good
Mean power (W)	15-36	0.89-0.94	8.5-12.4	0.01-0.35	Moderate
<i>Concentric</i>					
Peak velocity (m/s)	0.04-0.07	0.97-0.99	2.8-6.0	0.03-0.26	Good
Peak force (N)	2-34	0.98-0.99	2.3-3.4	0.002-0.11	Good
Peak power (W)	23-45	0.92-0.98	4.0-6.7	0.02-0.24	Good
Mean force (N)	6-40	0.99-1.00	0.9-2.5	0.04-0.10	Good
Mean power (W)	20-37	0.90-0.98	4.0-7.9	0.06-0.25	Good

* **15% - 30% - 45% - 60% - 75% 1RM loads** = the percentage bench throw loads utilised in respect to the subjects one-repetition maximum bench press. Overall reliability was assessed based on ICC > 0.70, CV < 10% and ES < 0.30 across entire loading spectrum for a given variable; **SEM** = standard error of measurement in SI units; **ICC** = intra-class correlation coefficient; **CV%** = coefficient of variation as a percentage; **ES** = Cohen's effect size.

Table 5.4 Variability of concentric only bench throw kinematics and kinetics*

Dependent variables	SEM	ICC	CV%	ES	Overall reliability
Peak velocity (m/s)	0.05-0.06	0.95-0.99	2.6-7.4	0.05-0.33	Moderate-Good
Peak force (N)	5-14	0.99-1.00	1.1-1.6	0.003-0.06	Good
Peak power (W)	22-35	0.95-0.98	3.8-6.7	0.04-0.38	Moderate-Good
Mean force (N)	4-13	0.99-1.00	0.6-2.1	0.02-0.06	Good
Mean power (W)	15-28	0.90-0.98	3.8-8.6	0.01-0.72	Moderate

* **15% - 30% - 45% - 60% - 75% 1RM loads** = the percentage bench throw loads utilised in respect to the subjects one-repetition maximum bench press. Overall reliability was assessed based on ICC > 0.70, CV < 10% and ES < 0.30 across entire loading spectrum for a given variable. **SEM** = standard error of measurement in SI units; **ICC** = intra-class correlation coefficient; **CV%** = coefficient of variation as a percentage; **ES** = Cohen's effect size.

5.4 Discussion

The current protocols quantified the ballistic performance capabilities of the lower and upper body through countermovement (SSC) and concentric only jumping and throwing across a spectrum of relative 1RM loads. Based on current results it would seem that the

SJ, CMJ, COBT and CMBT profiling protocols herein are relatively stable across testing sessions and will be subsequently discussed.

The vertical jump and bench throw testing protocols ability to detect changes in force, velocity and power across the loading spectrum in highly trained rugby union players are based on the inter-day standard error of measures. Vertical jump (SJ and CMJ) mean and peak power versus load profiles were considered capable of detecting changes of greater than 179 W and 224 W in highly trained rugby union players. Mean and peak force versus load profiles were found capable of detecting vertical jump changes of greater than 42 and 98 N, respectively; lastly vertical jump peak velocity was deemed valid to detect changes of greater than 0.07 m/s across the loading spectrum. The bench throw (COBT and CMBT) mean and peak power versus load profiles must to be greater than 37 W and 45 W, respectively to detect any meaningful changes. Mean and peak force versus load profiles were found capable of detecting bench throw changes of greater than 40 and 34 N. deemed valid to detect changes of greater than 0.07 m/s across the loading spectrum. The bench throw assessment protocols herein were deemed valid to detect peak velocity changes of greater than 0.07 m/s. Previous testing protocols have assessed vertical jump and bench throw performance using single and incremental loading schemes [27-29, 31, 32, 36, 117, 166, 190, 244, 301].

5.4.1 Lower Body Ballistic Profiling

The reliability of the kinematics and kinetics produced across the loading spectrum during past vertical jump investigations have been inadequately reported throughout the literature. Many studies have developed vertical jump profiles for the purpose of assessing ballistic performance without reporting the mechanical reliability and validity across the loading spectrum [27, 28, 166]. Alemany et al. [190] provided sufficient detail on the inter-session reliability of velocity, power and work produced during a 30% 1RM CMJ (ICC = 0.84 – 0.97; CV = 3.2 – 4.4%), which was similar to current reliability findings

utilising the same relative load (Table 5.1). However, they failed to assess the reliability of these variables across a spectrum of loads. A number of other studies reported the reliability of the maximal power load, but did not mention the reliability of any other variables or loads [27, 31, 36, 166]. Two studies assessed maximal power capabilities of the SJ across ten relative loads (10 - 100% 1RM) that could provide a robust ballistic profile if reported in its entirety [36, 166]. Harris et al. [36] reported moderately reliable inter-session outcomes (ICC = 0.61 and 0.45; CV = 5.7 and 7.4%) for maximal peak and mean power. Stone et al. [166] also reported highly reliable inter-trial outcomes (ICC = 0.88 and 0.92) for CMJ and SJ peak power, but failed to assess inter-session reliability. Bevan et al. [31] assessed maximal power capabilities across six relative loads (0 - 60% 1RM); reporting high inter-trial reliability for peak power (ICC > 0.95). Cormie et al. [430] also reported high inter-session reliability (ICC > 0.89) for all kinetic and kinetic variables across five relative loads (0 - 80 %1RM) during the CMJ; but failed to report specific ICC and CV for each variable/load. The above reliability findings were similar to the current CMJ and SJ outcomes reported using similar relative loads (Table 1 and 2).

A number of studies have provided adequate detail on the reliability of force, velocity and power using a body mass load (0% 1RM). Argus et al. [27] reported high inter-session reliability outcomes for peak power at body mass (ICC = 0.83; CV = 4.2%) during CMJ; which were comparable to our CMJ peak power reliability outcomes (Table 5.1). Cormie et al. [128] also reported high inter-session reliability (ICC > 0.78) for peak power during the body mass (0 % 1RM) CMJ. Samozino et al. [37] reported comparably high inter-trial reliability (CV = 2.5 – 7.2 %) for concentric mean force, mean velocity and mean power during the body mass CMJ. Cormack and colleagues [208, 439] provided a comprehensive reliability assessment of the body mass CMJ, reporting highly reliable inter-day mean force (CV = 1.1%) and mean power (CV = 5.7%), similar to our findings

(Table 1). CMJ and SJ profiling protocols have been largely documented and well researched, in contrast to the less investigated bench throw profiling protocols.

5.4.2 Upper Body Ballistic Profiling

The bench throw testing protocols herein consisted of ten CMBT or COBT per session. Similarly, Newton et al. ^[280] assessed the reliability of CMBT and COBT using six relative loads between 15 and 90 % 1RM. The reliability of the testing protocol was not assessed or not reported and the CMBT and COBT assessment protocols were conducted in a single session. The subject's performed three CMBT and three COBT trials at each load in randomised order, three minutes rest was given between trials; this lengthy [100+ min (warm-up and 36 trials x three min rest)] single session testing protocol may cause undue neuromuscular fatigue prior to the completion of the required 36 bench throw trials. The above study differs from the present study in that each movement pattern was assessed multiple times on separate occasions reducing the effects of neuromuscular fatigue and establishing inter-trial and inter-session reliability of the protocol. A number of papers by Cronin and colleagues ^[33, 112, 308] were also published on CMBT and COBT across a spectrum of relative loads (30-80% 1RM) on club level rugby players. These papers reported high inter-day reliability (ICC = 0.85 – 0.99) for mean and peak force, velocity and power across the loading spectrum, yet no load or movement specific reliability measures were reported. Evidently, past literature has insufficiently reported the reliability of CMBT and COBT assessment protocols. To reiterate, the kinematic and kinetic variables with greater ability to detect small performance changes should be utilised for ballistic monitoring and possibly assessments.

5.4.3 Eccentric Ballistic Variables

The eccentric phase variables herein (ICC > 0.81 CV < 17.1%; ES < 0.35) were slightly less consistent than the concentric phase variables (ICC > 0.92; CV < 7.9%; ES < 0.26) during CMJ and CMBT, as would be expected based on the variability of eccentric and concentric contractions during stretch-shortening-cycle movements. A potential factor influencing the variability between contraction phases may be due to the initial eccentric acceleration and final deceleration at the bottom of the eccentric phase, in comparison to the concentric phase where the aim is to accelerate the load through the entire phase. Past research was also in agreement with this phenomenon, as they found that kinematic and kinetic outputs during eccentric contractions were more variable than its concentric counterpart ^[440-443]. Variability around peak eccentric displacement and the rate of eccentric displacement, and where the braking phase begins could have large effects on the reliability of the variables of interest.

5.5 Conclusion

The addition of ES to the typical reliability analysis (i.e. ICC and CV) provided a more complete evaluation of the overall reliability of current ballistic protocols. The overall interday reliability (i.e. a high ICC [>0.70], a low CV [$<10\%$] and a small ES [<0.30]) of the vertical jump (CMJ and SJ) and bench throw (CMB and COB) kinematic and kinetic variables assessed across the loading spectrum was acceptable with the exception of eccentric CMJ mean power. Overall, mean and peak force were the most reliable variables (good), followed by peak power (moderate to good), peak velocity (moderate to good) and mean power (poor to moderate). Also of note, during the lower and upper countermovement patterns, the concentric variables were less variable than their eccentric counterparts. Current vertical jump and bench throw profiling protocols can be used to monitor concentric performance changes greater the following parenthesised mean force

(40 and 42 N), peak force (34 and 98 N), mean power (37 and 179 W), peak power (45 and 224 W) and peak velocity (0.07 m/s) values.

5.6 Practical Applications

When monitoring acute changes in performance the most sensitive load and variable should be utilised. Due to the insensitivity of certain variables, discretion is advised if using variables with high CV and high SEM to monitor performance changes over time. Ballistic profiling should not be limited to only the current variables, protocols and movement patterns. It is also recommended the reliability of the testing protocol be established for each group of athletes being assessed or monitored. The use of relative versus absolute incremental loading during profiling should also be considered for logistical purposes when working with individual or team sports. A detailed kinematic and kinetic analysis in conjunction with a ballistic incremental load testing protocol may provide the scientist and practitioner with a more robust athlete profile that could be used to monitor fatigue and performance changes in reliable variables. The scientist and practitioner must also be aware of the different devices, movement patterns, loading parameters and kinematic and kinetic variables available when designing a ballistic profiling protocol, as it must effectively evaluate the demands of their respective sport.

***IMPORTANCE OF STRENGTH TO BALLISTIC UPPER BODY
PERFORMANCE***

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6.0 Prelude

There is a necessary evolution of ballistic assessment methods in elite contact sports, as is required to continually improve the physical qualities of these respective athletes to match the growing sport and position specific performance demands. The majority of upper body profiling to date has evaluated maximum strength and BTH power capabilities. Chapter 6, focused on applying novel analytical approaches to previously collected BTH data (Chapter 5) examining the underlying effects of maximum strength on the BTH capabilities of semi-professional rugby union players with the overall aim of providing a greater mechanical understanding of these ballistic movements. Maximum predicted power (P_{max}) has received much attention, but only provides a partial representation of the athlete's true ballistic capabilities. Examining the maximum predicted force (F_{max}) and velocity (V_{max}) capabilities along with P_{max} may provide a more holistic representation and improved prognostic value for athlete profiling. P_{max} , F_{max} and V_{max} may also be used to highlight proficient and deficient areas in ballistic upper body performance; the individual rankings could be further utilised to identify and possibly remedy individual deficiencies.

6.1 Introduction

Strength and conditioners and sports scientists are constantly adapting and evolving current training and assessment methods with the aim of improving the physical qualities of their respective athletes. In contact sports, such as rugby union and American football, maximum upper body strength and power are vital to performing specific tasks and preventing injuries. The majority of resistance training programmes used by these athletes place a large emphasis on hypertrophy, strength and power development, as a strong-powerful upper body and a stable shoulder girdle are vital to maximising force production and impact absorption (i.e. injury prevention); while velocity and power production during the following actions are also crucial to excelling in contact team sports: pushing, pulling, tackling, fending and throwing. Developing more effective methods to assess and analyse upper body strength and ballistic capabilities may in turn better inform and possibly improve current means of programming.

At the elite level, numerous resisted pressing and throwing movement patterns are utilised to develop strength (isometric and dynamic), stability and ballistic capabilities. Subsequently these movements are thought to improve sports specific movement patterns and performance in competition [29, 41, 82, 117, 244, 296, 302, 308, 383]. One of the most common upper body movements for these purposes is the bench press and its' derivatives, which have been used to develop, as well as assess upper body strength and ballistic power in rugby union and American football players [29, 32, 54, 78, 112, 151, 244, 296]. The bench press is commonly used in upper body strength and power profiling to describe and differentiate the physical qualities within and between rugby union and American football squads. The limitations of these studies are not in the assessment protocols utilised, but in the lack of analytical detail and subsequent incomplete upper body profiles.

Practitioners currently utilise isometric and dynamic lab based assessments along with practical weight room assessments, such as 1RM testing to create upper body

strength profiles and monitor changes over-time in highly trained rugby-football code athletes [1, 78, 162, 296, 356]. Upper body power profiles are also created using incremental load (absolute and relative) testing to assess and monitor neuromuscular adaptations (increases and decreases) due to training and the physical demands of competition [29, 54, 117, 162, 308, 444]. Countermovement (CMB) and concentric only bench (COB) throws are also used to assess the stretch shortening cycle (SSC) and concentric only capabilities of the upper body, respectively. These two movements provide similar ballistic information, yet they are governed by slightly different mechanisms; therefore a comparison of these movements may help determine an athlete's level of SSC augmentation (i.e. ratio between countermovement and concentric-only performance) [112, 259]. Positional differences may exist between rugby union forwards (e.g. scrummaging) and backs (e.g. fending and passing) due to the physical demands of each position. The forwards may have a higher COB to CMB contribution (contractile element dominant) and the backs may have a higher CMB to COB contribution (i.e. elastic element dominant). Including both movement patterns in a ballistic profile may provide additional information, but it could also prove to be inefficient and time consuming if these movements are providing similar diagnostic information.

There are often large individual differences in upper body strength and power levels within a squad of rugby union (i.e. forwards vs. backs) and American football players (i.e. linemen vs. wide receivers), due to the wide range of physical demands and anthropometric characteristics between the various positions [1, 11, 32, 54, 277, 445]. Rugby union tight-five forwards (1RM bench press = ~ 150 kg; bench throw peak power = ~ 1250 W) and American football linemen (1RM bench press = ~ 160 kg; 1RM power clean = ~ 130 kg) generally possess larger levels of upper body strength and power than the outside backs (1RM bench press = ~ 135 kg; bench throw peak power = ~ 1150 W) and wide receivers (1RM bench press = ~ 125 kg; 1RM power clean = ~ 110 kg), respectively

[32, 78, 151, 152, 446]. It is purported that strength plays an important role in increasing power capabilities regardless of somatotype; as stronger athletes often have more developed morphological qualities and potentially greater neuromuscular capacity [32, 52, 54, 206, 296, 297, 302, 430]. This type of profiling provides valuable normative data and can be used to set national standards, identify starters and non-starters and used for talent identification and development purposes. However, in terms of its diagnostic value and the utility in guiding the individualisation of programming, such information is rather limited.

The majority of profiling thus far has determined maximum strength, Pmax and the power-load relationship. Whilst such information provides some diagnostic information, since power is the product of the optimum combination of force and velocity and not their respective maximums, power profiling only provides a partial representation of the athlete's true ballistic capabilities [37, 166]. The addition of Fmax and Vmax should provide a more holistic understanding of the mechanical properties that govern ballistic performance [37]. Fmax (velocity = 0 m/s) and Vmax (force = 0 N) incorporate the entire force-velocity spectrum, as they are hypothetical maximums produced at extreme ends of the force-velocity curve and could provide valuable prognostic information for athlete profiling and programming. Therefore, the purpose of this study was to examine the differences in ballistic upper body performance between strong and weak players. A secondary focus is to determine whether such analysis provides additional information to individualize programming.

6.2 Methods

6.2.1 Experimental Approach to the Problem

Prior to collecting any data for this study, all players underwent a five week complex strength and power training programme to improve their neuromuscular capabilities and musculoskeletal qualities, which in turn better prepared the players for the various loads

and movement patterns used during testing. Following the five week training block, the athletes were required to attend five testing sessions. The objective of the first session was to determine each athlete's 1RM for the bench press and collect anthropometric data [162]. Sessions two, three, four and five were dedicated to assessing each athlete's maximal effort countermovement (CMB) and concentric only bench (COB) throw performance across a spectrum of relative loads (15, 30, 45, 60 and 75% 1RM). Two sessions were allocated in randomised order for assessing each movement pattern (CMB and COB throw). Each athlete performed a total of ten bench throws per testing session (two attempts at each load) excluding warm-up. From these assessment batteries, a comprehensive ballistic bench throw profile including power-load, force-velocity, Pmax, Fmax and Vmax was created for each athlete; statistical comparisons between rugby union forwards and backs were performed to better describe the positional requirements and differences in strength and ballistic upper body capabilities. Suggestions as to the individualization of programming were made.

6.2.2 Subjects

Twenty elite male rugby union players (age = 21.2 ± 3.0 years; mass = 94.9 ± 9.7 kg; 1RM bench press = 121.3 ± 21.8 kg) competing in New Zealand's Provincial competition volunteered for this study, which was approved by AUT University Ethics Committee. Written informed consent was obtained from the subjects prior to study participation. The squad was split into two groups determined by absolute 1RM bench press performance: strong and weak. Players 0.5 SD above the group mean were allocated to the strong group (SG; n = 8) and players 0.5 SD below the group mean were allocated to the weak group (WG; n = 7); while the middle 34% were removed from this specific analysis (Table 6.1). The SG was comprised of six forwards and two mid-fields backs; while the WG was comprised of a halfback/scrumhalf, a first-five/fly-half and five outside backs.

Table 6.1. Physical characteristics of strong and weak semi-professional rugby union players

Variables	Strong (<i>n</i> = 8)	Weak (<i>n</i> = 7)	%	Effect Size	P-value
Age (yrs)	22.1 ± 3.4	19.9 ± 1.7	15.9	1.35	0.13
BM (kg)	101.0 ± 4.2	85.3 ± 6.5	10.3	2.94	0.0001
1RM BP (kg)	141.9 ± 8.0	96.4 ± 20.1	32.0	2.26	0.0001
1RM BP/BM (kg)	1.44 ± 0.09	1.12 ± 0.05	19.2	6.16	0.0001

BM = body mass; **1RM BP** = one repetition maximum bench press; **1RM/BM** = one repetition maximum bench press relative to body mass. % = percentage difference between strong and weak.

6.2.3 Procedures

The subjects partook in a total of five testing sessions. Session one was dedicated to determining the 1RM for the bench press as follows: 8 repetitions at ~50% of 1RM (2 min rest), 3-4 repetitions at ~ 70% 1RM (3 min rest), 1-2 repetitions at ~ 80% 1RM (3-5 min rest), 1 repetition at ~ 90% 1RM (3-5 min rest), 1 repetition at ~ 95-100% 1RM (3-5 min rest), 1 repetition at 100-105% 1RM. Sessions two, three, four and five were dedicated to ballistic bench throw testing and performed in balanced non-randomised order. During these sessions a single linear position transducer (Fitness Technology: Ballistic Measurement Systems [BMS], Adelaide, South Australia) was attached to the barbell and sampled at a frequency of 400 Hz. A spotter was used as safety precaution to decelerate the load once the bar was projected into the air. Two sessions were dedicated to assessing the reliability of acyclic countermovement (CMB) throws using relative loads of 15, 30, 45, 60 and 75% of 1RM bench press. The CMB utilised the stretch-shortening cycle, where the athletes performed an initial eccentric (downward movement of the bar) contraction (the bar was lowered to the chest), immediately followed by an explosive concentric (upward movement of the bar) contraction and subsequent bar release (flight phase). Two sessions were also dedicated to assessing the reliability of concentric only (COB) bench throws using relative loads of 15, 30, 45, 60 and 75% of 1RM bench press. The COB is a concentric only contraction, where the bar is initially

lowered to the athlete's chest with the aid of a spotter, followed by a three second pause, which is immediately followed by an explosive concentric contraction and subsequent flight phase. COB throw trials containing a countermovement prior to the concentric phase were deemed ineligible and re-tested. Two acyclic repetitions were performed at each relative load across all testing sessions; three min rest was given between sets; bench throw order progressed from low to high intensity (15 → 75% 1RM) for all testing sessions [28]. 72 hours rest were given between testing sessions.

6.2.4 Data Analysis

The use of linear position transducers for bench throw testing have been previously validated with a high level of precision (<1.2%; ICC > 0.99) for the measured (displacement) and the derived variables (i.e. velocity, force and power) [17, 434]. The displacement-time data were filtered using a second order Butterworth filter (low pass) with a cut off frequency of 5 Hz. The displacement data was then single and double differentiated to determine the velocity and acceleration, respectively. Force was calculated as the sum of the weight of external load (external load x gravity) and the external load (kg) multiplied by the acceleration of the load [36]:

$$F = mg + ma$$

Power was calculated as the product of force and velocity. The concentric and eccentric phases were determined based on velocity and force thresholds. The concentric phase was initiated when velocity increased above 0.01 m/s and terminated when force was less than 5% of the system weight. The kinematic and kinetic variables of interest included: concentric peak force (N), concentric peak velocity in (m/s) and concentric peak power (W). Peak force (N), velocity (m/s) and power (W) were calculated using the Ballistic Measurement System and customized Microsoft Excel software programs. To determine the predicted Pmax load, quadratic equations were fitted to the individual data across the

loading spectrum ^[36]. Linear equations were also fitted to individual and group peak force-peak velocity curves to predict the hypothetical Fmax and Vmax capabilities ^[37]. A Pmax eccentric utilisation ratio was also calculated to help determine the group and athlete's level of SSC enhancement/augmentation.

6.2.5 Statistical Analysis

Means and standard deviations (SD) were used to represent centrality and spread of data. Independent t-tests were used to assess statistical significance ($p < 0.05$) between WG and SG for the following measures: body mass, peak power-load curves, peak force-peak velocity curves, Pmax, Fmax and Vmax. Independent t-tests were also used to assess the statistical differences between the CMB and COB throws. Effect size calculations were used to determine the magnitude of the differences in means between the groups ($ES = [X_{strong} - X_{weak}] / SD_{weak}$) and movement patterns ($ES = [X_{CMB} - X_{COB}] / SD_{COB}$). Effect size criteria were as follows: trivial (0.00 – 0.25), small (0.25 – 0.50), moderate (0.50 – 1.00), large (1.00 – 1.50) and very large (> 1.50) ^[157]. A table of individual data were also included for visual analysis of rankings of the dependent variables of interest.

6.3 Results

The inter-trial and inter-day reliability of force ($ICC > 0.96$; $CV < 3.5\%$), velocity ($ICC > 0.94$; $CV < 7.5\%$) and power ($ICC > 0.89$; $CV < 8.7\%$) measured during the CMB ($ICC > 0.91$; $CV < 8.0\%$) and COB ($ICC > 0.89$; $CV < 8.7\%$) throws across the loading spectrum was acceptable.

6.3.1 Maximum Power

Table 6.2. Ballistic bench throw comparisons between strong and weak semi-professional rugby union players

Dependent variables	Strong (<i>n</i> = 8)	Weak (<i>n</i> = 7)	%	Effect Size	P-value
Countermovement bench throw					
Pmax (W)	817 ± 98	702 ± 125	14.1	0.92	0.07
Pmax/BM (W/kg)	8.1 ± 1.0	8.2 ± 1.2	-1.8	-0.12	0.80
Abs load (kg)	60 ± 10	44 ± 6	26.8	2.53	0.004
Rel load (%)	42 ± 7	45 ± 5	-8.0	-0.74	0.28
Fmax (N)	1637 ± 204	1352 ± 183	17.4	1.56	0.01
Vmax (m/s)	3.09 ± 0.36	3.35 ± 0.46	-7.8	-0.57	0.24
Concentric only bench throw					
Pmax	773 ± 178	671 ± 97	13.2	1.05	0.20
Pmax/BM (W/kg)	7.6 ± 1.7	7.9 ± 0.8	-3.1	-0.29	0.73
Abs load (kg)	61 ± 9	40 ± 8	34.1	2.45	0.0005
Rel load (%)	43 ± 6	42 ± 8	2.8	0.15	0.74
Fmax (N)	1371 ± 136	1008 ± 137	26.5	2.65	0.0002
Vmax (m/s)	3.01 ± 0.64	3.73 ± 0.65	-19.2	-1.11	0.05
Eccentric utilisation ratio					
PPmax (U)	1.07 ± 0.20	1.08 ± 0.13	3.2	-0.11	0.62

Pmax(W) = maximum predicted peak power Watts (W); **Abs load (kg)** = absolute load in kg where maximum power occurs; **Pmax/BM** = maximum peak countermovement bench throw power relative to body mass; **Rel load** = percentage 1RM load where maximum power occurs; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **eccentric utilisation ratio** = countermovement Pmax divided by concentric only Pmax; % = percentage difference between strong and weak.

The SG's Pmax values were 14 and 13 % (ES > 0.92; p < 0.20) greater than the WG during the CMB and COB throws, respectively (Table 6.2); but when Pmax was normalised to body mass there were no significant (p > 0.73) differences (ES < -0.29). The absolute Pmax loads (kg) were 18 kg larger during the CMB (ES = 2.53; p = 0.004) and COB (ES = 2.45; p = 0.0005) throws in the SG; whereas there were no significant difference in the relative Pmax loads (% 1RM) (p > 0.28) between the two groups (ES_{CMB} = -0.74 and ES_{COB} = 0.15). Peak power outputs at 15 and 30% 1RM loads for CMB were significantly greater (p < 0.05) in the SG with moderate to large effects (ES = 0.96 - 1.12). Peak power outputs at 30, 45 and 60% for the COB were also significantly (p < 0.05) greater (ES = 1.01 – 1.60) for the SG (Figure 6.1).

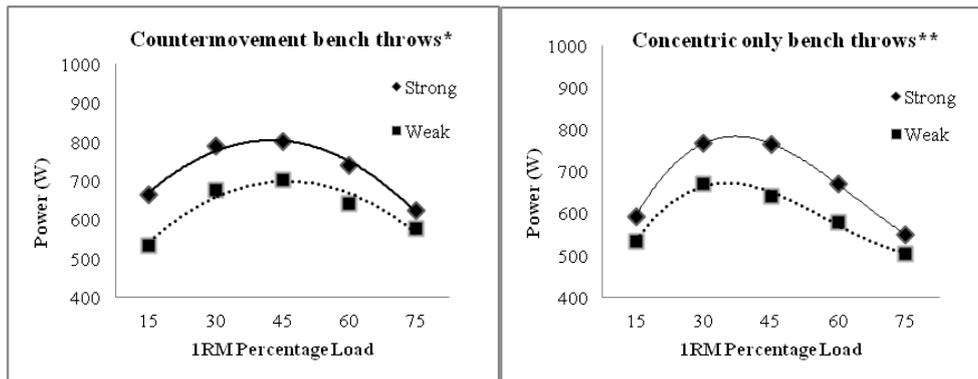


Figure 6.1. Bench throw peak power outputs across a spectrum of loads for strong and weak athletes.

6.3.2 Force-Velocity

The SG Fmax values were 21% and 36% greater than the WG; in contrast the WG Vmax values were 8% and 19% greater than the SG during the CMB and COB throws, respectively (Table 6.2). In support of the above findings, the SG produced significantly greater (ES = 2.24 – 4.14) peak forces and significantly less (ES = -0.68 to -1.20) peak velocities across the relative loads. (Figure 6.2)

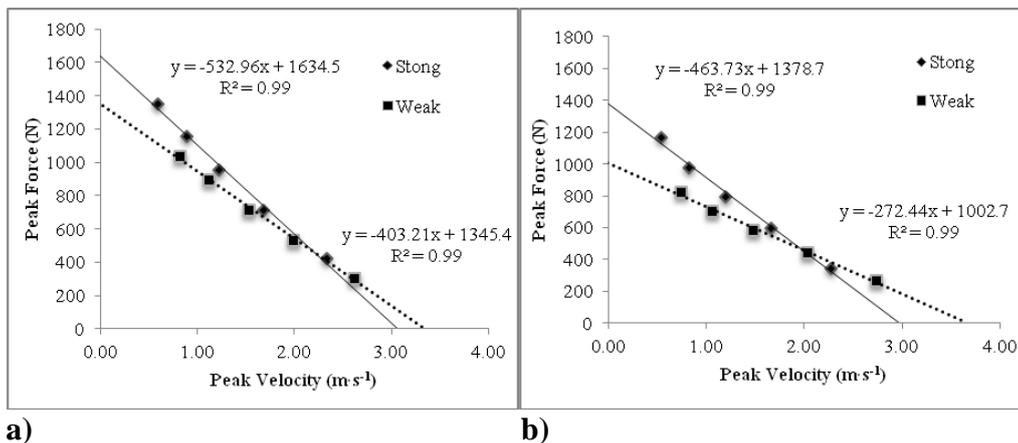


Figure 6.2. Peak force-velocity curves for a) countermovement and b) concentric only bench throws.

6.3.3 Countermovement versus Concentric-only

When comparing the SG and WG, similar trends were observed across CMB and COB throws for the included ballistic variables (Table 6.2). There was a trivial (ES = -0.11)

non-significant difference ($p = 0.62$) in EUR between groups. There was a moderate ($ES = 1.45$) significant ($p = 0.0001$) difference (24%) in Fmax between CMB and COB throws; while Pmax and Vmax produced trivial non-significant differences between movement patterns (Table 6.3).

Table 6.3. A comparison of countermovement and concentric only bench throws

Dependent variables	CMB	COB	%	Effect Size	P-value
PPmax (W)	748 ± 118	707 ± 145	5.8	0.29	0.33
Fmax (N)	1497 ± 213	1207 ± 199	24.0	1.45	0.0001
Vmax (m/s)	3.14 ± 0.47	3.24 ± 0.72	-3.2	-0.15	0.59

CMB = countermovement bench throws; **COB** = concentric only bench throws; **Pmax(W)** = maximum predicted peak power Watts (W); **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; % = percentage difference between CMB and COB throws.

6.3.4 Player Rankings

The strength, force, velocity and power rankings of the squad can be observed below (Table 6.4). The rankings help identify individual strengths and weaknesses and possible training emphases across these dependent variables of interest. For example, Subject 1 the strongest subject (160 kg 1RM), ranked middle of the sample in terms of power output (10th) and in the lower quartile in terms of velocity capability (17th). Conversely Subject 19 had the equal lowest maximal strength (85 kg 1RM), but was in the upper quartile in terms of power output (4th) and demonstrated the fastest velocity capability. EUR_{Pmax}, across the squad ranged from a high SSC augmentation (EUR_{Subject 5} = 1.44) to an SSC decrement (EUR_{Subject 4} = 0.86).

Table 6.4. Strength, power, force and velocity rankings across a squad of semi-professional rugby union players

Sub	Pos	1RM BP		Body mass		CMB Pmax		CMB Fmax		CMB Vmax		EUR Pmax	
		kg	Rank	kg	Rank	W	Rank	N	Rank	m/s	Rank	U	Rank
1	12	160	1	101	8	774	10	1517	8	2.74	17	1.12	6
2	6	145	2	95	11	912	3	1869	2	2.97	12	1.11	8
3	4	140	3	104	3	918	2	1689	3	3.82	2	0.88	19
4	2	140	3	104	3	837	5	1560	7	3.18	9	0.86	20
5	7	140	3	99	9	778	9	1597	6	3.33	8	1.44	1
6	1	140	3	108	2	925	1	1994	1	3.01	11	1.09	11
7	13	135	7	97	10	737	12	1460	11	2.87	15	1.10	9
8	7	135	7	103	6	653	16	1407	14	2.78	16	1.09	10
9	11	130	9	90	16	810	7	1446	12	3.56	5	0.97	16
10	3	125	10	112	1	778	8	1689	3	2.88	14	1.18	3
11	15	120	11	91	14	662	15	1492	10	2.65	19	1.06	13
12	6	120	11	104	3	722	14	1372	17	3.46	6	1.13	5
13	7	120	11	103	6	548	19	1394	15	2.09	20	1.11	7
14	14	110	14	91	14	769	11	1427	13	3.80	3	0.93	17
15	10	110	14	92	13	823	6	1612	5	2.90	13	1.08	12
16	12	105	16	93	12	727	13	1386	16	3.15	10	1.18	4
17	9	90	17	77	20	628	17	1227	18	3.57	4	1.02	15
18	10	90	17	81	18	519	20	1150	19	2.70	18	0.88	18
19	14	85	19	84	17	854	4	1515	9	3.95	1	1.21	2
20	15	85	19	79	19	593	18	1145	20	3.39	7	1.03	14

Rank = individual ranking for each dependent variable from highest to lowest; **Sub** = subject number **Pos 1,2,3,4,5** = tight five forwards; **Pos 6,7,8** = loose forwards; **Pos 9,10,11,12,13,14, 15** = back line players; **1RM BP (kg)** = one-repetition maximum bench press; **BM (kg)** = body mass; **CMB** = countermovement bench throw; **Pmax (W)** = maximum predicted peak power; **Fmax (N)** = hypothetical maximum force capabilities at zero velocity; **Vmax (m/s)** = hypothetical maximum velocity capabilities at zero force; **EUR** = eccentric utilisation ratio (CMB Pmax divided by COB Pmax)

6.4 Discussion

The purpose of this study was to explore the difference between maximum ballistic bench throw capabilities in strong and weak semi-professional rugby union players; and provide a greater mechanical understanding of the required strength and ballistic capabilities of these athletes. The underlying objective was to improve strength and ballistic profiling through novel analyses and in turn enhance future training strategies for elite rugby codes.

6.4.1 Maximum Strength

As mentioned previously, maximum upper body strength in rugby union is vital to force production and impact absorption during contact, and its assessment provides valuable diagnostic information for the strength and conditioning coach. The SG was comprised of six forwards and two midfield backs; whereas the WG was comprised of two inside and five outside backs, as expected based on the physical demands and physical attributes essential for success in these respective positions. This study revealed very large differences in body mass (10%) between the SG and WG. Enhanced strength and body mass qualities may in turn be beneficial to specific on-field tasks that require greater body mass and upper body strength, such as close-courter contact, blocking, rucking, mauling, scrummaging, fending and tackling. Enhanced upper body strength has also been known to dictate power and ballistic capabilities; it has been speculated that athletes with greater maximum strength are also more likely to have greater neuromuscular capabilities [240, 296, 447]. Current upper body strength assessments could be improved by assessing the maximum force, power and velocity produced during rugby specific tasks, such as a fending, tackling and scrummaging to provide a more representative measure of maximum rugby specific strength [6, 11, 23, 24, 164].

6.4.2 Maximum Power

The optimal load for producing Pmax varies greatly depending on the population and individual being assessed. There are generally large inter-individual differences in upper body power production within a group of rugby players, due to the wide range in physical characteristics between the various positions [32]. In the present study, the SG was significantly heavier (ES = 2.49; $p = 0.0001$) and produced small non-significant to large-significantly (ES = 0.39 – 1.61) greater peak bench throw power outputs (SG = 551 – 801 W; WG = 506 – 704 W) across a spectrum of relative loads (30-75% 1RM); indicating

that increasing upper body strength and body mass (i.e. muscle mass) in elite rugby union players may be partially responsible for increasing upper body power production capabilities.

Previous research is in agreement with these findings, in that athletes with greater strength and size also produce greater absolute power outputs ^[1, 32, 277, 296]. However, when power was normalised to body mass minimal relative Pmax differences were observed ($p > 0.73$) between groups (ES = -0.12 – -0.29), suggesting that body mass greatly influences absolute power output and that relative Pmax is similar between strong and weak rugby union players.

The Pmax relative loads of the SG and WG ranged from 35 to 50% 1RM and 40 to 50%, respectively. These relative (40 – 60% 1RM) Pmax loads were similar to previous findings ^[28, 30-32, 54, 246, 296, 308]. Some studies have found that stronger athletes produce Pmax at lighter relative loads in comparison to weaker athletes; this trend was not observed in the present study ^[302]. The absolute load at which Pmax occurred varied significantly ($p < 0.003$; ES > 2.45) between the SG (49 - 69 kg) and WG (32 – 50 kg). This phenomenon was also observed in a study comparing strong-elite (Pmax absolute load = 70 kg) and weaker-sub-elite (Pmax absolute load = 60 kg) rugby league players ^[39]. As mentioned previously, power profiling provides certain diagnostic information, however, quantifying Fmax and Vmax may provide pertinent mechanical information regarding the maximum force and maximum velocity capabilities of players ^[37].

6.4.3 Force-Velocity

Analysis of the peak force- and peak velocity- load profiles revealed that the SG produced significantly greater forces (SG = 344 – 1353 N; WG = 267 – 1033 N) and the WG produced non-significantly larger velocities (SG = 0.54 – 2.33 m/s; WG = 0.75 – 2.74 m/s) across the five relative loads; indicating that the stronger players were possibly more

force dominant and the weaker players were more velocity dominant. This trend can most likely be attributed to the SG (absolute load = ~ 20 – 110 kg) utilising absolute ballistic loads 43% larger than the WG (absolute load = ~ 15 - 80 kg) during bench throw testing. Similar trends were also observed in the peak force-velocity curves.

From the slopes of the force-velocity curves (Figure 6.2), it was predicted that the SG would produce much larger F_{max} (~ 16 - 36%) and the WG would generate greater V_{max} (~8 - 19%). From this observation, the slopes of the individual and group force-velocity curves may provide pertinent information for the player and coach when attempting to improve force-velocity capabilities. Players with a lower F_{max} (i.e. backline), could attempt to improve their force-velocity profile using heavier ballistic loads; while players with lower V_{max} (i.e. forward pack), should attempt to improve their force-velocity profiles using lighter ballistic loads. Improving these mechanical deficiencies should shift the various portions of the force-velocity curve, and possibly increase individual P_{max} outputs, since power is a product of force and velocity. In future, these findings could be used to improve and guide ballistic, strength and complex training strategies. However, the effects of strength and ballistic training on the peak force- peak velocity curves were not investigated in this study; further investigation to determine if these curves can be shifted to improve F_{max} and V_{max} capabilities is warranted.

6.4.4 Countermovement versus Concentric-only

There was a significant F_{max} difference between the CMB and COB throw due to the distinctive mechanical properties that govern these two movement patterns. The eccentric pre-stretch and utilisation of elastic potential energy during the CMB throw most likely contributed to the large ($ES = 1.45$) differences (24%) in F_{max} between movement patterns, which is supported by previous literature^[112, 259, 280]. The power-load differences

between SG and WG (Figure 1) during CMB and COB throws provided almost identical diagnostic information; therefore the inclusion of both movements in a ballistic profile may be redundant/unnecessary for between group investigations. The inclusion of EUR for the purpose of individualised programming may be of value to the practitioner as indicated in the next section.

6.4.5 Player Rankings

Grouping data only allows the reader to observe the mean response of the sample and therefore the individual responses to the assessments are masked. Since programming needs to be connected to the assessment and individualised, a table of the individual results and rankings was included for visual analysis. Such tables provide a basic strategy to help detect individual strengths and weaknesses and in turn determine the type of strength, ballistic and complex training needed for each individual. For example Subject one could be prescribed light ballistic loading to improve his velocity capabilities as he was ranked 1st for maximum strength and 17th for Vmax; whereas subject nineteen ranked 20th for strength and 1st for Vmax, therefore could be prescribed maximum strength training blocks supplemented with heavy ballistic loading to improve his strength and force capabilities (Table 6.4).

The individual EUR calculations and rankings can also be used to guide programming. For example Subject 5 has an EUR of 1.44, indicating that he has maximized the elastic contribution of muscle to force production and therefore would most likely benefit from ballistic concentric-only training; conversely Subject 4 has an EUR of 0.86 and would most likely benefit from SSC/plyometric training.

6.5 Practical Applications

Assessment informs programming, therefore it is crucial that the assessment profiles strength and conditioning coaches' use, provide reliable and meaningful information that guide the development of the athlete. Theoretically, the better the assessment battery, the more accurate the programming may be. In this regards the scientist and practitioner must be cognisant of the various ballistic movement patterns, loading parameters, testing equipment and outcome variables available to create a ballistic profile reflective of the performance demands of the respective sport.

Maximal strength, P_{max} and power-load curves provide important information regarding overall explosive capabilities of the athlete. The addition of F_{max} and V_{max} to the traditional power profiling, may provide sports scientists and practitioners with a greater and more holistic mechanical understanding of ballistic performance in elite rugby players and other highly trained athletes; which in turn may have a positive influence on programming. The slope (F_{max} and V_{max}) of a force-velocity curve should be used to (i.e. force deficient, velocity deficient or force-velocity deficient). Based on these acute outcomes, various strength and ballistic loading schemes could be prescribed to rectify these deficiencies; for example, force deficient players would train with heavy strength and heavier ballistic loads and velocity deficient players would train with lighter ballistic loads.

***IMPORTANCE OF STRENGTH AND SPRINT ABILITY TO
BALLISTIC LOWER BODY PERFORMANCE***

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**Journal of Australian Strength and Conditioning
In Review (Appendix 4f)**

7.0 Prelude

In Chapter 6, the rationale for the use of an extensive upper body profile was established. The main findings of the previous chapter were that the stronger players produced higher BTH Pmax and Fmax. This chapter adopts a similar approach to Chapter 6, however the focus was to examine and identify VJ performance differences between strong and weak athletes and also fast and slow athletes across the force-velocity-power spectrum. The assessment of maximum back squat strength, sprint running ability and maximum VJ Pmax, Fmax and Vmax may provide a more holistic lower body performance profile. Similar to the previous chapter, Pmax, Fmax and Vmax may be used to identify proficient and deficient areas in VJ performance; the individual rankings could be further utilised to identify and possibly rectify individual deficiencies. The aim of this chapter was to determine if such contentions were valid.

7.1 Introduction

Movements that are initiated with the intention of moving a load as fast as possible and result in a flight phase have been termed ballistic. Ballistic movements, such as sprinting, jumping and throwing are essential components to many sports. Such movements are also commonly used in training to elicit specific neuromuscular adaptations over time; as well as being used to assess and monitor the capacity of the neuromuscular system [52, 206, 303, 381, 448, 449]. During these ballistic movements, acceleration is a vital ingredient in the movement profile (i.e. the rapid change in velocity over time). In order to accelerate a body from rest and overcome inertia, an athlete must generate large forces over a short time period. Therefore the velocity, force and consequently power outputs produced during ballistic movements provide insight into mechanical and performance properties of the neuromuscular system.

Lower body strength, speed and power ballistic profiles are extensively utilised to describe and differentiate performance capabilities within and between rugby squads for the purpose of setting national standards, talent identification and performance tracking. However, in terms of diagnostic value and the utility in guiding the individualisation of programming, the information provided from such profiling is rather limited. For example, a number of isometric and dynamic lab based assessments along with practical weight room assessments (e.g. 1RM strength) have been utilised to create lower body strength profiles and monitor changes over-time in highly trained rugby-football code athletes [1, 78, 242, 356, 397]. Individual mean and peak isometric forces of 1400-2000 N and 2500-3500 N have been found in elite rugby players during squat (135° knee angle) and mid-thigh pull (~120° knee angle) movement patterns. These isometric strength tests provide a non-specific measurement of strength for rugby union players, but may not provide a true representation of the required rugby specific isometric strength qualities [1, 24]. The 1RM back squat and power clean values of 180-220 kg and 100-120 kg,

respectively, have been reported in semi- and professional rugby players; which also provides a non-specific measure of maximum dynamic strength in rugby players [27, 32, 54, 115, 446]. Such assessments provide general information regarding the strength qualities of rugby players that may not entirely represent the required rugby specific strength qualities.

Rugby union is typified by a spectrum of match specific force-velocity-power actions. For example, players need to perform high force (2-3 x BW)/power tasks such as in tackling, scrummaging, mauling, rucking and lifting in the lineouts. At other times they need to perform high velocity/power tasks such as sprinting and rapid changes in/of direction to evade the opposition. Finally, players need to pass/throw and kick a ~460 gm ball with high arm and leg velocity and accuracy. It makes sense that profiling incorporating a variety of loads is utilised to assess and monitor ballistic performance. In that regards vertical jump/lower body power profiles have been created using incremental load (absolute and relative) testing to assess and monitor neuromuscular adaptations (i.e. fatigue, recovery and development) due to training, rest and the physical demands of competition [32, 54, 56-58, 162, 308, 439, 444]. Incremental loading allows for the creation of load-power, load-velocity and load-force curves [27-29, 31, 117, 244, 255]. Based on individual load-curves, force, velocity and power loads can then be prescribed to shift various portions of these respective curves and possibly elicit position or activity specific adaptation.

As mentioned previously, the majority of athlete profiling thus far has characterised maximum strength, speed, power in a fairly non-specific manner. Whilst such information provides some diagnostic information, since power is the product of the optimum combination of force and velocity and not their respective maximums, power profiling only provides a partial representation of the athlete's true ballistic capabilities [37, 166]. The addition of Fmax and Vmax as assessed during sports specific movements should provide a more holistic understanding of the mechanical properties that govern

ballistic performance ^[37]. Fmax (velocity = 0 m/s) and Vmax (force = 0 N) incorporate the entire force-velocity spectrum, as they are hypothetical maximums produced at extreme ends of the force-velocity curve and could provide valuable prognostic information for athlete profiling and programming. This is especially so given the spectrum of force-velocity-power activities rugby players engage in.

Countermovement jumps (CMJ) and squat jumps (SJ) are commonly utilised in power profiling and assess the stretch-shortening cycle (SSC) and concentric only capabilities of the lower body, respectively ^[56, 166, 259]. Peak CMJ and SJ power outputs of 4000-9000 W have been reported in elite rugby players using loads between 0 (body mass) and 50% of the 1RM back squat ^[27, 31, 32, 35, 54]. Maximum peak power (Pmax) most often occurs at body mass during CMJ and SJ ^[27, 31, 35]. These two movements provide similar kinematic and kinetic information, yet they are governed by slightly different mechanisms; therefore a comparison of these movements may help determine an athlete's level of SSC augmentation (i.e. ratio between countermovement and concentric-only performance) ^[259], which in turn may guide the individualisation of programming to better effect. On these grounds, it intuitively makes sense to include the CMJ and SJ in a ballistic profile, however this is based on the premise that SSC and/or concentric movements are fundamental to the sport and these assessments provide differential diagnostic information.

Given the preceding information, the purpose of this investigation was to examine and identify mechanical differences in ballistic lower body performance (vertical jump kinematics and kinetics) between strong and weak and fast and slow rugby players. A secondary focus is to determine whether such analysis provides additional information to individualize programming.

7.2 Methods

7.2.1 Experimental Approach to the Problem

Prior to collecting any data for this study, the group of semi-professional rugby players underwent a five week complex strength and power training programme to improve their neuromuscular capabilities and musculoskeletal qualities, which in turn better prepared the players for the various loads and movement patterns used during testing. Following the five week training block, the athletes were required to attend five testing sessions. The objective of the first session was to measure sprint capabilities (10, 20 and 30 m sprint times) and determine each athlete's 1RM for the bench press and collect anthropometric data ^[162]. Sessions two, three, four and five were dedicated to assessing each player's maximal effort countermovement jump (CMJ) and static squat jump (SJ) across a spectrum of relative loads (body mass/0, 15, 30, 45, 60 and 75% 1RM). Two sessions were allocated in randomised order for assessing each movement pattern (CMJ and SJ). Each player performed a total of 12 jumps per testing session (2 attempts at each load) excluding warm-up. From these assessment batteries, a comprehensive ballistic vertical jump profile including power-load and force-velocity curves were created for each athlete. Statistical comparisons between strong and weak and fast and slow highly trained rugby union players were performed to better describe the respective differences in strength and ballistic lower body capabilities. Suggestions as to the individualization of programming were also made.

7.2.2 Subjects

Eighteen semi-professional male rugby union players (age = 21.3 ± 3.3 yr; body mass = 93.2 ± 10.0 kg; 1.83 ± 0.07 m) competing in New Zealand's Provincial rugby competition were volunteered for this study, which was approved by Auckland University of Technology Ethics Committee. Written informed consent was obtained from the players

prior to study participation. The sample was split into groups based on 1RM back squat strength and 30 m sprint times. The following four groups were created: strong, weak, fast and slow. Players 0.5 standard deviations (SD) above the 1RM mean were allocated to the strong group and players 0.5 SD below the 1RM mean were allocated to the weak group. The same process was used to divide the fast and slow sprinters, where players 0.5 SD below the 30 m sprint time mean were allocated to the fast group and players 0.5 SD above the 30 m sprint time mean were allocated to the slow group. The middle 34% were removed from the analysis.

7.2.3 Procedures

The players partook in a total of five testing sessions. Session one was dedicated to determining sprint times (10, 20 and 30 m) and the 1RM parallel back squat. During the sprint testing the athletes performed a standardised warm-up that consisted of the following in sequential order: light 400 m jog, ankling 40 m, A-skips 40 m, C-skips 40 m, high kicks 40 m, 10 walking lunges, 10 military push ups, 20 trunk rotations, 20 forward arm circles, two 30 m sprints at ~ 75% of maximal sprinting speed and one 30 m sprint at ~ 90% of maximal sprinting speed. Three minutes rest was then given, which was followed by three 30 m maximal sprint trials (3 min rest was given between each maximal sprint trial), starting in a split stance 50 cm behind the first set of timing lights. Sprint times were measured using dual beam infrared timing lights (Swift Performance, Lismore, Australia) at 10, 20 and 30 m splits. After the sprint testing athletes were given 30 min to recover before performing the 1RM parallel back squat testing as follows: 8 repetitions at ~50% of 1RM (2 min rest), 3-4 repetitions at ~ 70% 1RM (3 min rest), 1-2 repetitions at ~ 80% 1RM (3-5 min rest), 1 repetition at ~ 90% 1RM (3-5 min rest), 1 repetition at ~ 95-100% 1RM (3-5 min rest), 1 repetition at ~105% 1RM ^[162]. Sessions two, three, four and five were dedicated to ballistic vertical jump testing and performed

in a randomised and balanced order. During the vertical jump testing sessions a single linear position transducer (Celesco PT5A-150, Chatsworth, CA) was attached to the barbell and sampled at a frequency of 400 Hz via a computer interface (Fitness Technology: Ballistic Measurement Systems, Adelaide, South Australia). A power cage equipped with a magnetic braking system (Fitness Technology: FT700 Power Cage-Magnetic Breaking Unit, Adelaide, South Australia) was used as a safety precaution to decelerate the load once the bar/athlete was projected into the air. Tension supplied by the breaking system cable was negligible (< 1 kg) and therefore not factored into the analysis. Two sessions were dedicated to assessing the acyclic CMJ using relative loads of 0, 15, 30, 45, 60 and 75% of 1RM back squat. The CMJ utilised the SSC, where the athletes performed an initial eccentric (downward movement) contraction (~120 degree knee angle), immediately followed by an explosive concentric (upward movement) contraction and subsequent flight phase. Two sessions were also dedicated to assessing the SJ using the same relative loads. The SJ utilises a concentric only contraction, where the athlete initially squats down to a self-selected depth (~120 degrees), followed by a three second pause, which is immediately followed by an explosive concentric contraction and subsequent flight phase. SJ trials containing a countermovement prior to the concentric phase were deemed ineligible and re-tested. Two acyclic repetitions were performed at each relative load across all testing sessions; three min rest was given between sets; the ballistic loads increased from low to high intensity (0 → 75% 1RM) across all testing sessions ^[28]. A minimum of 72 hours rest was given between testing sessions.

7.2.4 Data Analysis

The use of linear position transducers for vertical jump assessments has been previously validated with a high level of precision (<1.2%; ICC > 0.99) for the measured (i.e.

displacement) and the derived variables (i.e. velocity, force and power) ^[17]. The displacement-time data were filtered using a second order Butterworth filter (low pass) with a cut off frequency of 5 Hz. The displacement data was then single and double differentiated to determine the velocity and acceleration, respectively. Force was calculated as the sum of the system weight ([body mass + external load] x gravity) and the system mass multiplied by the acceleration of the athlete-load during jump testing ^[36]:

$$F = mg + ma$$

Power was calculated as the product of force and velocity. The concentric and eccentric phases were determined based on velocity and force thresholds. The eccentric phase was initiated when velocity dropped below -0.01 m/s and terminated when velocity returned back to zero (i.e. at the bottom of the movement); the subsequent concentric phase was initiated when velocity increased above 0.01 m/s and terminated when force was less than 5% of the system weight (body weight + external load).

The kinematic and kinetic variables of interest included: peak force (N), peak velocity (m/s) and peak power (W). Quadratics were also fitted to the individual and group power-load data to determine Pmax. A Pmax eccentric utilisation ratio was also calculated to help determine the group and athlete's level of SSC enhancement/augmentation. Linear regression lines were also fitted to the peak force-peak velocity data developed from the relative load profiles to predict hypothetical maximum jumping force (Fmax) and velocity (Vmax) capabilities for each group and individual ^[37]. The slopes (Sfv) of the respective regression lines were also calculated to create a ratio between Fmax and Vmax:

$$Sfv = Fmax/Vmax$$

7.2.5 Statistical Analysis

Means and standard deviations were used to represent centrality and spread of data. The reliability of the included variables and protocols was previously established. Independent t-tests were used to determine if the peak power, force and velocity load spectrum curves differed between the strong and weak and fast and slow players. Pmax, Fmax, Vmax and Sfv for each group were also compared for significant differences. An alpha level of 0.05 was used to assess statistical significance and the magnitude of the differences in means between the strong and weak ($ES = [X_{strong} - X_{weak}] / SD_{weak}$) and fast and slow ($ES = [X_{fast} - X_{slow}] / SD_{slow}$) players. Effect size criteria were as follows: trivial (0.00 – 0.25), small (0.25 – 0.50), moderate (0.50 – 1.00), large (1.00 – 1.50) and very large (> 1.50)^[157]. A ranking table of individual data were also included for visual analysis of the dependent variables of interest.

7.3 Results

The inter-trial and inter-day reliability of force ($ICC > 0.93$; $CV < 3.6\%$), velocity ($ICC > 0.86$; $CV < 5.0\%$) and power ($ICC > 0.90$; $CV < 5.5\%$) measured during the CMJ ($ICC > 0.86$; $CV < 5.5\%$) and SJ ($ICC > 0.88$; $CV < 6.5\%$) across the loading spectrum was acceptable.

The strong group was significantly heavier ($p = 0.001$; $ES = 4.34$) and moderately older ($p = 0.17$; $ES = 1.27$) than the weak group. There were no significant differences in sprint times between the strong and weak group ($P > 0.88$; $ES < -0.24$). There were no significant age ($p = 0.47$; $ES = -0.34$), body mass ($p = 0.96$; $ES = 0.02$) or strength ($p = 0.96$; $ES = -0.03$) differences between the fast and slow players (Table 7.1).

Table 7.1 Strength and speed characteristics

	Strong	Weak	ES	P-value	Fast	Slow	ES	P-value
Age (yrs)	22.9 ± 4.1	20.2 ± 2.1	1.27	0.17	20.7 ± 1.9	22.0 ± 4.0	-0.34	0.47
BM (kg)	98.4 ± 5.9	82.2 ± 3.8	4.34	0.00	91.7 ± 2.0	91.5 ± 10.8	0.02	0.96
Sqt (kg)	178.8 ± 11.3	130.0 ± 8.9	5.45	0.00	155.0 ± 24.3	155.7 ± 25.7	-0.03	0.96
Sqt / BM	1.82 ± 0.15	1.59 ± 0.16	1.44	0.02	1.70 ± 0.25	1.69 ± 0.08	0.01	0.99
10 m (s)	1.72 ± 0.06	1.73 ± 0.06	-0.24	0.89	1.67 ± 0.02	1.76 ± 0.04	-2.55	0.00
20 m (s)	2.95 ± 0.08	2.97 ± 0.09	-0.16	0.94	2.87 ± 0.04	3.03 ± 0.03	-6.14	0.00
30 m (s)	4.11 ± 0.09	4.13 ± 0.12	-0.09	0.98	4.00 ± 0.05	4.20 ± 0.02	-9.92	0.00
30-20 m (s)	1.16 ± 0.03	1.16 ± 0.04	0.10	0.98	1.13 ± 0.01	1.17 ± 0.03	-1.64	0.01

BM = body mass in kg; **1RM Squat** = one-repetition maximum parallel back squat; **1RM/BM** = relative back squat strength scaled to body mass; **10 m – 20 m – 30m** = 10, 20 and 30 meter sprint times.

7.3.1 Maximum Power

There were small non-significant group differences ($p > 0.43$) in Pmax for the CMJ (ES = -0.43) and SJ (ES = -0.59) between strong and weak players (Table 7.2). Pmax relative (ES = -0.98; $p = 0.02$) and absolute (ES = -0.95; $p = 0.04$) loads were significantly less for the strong group during the CMJ; yet non-significantly ($p > 0.18$) larger during the SJ (ES = 0.79 and 1.35).

There were trivial to small non-significant differences ($p > 0.28$) in Pmax for CMJ (ES = -0.70) and SJ (ES = 0.29) between the fast and slow players. The Pmax relative (%1RM) and absolute loads (kg) produced small non-significant ($p > 0.23$) differences between groups (fast vs slow) during the CMJ (ES = 0.38 and 0.52) and SJ (ES = 0.64 and 0.64) (Table 7.2).

Table 7.2. Predicted countermovement and static squat jump performance maximums

	Strong	Weak	ES	P-value	Fast	Slow	ES	P-value
<i>Countermovement jump</i>								
PP Max (W)	4068 ± 1073	4432 ± 856	-0.43	0.51	4373 ± 999	3825 ± 788	0.70	0.29
PP %1RM	1.9 ± 5.3	15.0 ± 13.4	-0.98	0.02	15.0 ± 25.1	10.7 ± 11.3	0.38	0.69
PP load (kg)	3.2 ± 9.0	19.3 ± 16.8	-0.95	0.04	23.0 ± 38.0	15.0 ± 15.4	0.52	0.62
Fmax (N)	4110 ± 736	3744 ± 374	0.98	0.29	4027 ± 634	3867 ± 701	0.23	0.67
Vmax (m/s)	5.19 ± 0.74	5.89 ± 1.26	-0.55	0.74	5.92 ± 1.21	5.31 ± 0.61	0.99	0.26
Sfv	813 ± 213	663 ± 159	0.94	0.17	706 ± 183	746 ± 208	-0.19	0.72
<i>Squat jump</i>								
PP Max (W)	3546 ± 1003	3945 ± 675	-0.59	0.43	3815 ± 983	3536 ± 966	0.29	0.62
PP %1RM	34.3 ± 30.9	20.0 ± 18.2	0.79	0.34	35.0 ± 22.6	17.1 ± 28.0	0.64	0.23
PP load (kg)	60.6 ± 55.8	25.5 ± 22.9	1.35	0.18	57.3 ± 45.3	27.4 ± 46.8	0.64	0.27
Fmax (N)	4102 ± 703	3743 ± 610	0.59	0.27	4194 ± 635	3823 ± 702	0.53	0.36
Vmax (m/s)	5.43 ± 2.63	5.44 ± 1.15	-0.01	0.93	4.57 ± 0.70	5.67 ± 2.63	-0.42	0.34
Sfv	902 ± 379	718 ± 206	0.90	0.25	935 ± 183	793 ± 360	0.40	0.41
EUR PPmax	1.09 ± 0.10	1.12 ± 0.10	-0.32	0.56	1.16 ± 0.10	1.10 ± 0.09	0.65	0.29

PP Max = maximum peak power output in watts; **PP %1RM** = percent 1RM load where peak power occurred; **PP load** = load in kg where peak power occurred; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax; **EUR Pmax** = maximum peak power eccentric utilisation ratio (countermovement jump maximum power divided by squat jump maximum).

The weak group produced trivial to small (ES = -0.13 to -0.78) non-significantly ($p > 0.42$) larger peak power outputs during CMJ and SJ across the loading spectrum in comparison to the strong group (Figure 7.1). Whereas the fast group produced trivial to moderate (ES = 0.11 – 0.90) non-significantly ($p > 0.43$) larger peak power outputs across the spectrum of loads during the CMJ in comparison to the slow group (Figure 7.1).

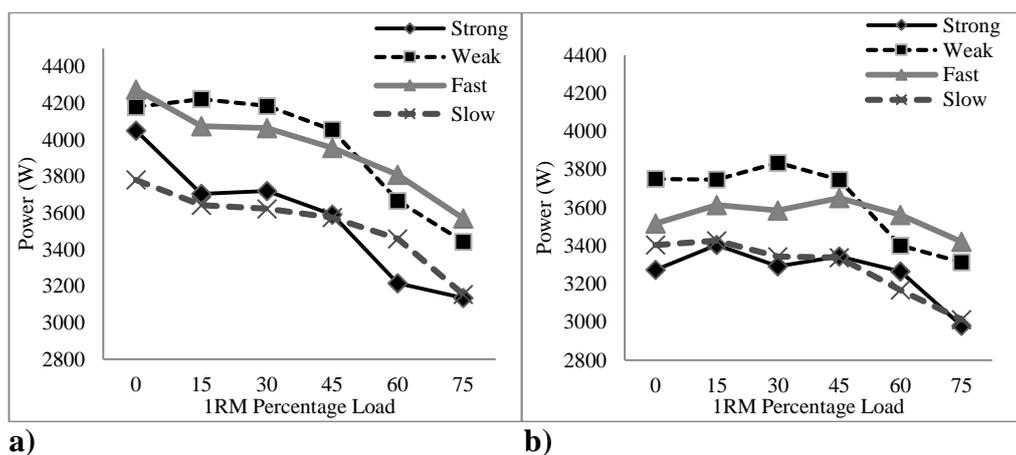


Figure 7.1. Peak power outputs across the loading spectrum during a) countermovement jumps and b) static squat jumps

7.3.2 Force-Velocity

The strong group's CMJ and SJ Fmax values were 10% (ES = 0.98) and 11% (ES = 0.59) greater than the weak groups; in contrast the weak group's Vmax values were 12% (ES = -0.55) and 2% (ES = -0.01) larger than the strong group during the CMJ and SJ, respectively. The CMJ and SJ Sfv ratios were also 23% (ES = 0.94) and 30% (ES = 0.90) larger in the strong group, respectively (Table 7.2). In support of these findings, the difference in peak force between the strong (2054 – 3183 N) and weak (1925 – 2738 N) increased from 5% at the 15% 1RM to 16% at the 75% 1RM load. The peak velocity-load differences between the strong group and weak group, were also in agreement to the Vmax findings above; as small (9%; ES = -0.63) to very large (19%; ES = -3.00) negative between group differences were observed with increasing load.

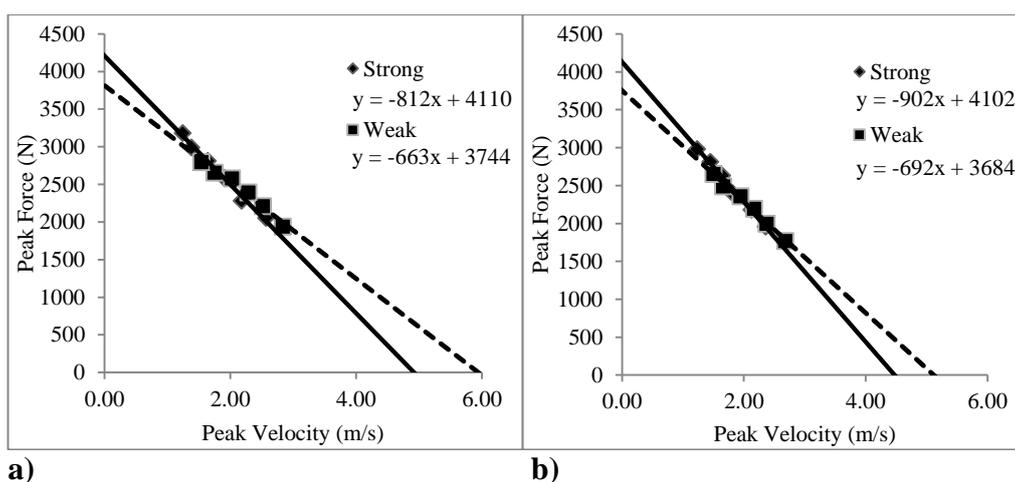


Figure 7.2. Peak force- peak velocity curves of strong and weak athletes for a) the counter-movement and b) squat jump

The fast group's CMJ and SJ Fmax values were 4% (ES = 0.23) and 10% (ES = 0.53) larger than the weak groups. The slow group's Vmax values were -11% (ES = 0.99) less during the CMJ and 19% (ES = -0.42) larger during the SJ. The CMJ Sfv ratio was 5% (ES = -0.19) larger in the slow group; whereas the SJ Sfv was 18% (ES = -0.40) larger in the fast group (Table 6.2). No significant ($p > 0.76$; $ES < 0.38$) peak force-load differences (0.2 – 6.7%) were found between fast and slow athletes. The fast group produced 7 to 12% larger peak velocities across the loading spectrum during CMJ (ES =

0.83 – 2.03) and SJ (ES = 0.55 – 1.02). A very large (10%; ES = 2.03) difference in peak velocity (fast group = 2.95 m/s; slow group = 2.67 m/s) was evident during the body mass CMJ (0% 1RM).

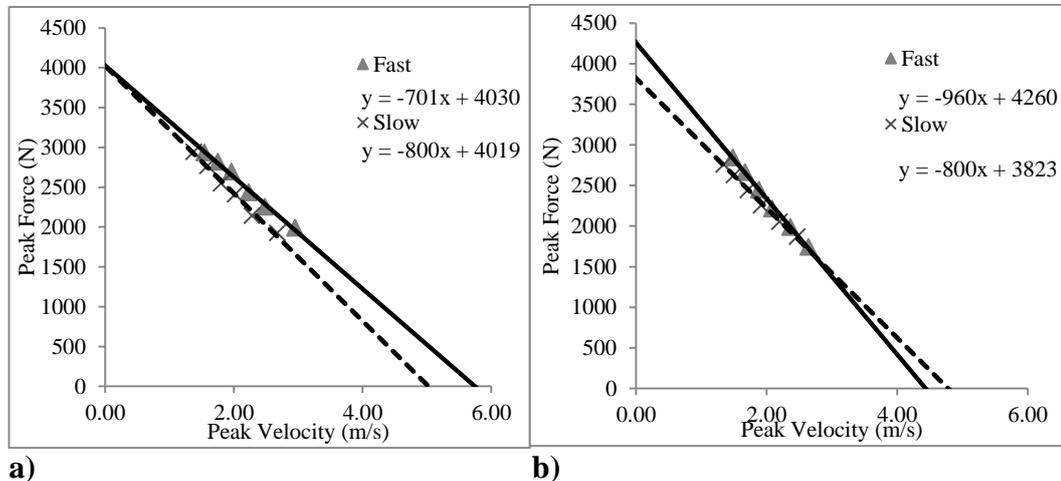


Figure 7.3. Peak force- peak velocity curves of fast and slow athletes for a) the counter movement and b) squat jump

7.3.3 Countermovement Jumps versus Squat Jumps

There were small non-significant differences in EUR between the strong and weak (ES = -0.32; $p = 0.56$), and fast and slow (ES = 0.65; $p = 0.29$) groups, respectively (Table 7.2). There was a small (ES = 0.54) non-significant ($p = 0.13$) difference (12%) in Pmax between CMJ and SJ (Table 7.3).

Table 7.3 Comparison of counter movement jumps and squat jumps

Ballistic variables	CMJ	SJ	% Diff	Effect Size	P-value
Pmax (W)	4197 ± 903	3733	12.4	0.54	0.13
Fmax (N)	3998 ± 600	3986 ± 622	0.3	0.02	0.96
Vmax (m/s)	5.48 ± 0.92	5.27 ± 1.80	4.0	0.12	0.67
Sfv (N/m/s))	754 ± 187	832 ± 275	-9.4	-0.28	0.34

Pmax(W) = maximum predicted peak power Watts (W); **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax.

7.3.4 Player Rankings

The rankings help identify individual strengths and weaknesses and possible training strategies across these performance variables (Table 7.4). For example, Subject 1 the

fastest (3.94 s) and second strongest subject (190 kg 1RM) ranked middle of the sample in terms of Vmax (8th). Conversely Subject 2 had low (13th) maximal strength (140 kg 1RM), high Vmax (2nd) capabilities and was tied with Subject 1 for speed (3.94). EUR_{Pmax}, across the squad ranged from a high SSC augmentation (EUR_{Subject 3} = 1.27) to an SSC decrement (EUR_{Subject 8} = 0.93).

Table 7.4. Speed, strength, power, force and velocity rankings across a squad of semi-professional rugby union players

Subject	Position	30 m		10 m		1RM squat		CMJ Pmax		CMJ Fmax		CMJ Vmax		EURPmax	
		sec	Rank	sec	Rank	kg	Rank	W	Rank	N	Rank	m/s	Rank	U	Rank
1	12	3.94	1	1.62	1	190	2	4454	6	4732	2	5.63	8	1.11	9
2	9	3.94	1	1.67	2	140	13	5877	2	4200	8	6.93	2	1.23	3
3	14	4.00	3	1.67	2	120	17	4200	11	3250	17	7.81	1	1.27	1
4	12	4.02	4	1.67	2	170	5	2981	18	3251	16	4.99	11	1.21	4
5	11	4.04	5	1.69	6	160	9	3746	12	4207	7	4.67	17	1.14	6
6	4	4.07	6	1.68	5	150	11	4977	4	4522	4	5.47	9	0.99	16
7	6	4.08	7	1.69	6	170	5	3325	14	4376	6	4.16	18	1.05	12
8	13	4.14	8	1.72	8	180	3	4255	10	4515	5	4.99	11	0.93	17
9	12	4.16	9	1.72	8	180	3	5930	1	3570	13	6.48	3	na	na
10	15	4.17	10	1.72	8	120	17	4626	5	3689	12	4.72	15	1.13	7
11	3	4.17	10	1.72	8	160	9	4397	8	4589	3	5.64	7	1.10	10
12	6	4.18	12	1.8	17	170	5	3385	13	4119	9	4.69	16	1.12	8
13	7	4.19	13	1.72	8	170	5	3054	17	3126	18	5.82	6	1.19	5
14	15	4.19	13	1.73	13	150	11	3288	15	3304	15	6.05	4	1.24	2
15	11	4.19	13	1.75	15	130	15	4257	9	4066	10	5.00	10	1.00	15
16	1	4.2	16	1.78	16	200	1	5156	3	5192	1	4.76	14	1.02	14
17	10	4.21	17	1.82	18	130	15	3228	16	3870	11	4.87	13	1.09	11
18	10	4.24	18	1.74	14	140	13	4404	7	3392	14	5.99	5	1.04	13

Rank = individual ranking for each dependent variable from highest to lowest; positions; **1,2,3,4,5** = tight five forwards; positions **6,7,8** = loose forwards; positions **9,10,11,12,13,14,15** = back line players; **1RM squat** = one-repetition maximum back squat; **CMJ** = countermovement jump; **Pmax** = maximum predicted peak power; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **EUR Pmax** = maximum peak power eccentric utilization ratio (countermovement jump maximum power divided by squat jump maximum); **na** = information not available.

7.4 Discussion

The aim of this study was to identify kinematic and kinetic differences in vertical jump profiles between strong and weak and fast and slow semi-professional rugby union players. A comprehensive profile was implemented to provide a greater mechanical understanding of the required ballistic capabilities of these athletes. The underlying objective was to evolve speed, strength and force-velocity-power profiling methodologies and in turn improve programming strategies for elite rugby codes.

7.4.1 Maximum Strength

Maximum lower body strength in rugby codes is thought to be important to force production for rucking, mauling, scrummaging and impact absorption during contact; it's assessment also provides valuable diagnostic information for the strength and conditioning coach. Researchers ^[40, 133, 366] have suggested that increasing body mass in rugby union may be beneficial to improving the 1RM squat, which was supported by the 20% body mass differential between strong (98 kg) and weak (82 kg) players (Table 6.1). Enhanced strength qualities may in turn be beneficial to specific on-field tasks that require greater body mass and lower body strength, such as close-counter contact, rucking, mauling, scrummaging and tackling. Current strength assessments could be improved by assessing maximum force capabilities during these sports specific tasks to provide a more representative measure of maximum rugby specific strength ^[1, 24, 356]. It has been reported that strength plays an important role in increasing speed and ballistic power capabilities ^[34, 78, 82, 92, 166, 206, 297]; this contention was not observed in the current comparison of highly trained rugby union players.

7.4.2 Maximum Power

The optimal power (P_{max}) load for vertical jump assessments most often occurs around body mass (0% 1RM), but may vary depending on the group and individual being assessed; as well as the equipment and profiling protocol utilised [15, 17, 27, 31, 35, 166, 201]. There are generally large inter-individual differences in lower body peak power production (4000 – 9000 W) within a group of rugby players, due to the wide range in physical characteristics between the various positions [1, 27, 31, 32, 35, 206]. In the present study, the weak (range = 3443 – 4185 W) and fast (range = 3571 – 4275 W) groups produced larger but non-significant different peak power outputs across the five loaded jumps in comparison to the strong (range = 3136 – 4050 W) and slow (range = 3156 – 3781) groups (Figure 6.1). It appears that increased strength levels may have little effect on power production capabilities in elite rugby players, these findings were similar to other research [82, 297, 450].

Similar to the above outcomes the fast and slow groups predicted P_{max} were non-significantly larger than the strong and weak groups, respectively. The relative (% 1RM) and absolute (kg) P_{max} loads were group and movement pattern dependent (Table 6.2). During the CMJ, the strong group produced P_{max} utilising loads between -3 and 7% 1RM (i.e. -6 to 12 kg); whereas the weak group produced P_{max} across a greater range of relative loads (2 – 28% 1RM [2 to 36 kg]). Large variations in relative P_{max} loads were also observed in the fast (-10 to 40% 1RM [-15 to 60 kg]) and slow (-1 to 22% 1RM [-1 – 30 kg]) groups. The optimal power loads were similar to previous findings [27, 28, 31, 35, 36, 243, 283, 296, 308, 433], where P_{max} occurred across a range of relative loads (i.e. 0 to 63% 1RM) in elite athletes. Some studies have found that stronger athletes produce maximum power at greater absolute loads in comparison to weaker athletes; this trend was not observed in the present study [166, 302].

As mentioned previously, power profiling provides specific diagnostic information; however, quantifying Fmax and Vmax may provide pertinent mechanical information regarding the differences in maximum force and maximum velocity capabilities between strong, weak, fast and slow rugby players. [37].

7.4.3 Force-Velocity

The CMJ and SJ profiling protocols produced inverse peak force-peak velocity relationships with an increasing external load. This inverse relationship was expected and has also been observed in past lower extremity force-velocity research [381, 433, 451-453].

The linear regression equations used to estimate the hypothetical Fmax, Vmax and Sfv (slope) generated nearly perfect linear relationships between peak force and peak velocity ($R^2 > 0.97$) for all groups across the spectrum of relative loads (Figures 6.2 and 6.3). From the CMJ analysis, it was predicted that the strong players would produce the largest Fmax (2 - 10%) and Sfv (9-23%); while the faster players would generate the highest Vmax (1-14%). The slopes (Sfv) of the force-velocity curves revealed that greater Fmax and a larger Sfv were observed in the stronger players; on the other hand greater Vmax and smaller Sfv were associated with the faster players. These trends were not observed during the SJ assessment, as Fmax (2-12%) and Sfv (3-30%) were largest in the fast group; whereas Vmax (4-24%) was largest in the weak group. The significance of these findings will be discussed in the next section.

Vmax and Fmax may provide critical information for the player and coach when attempting to improve force-velocity capabilities. Force (Fmax) deficient players (i.e. weak players) could attempt to improve their force and velocity production capabilities using heavier ballistic loads; while velocity (Vmax) deficient players could attempt to improve their velocity capabilities using assisted or light ballistic loads (i.e. -15-15% 1RM). Improving these mechanical deficiencies should shift the various portions of the

force-velocity curve and possibly increase individual power-load and Pmax outputs, since power is a product of force and velocity. Observing individual differences in the Sfv ratio can help identify if an athlete is force or velocity dominant; a larger Sfv indicates a more force-dominant athlete in contrast a smaller Sfv indicates a more velocity-dominant athlete. In future, determining individual weaknesses along with position specific requirements could be used to improve and guide ballistic, strength and complex training strategies for rugby union. Since the effects of speed, strength and ballistic lower body training on the force-velocity curves were not investigated in this study; future research is required to determine which types of training combinations elicit the desired shifts in the force-velocity-power capabilities.

7.4.4 Countermovement Jumps versus Squat Jumps

There was small difference in Pmax (12%) between the CMJ and SJ due to the distinctive mechanical properties that govern these two movement patterns. Pmax occurred at lower relative loads during the CMJ (2 - 15% 1RM) in comparison to the SJ (17 – 35% 1RM) across all groups (Table 6.2); therefore the SSC may have a larger effect on power during light load jumping. The Pmax relative load SD also indicated that CMJ (SD = 5 – 25% 1RM) was less variable than the SJ (SD = 18 – 31% 1RM); which were expected based on previous findings, due to movement familiarity and the different mechanisms governing these ballistic movements ^[166, 259]. The power-load differences between strong and weak groups and fast and slow groups (Figure 6.1) during CMJ and SJ provided almost identical diagnostic information; therefore the inclusion of both movements in a force-velocity-power profile may be unnecessary for between group investigations. However, the inclusion of EUR for the purpose of individualised programming may be of value to the practitioner as indicated in the next section.

7.4.5 Player Rankings

Aggregating data into groups masks the individual responses to an assessment and therefore limits the diagnostic information. Since programming needs to be connected to the assessment and individualised, a table of the individual results and rankings was included for visual analysis. Such tables provide a basic strategy to help detect individual strengths and weaknesses and in turn determine the type of ballistic and complex training needed for each individual. For example, Subject 1 could be prescribed light ballistic loading to improve his velocity capabilities as he ranked 1st for maximum strength and 8th for Vmax; whereas Subject two ranked 13th for strength and 1st for Vmax, therefore could be prescribed maximum strength training blocks supplemented with heavy ballistic loading to improve his strength and force capabilities (Table 6.4). However, this prescription needs to be based on positional demands and it may be that a pre-requisite to certain positions is force dominant or velocity dominant training. Of note, subjects one and two were both ranked first for speed, further illustrating the importance profiling for individualised programming. The individual EUR calculations and rankings can also be used to guide programming. For example, Subject 3 had an EUR of 1.27, indicating that he has maximized the elastic contribution of muscle to force production and therefore would most likely benefit from ballistic concentric-only training; conversely Subject 8 has an EUR of 0.93 and would most likely benefit from SSC/plyometric training.

7.5 Practical Applications

The underlying objective of a player profile is to inform programming and improve individual and develop position specific speed, strength and ballistic qualities. Therefore it is vital that the battery of assessments used by strength and conditioning coaches provides biomechanical information that is reflective of the athlete's developmental and

positional needs. In this regard the scientist and practitioner must be aware of the various positional demands, movement patterns, loading parameters, testing equipment and outcome variables available to create a profile representative of the strength and ballistic demands of the respective sport.

P_{max} and power-load curves provide vital information regarding neuromuscular/ballistic capabilities of the athlete. It appears that possessing high strength qualities has little effect on power production capabilities in highly trained rugby players; whereas players with greater sprint capabilities also produce slightly larger lower body P_{max} outputs. Therefore it appears P_{max} capabilities may be linked to enhanced sprint ability and vice versa; therefore improving one or both of these respective qualities may improve the other; in turn enhance rugby specific qualities, such as tackling, accelerating, side stepping and changing directions.

It is advantageous for all rugby players to possess high force and velocity capabilities, but certain force-velocity qualities may be more important to performing positional-match specific tasks; and Identifying individual weaknesses and determining the position specific force-velocity requirements, may in turn be used to develop individual and positional specific training programmes. The inclusion of F_{max} and V_{max} to the conventional lower body power profiling, may provide coaches with more holistic mechanical understanding of vertical jump performance in highly trained rugby players; which in turn may have a pronounced impact on programming. S_{fv} should be used to correct deficient areas (i.e. force deficient, velocity deficient or force-velocity deficient) along the force-velocity curve curve ^[37]. Current observations revealed that stronger players produced the largest F_{max} and the faster players generated the highest V_{max} ; the large and small S_{fv} associated with the stronger and faster player, respectively reinforced these force and velocity findings. These observations suggest that possessing and improving strength and speed in rugby union players may positively affect F_{max} and

Vmax capabilities and vice versa. Based on these acute comparisons, various speed, strength and ballistic lower body loading schemes could be prescribed to rectify these deficiencies.

***EFFECTS OF COMPLEX STRENGTH AND BALLISTIC (HEAVY
AND LIGHT) TRAINING ON PERFORMANCE***

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8.0 Prelude

In the previous chapters it has been established using cross-sectional designs that maximum strength and sprint ability may affect the resultant BTH and VJ force-velocity-power capabilities. The next three chapters use the major findings of these studies in longitudinal designs. This chapter implements a complex training design, where a strength exercise is followed by a heavy or light ballistic exercise in order to potentiate the performance of the ballistic exercise. In the past, strength and conditioning coaches have placed an isolated (block) or mixed (i.e. complex) emphasis on strength and ballistic development in accordance to the training phase (i.e. off-season, pre-season, in-season). Research has shown that both methods may cause worthwhile adaptations in strength and ballistic performance. Given the spectrum of strength and ballistic demands between the tight-five, loose forwards and inside and outside backs, it would be advantageous to determine whether certain types of complex training affect different parts of the force-velocity continuum (F_{max} and V_{max}) during BTH and VJ. Therefore, the primary purpose of this chapter was to determine the effects of strength coupled with heavy ballistic loading (SHB) and strength coupled with light ballistic loading (SLB) on the force-velocity-power continuum of these ballistic movements.

8.1 Introduction

Rugby union players must possess high amounts of strength, speed and power to excel at the elite level. Mechanically, a rugby union match is embodied by a spectrum of match and position specific force (e.g. scrummaging, mauling, rucking and lifting), power (e.g. tackling, fending, jumping, decelerating, accelerating and changing directions) and velocity (e.g. sprinting, kick-chasing, counter-attacking, line breaking, kicking and passing) governed actions [3, 4, 10, 84, 192, 454]. In general, the front row forwards perform more force dominant tasks, such as rucking and mauling; in contrast the backs perform more velocity dominant tasks, such as maximum speed sprinting and kicking; while the loose forwards perform a combination of force, velocity and power specific tasks [3, 5, 6, 84, 192].

Current training programmes implemented in rugby union often embrace a shifting focus that fluctuates with the yearly training plan, positional demands and individual strengths/weaknesses. Programmes may place an isolated (block) or mixed (i.e. conjugate, complex) emphasis on hypertrophy, strength, power and/or speed development in accordance to the training phase (i.e. off-season, pre-season, in-season) and individual needs. Isolated or block type training focus' on developing one primary variable per cycle; whereas mixed/conjugate or complex training concentrates on developing two or more performance variables simultaneously [380]. Research has shown that both methods may cause beneficial/worthwhile adaptations in strength and power in recreational and elite athletes [38, 44, 48, 52, 128, 256, 296, 303, 413, 448]. However, none of these studies have utilised complex training methods to improve the strength, power and speed demands specific to rugby union players.

During complex training a strength exercise is typically followed immediately by a ballistic exercise in order to potentiate the performance of the ballistic exercise; or vice versa [52, 277, 279]. Researchers have reported worthwhile/significant improvements in

strength, speed and ballistic performance (i.e. vertical jump height/power) in several athletic populations due to acute (4-8 weeks) complex training interventions of different combinations and sequences (i.e. strength coupled with heavy and/or light ballistic loads, strength coupled with speed training, and power coupled with speed training) [51, 52, 277, 301, 411, 455-457].

The majority of these training interventions have assessed changes in strength, speed and maximum ballistic power (P_{max}) without quantifying the changes in maximum force (F_{max}) and maximum velocity (V_{max}). Given the spectrum of strength and power demands between the tight-five, loose forwards and inside and outside backs in rugby union it would be advantageous to determine whether certain types of complex training affect different parts of the force-velocity continuum [37, 166]. It is hypothesised that strength coupled with heavy ballistic training should enhance P_{max} through positive shifts in F_{max} ; whereas complex strength coupled with light ballistic training should enhance P_{max} through positive shifts in V_{max} . Therefore, the primary purpose of this study was to determine the acute training effects of these two complex loading schemes on strength, speed and the ballistic force-velocity-power capabilities of semi-professional rugby union players.

8.2 Methods

8.2.1 Experimental Approach to the Problem

A cross-over within group design was implemented to investigate the hypothesis. Due to the high level of rugby player used within this experiment only a small number of players were able to be recruited. The cross-over design was utilised to allow for a smaller sample size to be utilised while still providing data for comparisons of group and individual responses to both interventions [458]. The players were homogeneously divided into two groups, where half of the players experienced intervention one and the other half

experienced intervention two; the groups then crossed over and underwent the other training intervention (Figure 8.1). The players experienced two complex training interventions of equal volume with a six week off-season washout period between interventions. During intervention one, the players underwent a five week complex strength (85-100% 1RM) coupled with a light ballistic load (15 and 30% 1RM) training programme. During intervention two, the players partook in a five week complex strength coupled with a heavy ballistic load (60 and 75% 1RM) training programme. The primary strength training exercises consisted of the bench press and back squat. Loaded bench throws (countermovement bench throw [CMBT] and concentric only bench throw [COBT]) and loaded vertical jumps (countermovement jumps [CMJ] and squat jumps [SJ]) were the primary exercises used to improve ballistic performance. Maximum bench press and back squat strength (1RM), incremental loaded bench throws and vertical jumps, and sprint times were assessed prior to and following the interventions to assess their effectiveness.

8.2.2 Subjects

Fourteen highly trained male rugby union players (Mean \pm SD; age = 20.9 \pm 1.6 years; mass = 95.2 \pm 7.4 kg; height = 1.85 \pm 0.05 m) participating in New Zealand's Provincial rugby union competition volunteered for this training study, which was approved by AUT University's Research Ethics Committee. Written informed consent was obtained from the subjects prior to study participation. Three of the players did not complete phase two of training as a result of off-season trades and acquisitions.

8.2.3 Procedures

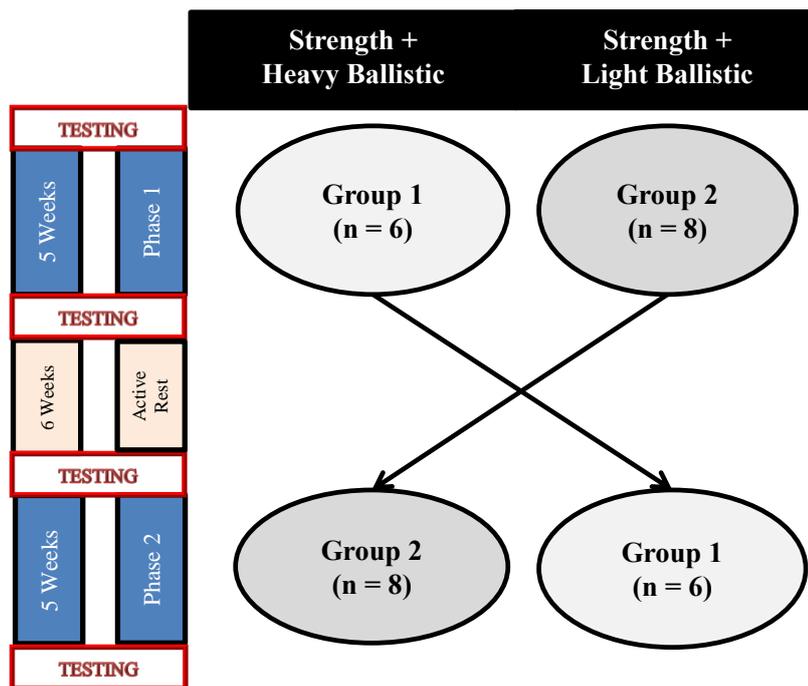


Figure 8.1 Cross-over complex strength and ballistic training design ^[458-461]

The players undertook speed, strength, and ballistic upper and lower body testing sessions, one week prior and one week following each training intervention. The testing week consisted of the three specific testing sessions. Session one was dedicated to measuring sprint times (10, 20 and 30 m) and assessing maximum dynamic upper and lower body strength (1RM). During the sprint testing, the athletes performed the following standardised warm-up in sequential order: light 400 m jog, ankling 40 m, A-skips 40 m, C-skips 40 m, high kicks 40 m, 10 walking lunges, 10 military push ups, 20 trunk rotations, 20 forward arm circles, two 30 m sprints at ~ 75% of maximal sprinting speed and one 30 m sprint at ~ 90% of maximal sprinting speed. Three minutes rest was then given, which was followed by three 30 m maximal sprint trials (3 min rest was given between each maximal sprint trial), starting in a split stance 50 cm behind the first set of timing lights (height of tripod = 25 cm). Sprint times were measured using dual beam infrared timing lights (Swift Performance, Lismore, Australia) at 10, 20 and 30 m splits (height of tripods = 50 cm). After the sprint testing athletes were given 30 min to recover before performing 1RM bench press (depth = bar-to-chest) and 1RM back squat (depth =

high parallel-to-floor) testing as follows: 8 repetitions at ~50% of 1RM (2 min rest), 3-4 repetitions at ~ 70% 1RM (3 min rest), 1-2 repetitions at ~ 80% 1RM (3-5 min rest), 1 repetition at ~ 90% 1RM (3-5 min rest), 1 repetition at 95-100% 1RM (3-5 min rest), 1 repetition at 100-105% 1RM ^[162]. The weighted 1RM chin-up was also assessed similar to the above method (4 repetitions at body mass [2 min rest], 2 repetitions at 50% of 1RM [2 min rest], 1 repetition at 75% 1RM [3-5 min rest], 1 repetition at 90% 1RM [3-5 min rest], 1 repetition at 100% 1RM [3-5 min rest], 1 repetition at 105-110% 1RM).

Sessions two and three were dedicated to assessing bench throw and vertical jump performance. The vertical jump and bench throw testing sessions were performed in a power cage (Fitness Technology: FT700 power cage, Adelaide, South Australia) utilising a free-weight barbell (a light weight wooden dowel was used for the body mass/0% 1RM load). A single linear position transducer (Celesco PT5A-150, Chatsworth, CA) was securely fixed to the top of the power cage, the cord was attached to the bar directly above the players left acromioclavicular joint during the vertical jump testing (Figure 8.2), and directly above the pectoralis major during the bench throw testing (Figure 8.3). The linear position transducer was connected to the computer interface (Fitness Technology: Ballistic Measurement Systems, Adelaide, South Australia) and sampled at a frequency of 400 Hz. A magnetic braking system (Fitness Technology: Magnetic Braking Unit [MBU], Adelaide, South Australia) was also attached to centre of the barbell and a spotter was positioned directly behind the athlete as safety precautions to decelerate the load once the bar-bell/athlete was projected into the air.

Session two was dedicated to assessing ballistic bench throw performance across a spectrum of five relative loads. The CMBT and COBT protocols consisted of two trials acyclic at each relative load (15, 30, 45, 60 and 75% 1RM) performed in sequential non-randomised order ^[29, 33]. The loading progressed from light to heavy; while the order of the CMBT (heads) and COBT (tails) trials were randomised (coin flip) at the beginning

of each testing session. A total of 20 bench throws were performed within the session. The CMBT utilised the SSC, where the subjects performed an initial eccentric (downward movement of the bar) contraction until the bar lightly touched the subject's chest, immediately followed by an explosive concentric (upward movement of the bar) contraction and subsequent flight phase. The COBT was a concentric only contraction, where the bar was initially lowered to the subject's chest with the aid of a spotter, followed by a three second pause, which was immediately followed by an explosive concentric contraction and subsequent flight phase.

Session three was dedicated to assessing vertical jump performance across a spectrum of six relative loads. The CMJ and SJ protocols consisted of two trials at each relative load (0, 15, 30, 45, 60 and 75% 1RM) also performed in sequential non-randomised order [28, 166]. The loading progressed from light to heavy; while the order of the CMJ (heads) and SJ (tails) trials were randomised (coin flip) at the beginning of each testing session. A total of 24 vertical jumps were performed within the session. The CMJ utilised the SSC, where the subjects performed an initial eccentric contraction to a self-selected depth (~ 120 degree knee angle), immediately followed by an explosive concentric (upward movement) contraction and subsequent flight phase. The SJ was a concentric only contraction, where the athlete initially squatted down to a self-selected depth (~120 degrees), followed by a three second pause, which was immediately followed by an explosively concentric contraction and subsequent flight phase. The subjects were instructed to apply downward pressure on the bar at all times to prevent it from displacing off the upper trapezius throughout testing.

Verbal encouragement was provided to all players at both testing sessions. Three minutes rest was given between each relative load during the bench throw and vertical jump testing sessions. Sessional order was also randomised (coin flip) and 72 hours rest was allocated between testing sessions.



Figure 8.2 Vertical jump testing set-up with magnetic breaking system



Figure 8.3 Bench throw testing set-up with magnetic breaking system

The players completed two, five week (20 sessions) complex training interventions (strength + heavy ballistic [SHB]; strength + light ballistic [SLB]) utilising a cross-over design [51, 110, 299, 458, 462]. Both interventions followed a four day complex training week with the same strength and power exercises with the only difference being the load that was moved in the ballistic movements (Table 1).

Table 8.1 Strength and ballistic training exercises completed during the five week training period [51, 383, 462]

Day 1	Day 2	Day 3	Day 4
Countermovement jumps*	Bench press ^σ	Back squat ^σ	Incline DB press ^σ
Countermovement bench throws*	Concentric-only bench throws*	¼ squat jumps (off-squat rack)*	Alternate arm DB bench press*
Power cleans* ^σ	Weighted chin ups ^σ	Bulgarian split squats ^σ	Box squat*
1 arm Jammer press ^σ	High pulls*	Speed lunge (elevated landing)*	Hip thrusts ^σ
1 arm DB snatch*	1 arm DB floor press ^σ		Calf raises ^σ
	1 arm DB rows ^σ		

*ballistic/power exercise; ^σstrength exercise; DB = dumbbell

The strength loading parameters (volume and intensity) were the same for both complex training interventions (linear stepwise progression) [459, 463, 464]. The heavy and light ballistic training loads were equated by intensity relative volume (IRV = % 1RM x # of Sets x # of Repetitions) and followed a wavelike periodised progression (Table 8.2) [459].

Table 8.2. Weekly strength and ballistic training loads expressed as mean intensity relative volumes

	Week 1	Week 2	Week 3	Week 4	Week 5
strength loading					
<i>IRV</i>	30.6	30.6	19.0	19.0	7.8
<i>sets x reps</i>	6 x 6	6 x 6	8 x 2-3	8 x 2-3	4 x 2
<i>intensity</i>	85	85	95-98	95-98	97-99
heavy ballistic loading					
<i>IRV</i>	10.8	9.0	9.0	15.0	6.0
<i>sets x reps</i>	4 x 4	4 x 3	5 x 3	5 x 4	4 x 2-3
<i>intensity</i>	60-75	75	60	75	60
light ballistic loading					
<i>IRV</i>	10.8	9.0	9.0	15.0	6.0
<i>sets x reps</i>	6 x 8	6 x 5	8 x 7-8	8 x 6-7	5 x 8
<i>intensity</i>	15-30	30	15	30	15

IRV = mean weekly intensity relative volume (# of sets x # of repetitions x percentage of 1RM).

8.2.4 Data Analysis

The use of position transducers in ballistic upper and lower body assessments have been previously validated with a high level of precision (CV<1.2%; ICC > 0.99) for the measured (i.e. displacement) and the derived variables (i.e. velocity, force and power) [17, 434]. The displacement-time data were filtered using a second order Butterworth filter (low pass) with a cut off frequency of 5 Hz. The displacement data was then single and double differentiated to determine the velocity and acceleration, respectively. Force was calculated as the sum of the system weight ([body mass + external load] x gravity) and the system mass multiplied by the acceleration of the athlete-load during jump testing [36]. Body mass was removed from the formula when calculating force from the bench throw data. Power was calculated as the product of force and velocity. The concentric and eccentric phases were determined based on velocity and force thresholds. The eccentric phase was initiated when velocity dropped below -0.01 m/s and terminated when velocity returned back to zero (i.e. at the bottom of the movement); the subsequent concentric phase was initiated when velocity increased above 0.01 m/s and terminated force was less than 5% of the system weight.

The kinematic and kinetic variables of interest included: peak force (PF), peak velocity (PV) and peak power (PP). Quadratics were fitted to the individual data across the loading spectrum to determine the load producing maximum PP (Pmax). Linear regression lines were fitted to the PF-PV data to predict hypothetical maximum bench throw and vertical jump force (Fmax) and velocity (Vmax) capabilities for each group [37]. The slopes (Sfv) of the respective regression lines were also calculated to create a ratio between Fmax and Vmax:

$$Sfv = Fmax/Vmax$$

8.2.5 Statistical Analysis

Means and standard deviations were used to represent centrality and spread of data. Percent change and effect size ($ES = ([X_{post} - X_{pre}]/SD_{pre})$) calculations were used to estimate the magnitude of change in the dependent variables due to training. ES were interpreted as trivial (0.00 – 0.25), small (0.25 – 0.50), moderate (0.50 – 1.00), large (1.00 – 1.50) and very large (> 1.50). Paired t-tests were used to determine if there were significant differences ($p < 0.05$) between pre and post testing. Independent samples t-tests were also used to determine if there were significant performance differences between the SHB and SLB training stimuli. Quadratic equations were also fitted to individual and group power-load and force (F_{max}) – velocity (V_{max}) curves compared for significant differences.

8.3 Results

The reliability of the included ballistic bench throw ($ICC > 0.89$; $CV < 8.7\%$) and vertical jump ($ICC > 0.86$; $CV < 6.5\%$) variables (PF, PV and PP) and testing protocols were previously established. The CMBT, COBT, CMJ and SJ provided almost identical diagnostic information ($r = 0.95 - 0.99$), therefore only the outcomes of the CMBT (Figures 8.3, 8.4 and Table 8.5) and CMJ (Figures 8.5, 8.6 and Table 8.7) data are reported.

Both complex training interventions (SHB and SLB) resulted in significant ($p < 0.03$) improvements in the 1RM bench press (4 – 9%) and 1RM back squat (9 – 12%). Sprint times were also improved over 10, 20 and 30 m (1 – 2%) (Tables 8.3 and 8.4).

Table 8.3. Effects of complex strength and ballistic training on strength and sprint times

	Strength + Heavy Ballistic Training				Strength + Light Ballistic Training			
	Pre	Post	ES	P-value	Pre	Post	ES	P-value
1RM BP (kg)	126 ± 19	131 ± 20	0.28	0.004	121 ± 14	132 ± 17	0.76	0.0006
Relative BP (U)	1.32 ± 0.20	1.35 ± 0.20	0.16	0.05	1.27 ± 0.14	1.35 ± 0.16	0.16	0.002
1RM squat (kg)	150 ± 23	168 ± 29	0.77	0.001	159 ± 19	173 ± 16	0.70	0.001
Relative squat (U)	1.54 ± 0.24	1.70 ± 0.29	0.68	0.002	1.58 ± 0.13	1.71 ± 0.14	0.98	0.003
10 m (s)	1.75 ± 0.06	1.73 ± 0.05	-0.37	0.07	1.76 ± 0.04	1.73 ± 0.05	-0.68	0.03
20 m (s)	3.02 ± 0.08	2.99 ± 0.07	-0.46	0.01	3.03 ± 0.08	3.00 ± 0.09	-0.37	0.001
30 m (s)	4.20 ± 0.10	4.17 ± 0.10	-0.26	0.20	4.19 ± 0.11	4.16 ± 0.10	-0.34	0.003

1RM BP = one-repetition maximum bench press; **Relative BP** = 1RM BP divided by body mass; **1RM Squat** = one-repetition maximum parallel back squat; **Relative Squat** = 1RM squat divided by body mass; **10 m – 20 m – 30m** = 10, 20 and 30 meter sprint times; **ES** = effect size.

The SLB training resulted in significantly larger increases (SLB = 9.0 % vs. SHB = 4.0 %) in 1RM bench press (Table 8.4).

Table 8.4. Between group difference in strength and sprint times

Variable	SHB Pre-Post % Change	SLB Pre-Post % Change	ES	P-Value
1RM BP (kg)	4.0 ± 3.4	9.0 ± 5.8	-0.86	0.04
Relative BP (U)	2.6 ± 3.6	7.0 ± 5.5	-0.81	0.04
1RM Squat (kg)	11.7 ± 7.8	9.2 ± 5.6	0.45	0.42
Relative Squat (U)	10.6 ± 7.7	8.2 ± 5.9	0.40	0.53
10 m (s)	-1.2 ± 1.8	-1.6 ± 1.7	0.25	0.63
20 m (s)	-1.2 ± 1.3	-1.0 ± 0.6	-0.35	0.66
30 m (s)	-0.6 ± 1.5	-0.9 ± 0.6	0.41	0.70

SHB = strength + heavy ballistic training; **SLB** = strength + light ballistic training; **1RM BP** = one-repetition maximum bench press; **Relative BP** = 1RM BP divided by body mass; **1RM Squat** = one-repetition maximum parallel back squat; **Relative Squat** = 1RM squat divided by body mass; **10 m – 20 m – 30m** = 10, 20 and 30 meter sprint times; **ES** = effect size.

8.3.1 Ballistic Upper Body Adaptations

The SHB and SLB training interventions produced significant ($p < 0.04$) increases in CMBT Pmax (12 - 18%) (Tables 8.5 and 8.6). Specifically, CMBT Fmax (10%) improved significantly ($p = 0.01$) in the SHB group; while Vmax (15%) improved significantly ($p = 0.02$) in the SLB group. Moderate to large ($ES = 0.61 - 1.02$) PP CMBT adaptations (13 - 24%) were also observed in both groups across all loads (Figure 8.4). Interestingly, the SLB group generated their largest improvements in PF (10 and 13%) and PV (11 and 13%) using CMBT loads of 15 and 30% 1RM, respectively (Figure 8.5a). In contrast, the

SHB group produced their largest improvements (13 – 16%) in CMBT PV using loads of 60% and 75% 1RM (Figure 8.5b).

Table 8.5 Effects of complex strength and ballistic training on countermovement bench throw performance

Variable	Strength + Heavy Ballistic Training				Strength + Light Ballistic Training			
	Pre	Post	ES	P-value	Pre	Post	ES	P-value
PPmax (W)	681 ± 127	789 ± 176	0.84	0.04	661 ± 116	759 ± 156	0.85	0.01
PP %1RM	46.1 ± 3.9	43.9 ± 6.0	-0.56	0.29	46.1 ± 3.2	45.5 ± 4.1	-0.17	0.67
PP load (kg)	57.7 ± 6.1	56.9 ± 8.0	-0.12	0.78	55.7 ± 6.1	60.2 ± 9.0	0.73	0.05
PFmax (N)	1376 ± 192	1508 ± 196	0.69	0.01	1421 ± 150	1516 ± 234	0.63	0.14
PVmax (m/s)	2.84 ± 0.39	3.08 ± 0.63	0.61	0.32	2.67 ± 0.31	3.05 ± 0.49	1.20	0.02
Sfv	492 ± 86	500 ± 76	0.09	0.84	536 ± 52	504 ± 83	-0.60	0.25

PPmax = maximum peak power output in watts; PP %1RM = percent 1RM load where peak power occurred; PP load = load in kg where peak power occurred; PFmax = hypothetical maximum peak force capabilities at zero velocity; PVmax = hypothetical maximum peak velocity capabilities at zero force; Sfv = PFmax/PVmax; ES = effect size.

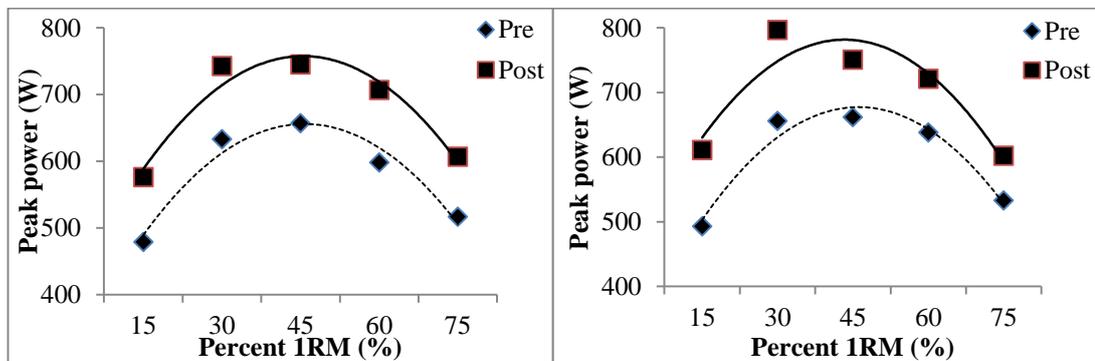


Figure 8.4 Countermovement bench throw peak power changes across the loading spectrum a) strength + light ballistic training b) strength + heavy ballistic training.

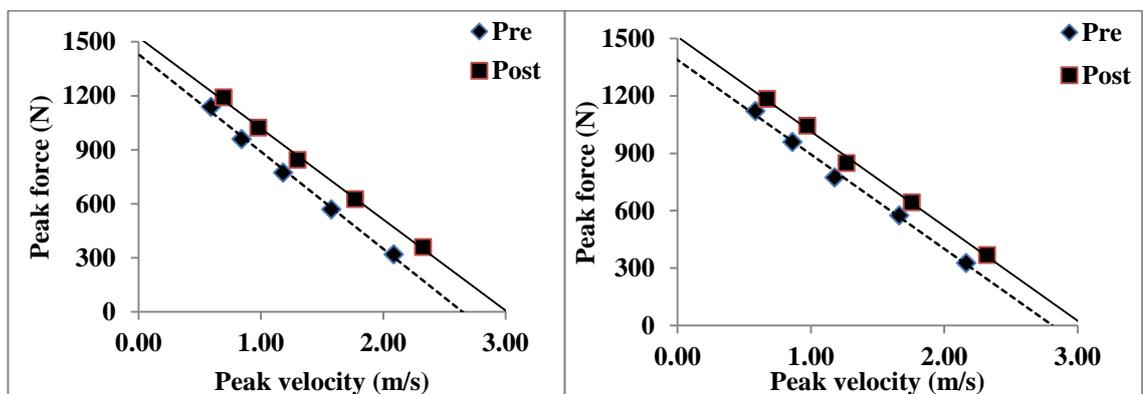


Figure 8.5 Countermovement bench throw peak force-velocity changes due to complex a) strength + light ballistic training b) strength + heavy ballistic training

There were only trivial to small non-significant differences in CMBT Pmax, Fmax and Vmax between the SHB and SLB training groups (Table 8.6).

Table 8.6. Between group differences in countermovement bench throw performance

Variable	SHB Pre-Post % Change	SLB Pre-Post % Change	ES	P-value
PP Max (W)	11.9 ± 17.4	15.5 ± 17.3	-0.21	0.66
Fmax (N)	10.1 ± 9.8	6.8 ± 13.2	0.25	0.62
Vmax (m/s)	10.4 ± 26.6	14.7 ± 16.1	-0.27	0.61
Sfv	5.0 ± 27.6	-5.4 ± 15.5	0.67	0.67

SHB = strength + heavy ballistic training; **SLB** = strength + light ballistic training; **PP Max** = maximum peak power output in watts; **PP %1RM** = percent 1RM load where peak power occurred; **PP load** = load in kg where peak power occurred; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax; **ES** = effect size.

8.3.2 Ballistic Lower Body Adaptations

There were large to very large (ES = 1.37 – 2.40) significant ($p < 0.004$) increases in CMJ Pmax following the SHB (46%) and SLB (36%) training (Tables 8.7 and 8.8). CMJ Pmax percentage 1RM decreased significantly ($p < 0.05$) due to SHB (pre = 12% 1RM; post = -2% 1RM) and SLB (pre = 4%; post = -1%) training. CMJ Vmax was significantly ($p < 0.02$) improved due to SHB (57%) and SLB (68%) training (Tables 8.7 and 8.8). The SHB training resulted in small increases in CMJ Fmax (10%); conversely the SLB training group had small decreases in their CMJ Fmax (-4%).

Both training groups had large to very large (ES = 1.04 – 2.78) improvements in CMJ PP-load curves with the largest improvements occurring at body mass (0% 1RM) in the SLB (34%; ES = 1.80) and SHB (46%; ES = 2.78) groups (Figure 8.5). SLB training also produced their largest increases in CMJ PF (14 - 15%) and PV (21 - 22%) at body mass and 15% 1RM (Figure 8.6a). The SHB training group also produced their largest increases in CMJ PF (20%; ES = 2.34 at body mass; however, substantial (ES > 2.11) increases in PV (28 – 33%) were observed across the light (body mass and 15% 1RM) and moderate loads (30-45% 1RM).

Table 8.7 Effects of complex strength and ballistic training on countermovement jump performance

Variable	Strength + heavy ballistic training				Strength + light ballistic training			
	Pre	Post	ES	P-value	Pre	Post	ES	P-value
PPmax (W)	3325 ± 588	4738 ± 482	2.40	0.0003	3783 ± 667	4997 ± 496	1.82	0.004
PP 1RM (%)	12.0 ± 24.3	-1.5 ± 8.5	-0.56	0.04	4.4 ± 12.4	-1.3 ± 11.9	-0.45	0.05
PP load (kg)	20.4 ± 40.2	-1.2 ± 14.0	-0.54	0.04	6.6 ± 19.5	-2.8 ± 20.9	-0.48	0.06
PFmax (N)	3589 ± 793	3886 ± 727	0.37	0.09	3807 ± 407	3666 ± 501	-0.35	0.38
PVmax (m/s)	5.58 ± 1.66	8.40 ± 2.72	1.70	0.01	6.03 ± 2.02	9.93 ± 3.46	1.93	0.004
Sfv (N/m/s)	703 ± 273	521 ± 230	-0.67	0.03	692 ± 232	422 ± 196	-1.16	0.001

PPmax = maximum peak power output in watts; **PP 1RM** = percent 1RM load where peak power occurred; **PP load** = load in kg where peak power occurred; **PFmax** = hypothetical maximum peak force capabilities at zero velocity; **PVmax** = hypothetical maximum peak velocity capabilities at zero force; **Sfv** = Fmax/Vmax; **ES** = effect size.

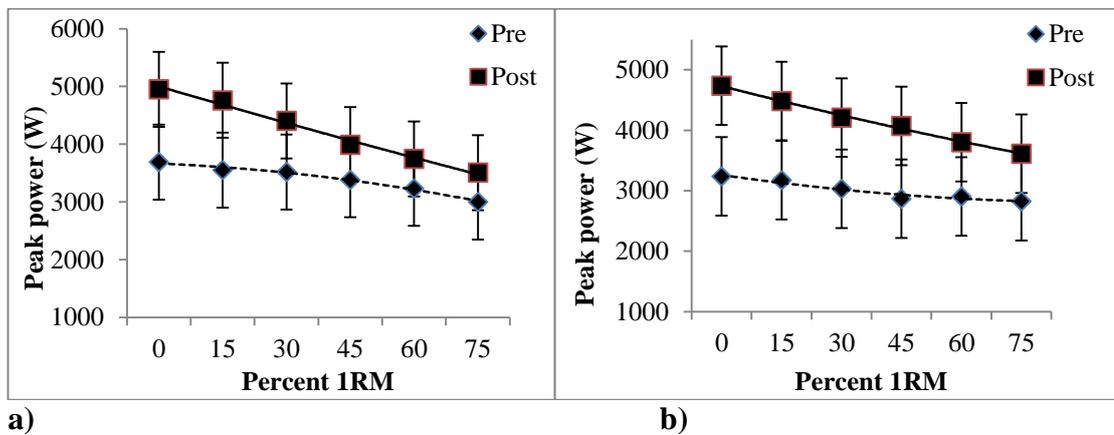


Figure 8.6 Vertical jump peak power changes across the loading spectrum: a) strength + light ballistic training b) strength + heavy ballistic training

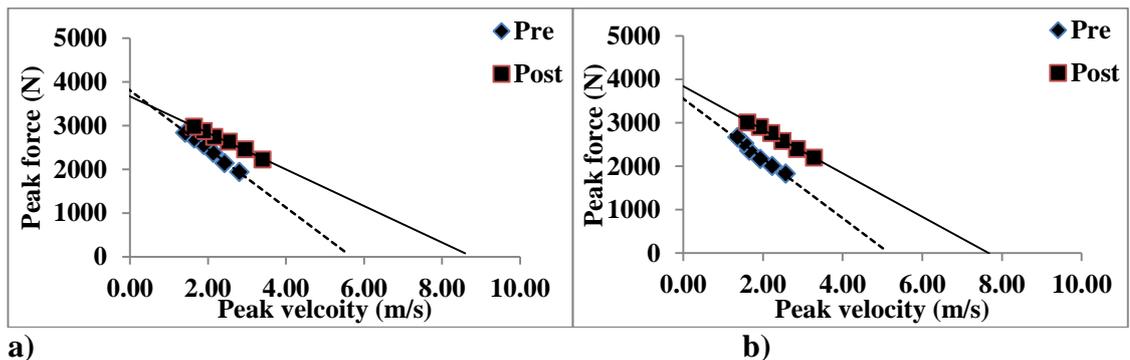


Figure 8.7 Countermovement jump peak force-peak velocity changes due to complex a) strength + light ballistic training b) strength + heavy ballistic training

The SHB training lead to substantially greater adaptations in CMJ Fmax (14%; $p = 0.06$; $ES = 1.24$) in comparison to the SLB training (Table 8.8)

Table 8.8. Between group differences in countermovement jump performance

Variable	SHB Pre-Post % Change	SLB Pre-Post % Change	ES	P-value
PP Max (W)	46.2 ± 27.6	35.6 ± 26.3	0.40	0.61
Fmax (N)	9.9 ± 13.5	-3.5 ± 10.8	1.24	0.06
Vmax (m/s)	57.1 ± 53.8	67.6 ± 42.3	-0.25	0.43
Sfv	-20.7 ± 33.0	-33.3 ± 15.6	1.19	0.35

SHB = strength + heavy ballistic training; **SLB** = strength + light ballistic training; **PP Max** = maximum peak power output in watts; **PP %1RM** = percent 1RM load where peak power occurred; **PP load** = load in kg where peak power occurred; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax; **ES** = effect size calculations.

8.4 Discussion

The aim of this study was to effect positive adaptations in strength, sprint ability and CMBT and CMJ force-velocity-power capabilities via acute complex strength and ballistic training in semi-professional rugby union players.

8.4.1 Maximum Strength

As expected SHB and SLB training caused significant increases in the 1RM bench press (4 and 9%) and the 1RM parallel back squat (12 and 9%), however there were no clear/definitive differences between groups. Current findings are in agreement with other acute (five to twelve weeks) strength training studies in highly trained rugby and American football players; with similar to much larger improvements in upper (3 to 13%) and lower (8 to 18%) body strength [38, 44, 46-50, 245, 303, 321, 354, 390, 395, 400, 402, 403, 465] reported.

These training studies implemented a range of different hypertrophy, strength and power loading schemes to increase maximum strength qualities including: conjugate-mixed method [38, 47, 321, 354, 395], stepwise-blocks [402], linear [47, 245, 390, 403, 465], non-linear [47], cluster sets [44], heavy load-high force [303, 321], power specific [303, 321] and strength coupled

with electromyostimulation training ^[50]. Regardless of the method of periodisation utilised, it appears that maximum strength can be improved with as little as twelve to twenty strength training sessions (four to six weeks) if a strength specific stimulus is prescribed (i.e. 3 to 8 sets of 2 to 6 reps at 85 to 95% 1RM) ^[54, 354, 400, 403]. Based on the literature, the magnitude (ES) of change in strength appeared to be dependent on the total number of training sessions (duration x frequency) performed during the respective intervention. To further support this notion, Hoffman et al.^[47] found 5 to 7% and 10 to 14% improvements in the 1RM bench press and 1RM squat after six weeks of resistance training; and slight larger increases in bench press (7 to 8%) and squat (10 to 17%) strength after fifteen weeks of training, respectively ^[47]. The long term effects of resistance training on strength were not investigated and are beyond the scope of this present study ^[49, 104, 105]. Previous literature also suggests that gains in strength may also contribute to improvements in sprint performance due to an increase in force generating capabilities ^[34, 82, 466].

8.4.2 Sprint Performance

Sprint ability is a key rugby-football performance indicator and is often used along with strength and power measures for training prescription, talent identification, national selection criteria and to differentiate elite from non-elite ^[4, 84, 90, 192, 297, 467]. Both complex training interventions (SHB and SLB) resulted in small to moderate improvements in sprint times over 10 to 30 m (-1 to -2%); indicating that both loading schemes lead to similar and possibly worthwhile adaptations in sprint performance. Our findings illustrate that acceleration (10 m) and maximum speed (30 m) specific to rugby union can be improved in highly trained players using heavy (60 and 75% 1RM) and/or light ballistic (15 and 30% 1RM) complex training modalities. Previous training studies on rugby-football code athletes also found similar as well as larger improvements (1 to 9%) in sprint

ability (i.e. acceleration, maximum speed and 5 to 40 m sprint times) [46-48, 53, 88, 95, 256, 303, 468, 469]. These short-term training studies utilised a range of training methods to improve sprint performance that included: mixed [469], linear [46] and block type strength [46, 95, 469, 470], complex [88, 95, 468], contrast [88], power [46, 303, 470], heavy ballistic load [303], light ballistic load and resisted and non-resisted sprint [53, 169, 468-470] training. Acute (five to eight weeks) adaptation in sprint ability varied greatly depending on the training method utilised during training. Strength and ballistic based training studies [46, 48, 52, 88, 95, 303, 470] reported slightly smaller improvements (1 to 6%) in sprint performance, in comparison to training studies including a resisted or non-resisted sprint training stimulus (4 to 9%) [53, 468-470].

Current complex strength and ballistic training findings suggest that lower body strength increases of 6 to 10% and power increases of 23 to 40% may be required to cause a 1% improvement in sprint performance. These inferences are further supported by previous research that suggested strength increases of 12 to 13% may be needed to cause a 2% reduction in sprint times [46-48, 303, 449]. The two complex training interventions in the present study provided no sprint acceleration or maximum speed specific stimuli; therefore larger and more rapid adaptations in sprint performance would most likely be induced if a sprint training stimulus was included [53, 84, 403, 455, 468, 469]. Developing ballistic force, velocity and power capabilities may also be of equal importance to improving rugby-football code specific performance (e.g. changing directions, jumping, kicking, tackling and fending) and will be subsequently discussed.

8.4.3 Ballistic Adaptations

Heavy load ballistic training adaptations have been attributed to increases in strength, rate of motor unit recruitment (size principle), the activation of type II muscle fibres and subsequent improvement in Fmax capabilities [379]. Light load ballistic training is thought

to allow athletes to train at velocities similar to on-field tasks (i.e. sprinting, jumping, changing directions, passing, kicking and fending) and to elicit positive increases in neural activation rates, enhance inter-muscular coordination and improve Vmax capabilities [128, 256, 303, 404]. It is suggested that these training methods follow the principle of specificity, which states that training induced adaptations are greatest at or around the loads, velocities and movement patterns utilised during training [404, 471-474].

8.4.3.1 Ballistic Upper Body Adaptations

The SHB training lead to larger shifts in PV utilising the heavier CMBT loads (60 and 75% 1RM) adhering to the principle of specificity. Contrary to current principles and past literature [37, 256, 296, 307, 406] reciprocal trends in PF and PP were observed as a result of SHB training, where the largest adaptations were found in the lighter CMBT loads (15 and 30% 1RM). As predicted, the SLB training lead to larger shifts in PF (13 to 10%) using the lighter loads (15 and 30% 1RM); moderate to large improvements in PV (10 to 17%) and PP (13 to 20%) were observed across all CMBT loads. In light of these findings, no definitive PF-PV-PP- versus load trends could be established, as it appears that SHB and SLB training may be implemented to improve CMBT PF, PV and PP across the entire loading spectrum in semi-professional rugby union players. Previous short-term strength and ballistic upper body training research on American football players also found improvements in upper body force, velocity and power [395, 465].

Jones et al. [465] found moderate improvements in plyometric push-up mean power (12%) and PF (5%) following fourteen weeks of linear strength training (i.e. 3 to 5 sets of 2 to 10 repetition using 50 to 95% 1RM) with an acceleration focus in collegiate American football players [465]. These improvements were less than current PF (7 to 10%) and PP (13 to 18%) findings utilising absolute loads (45 to 60% 1RM; 54 to 73 kg) similar to those moved during the plyometric push-up (~ 65% body mass; ~ 60 kg). These discrepancies can most likely be attributed to the lack of a ballistic training stimulus (e.g.

plyometric push-up) within the fourteen week strength training programme^[465]. A shorter (seven week) band resisted strength and power based training study also found small improvements in PV (3%) and PP (3%) during the speed bench press (~85% 1RM) in collegiate American football players; which were substantially lower than current PV (16 to 17%) and PP (13 to 17%) CMBT adaptations utilising a similar relative load (75% 1RM)^[395]. The smaller improvements in PP and PV observed above may have been a result of the non-ballistic nature of the power training stimuli and movement pattern (e.g. speed bench press) utilised during training and testing. Mechanically, there is a deceleration phase which occurs towards the end range in all non-ballistic movements that may impair the development of upper body velocity and power capabilities^[33, 246, 395]. These findings strengthen the argument that increases in upper body force, velocity and power are amplified as a direct result of ballistic training. No previous studies have investigated the effects of strength and/or ballistic upper body training on CMBT PV, PF, Vmax and Fmax in any athletic populations; but certain deductions can be made from current observations and previous ballistic upper body power based research^[29-31, 41, 104, 109, 240, 278, 280, 296, 395, 465].

SHB and SLB training produced significant improvements in CMBT Fmax (10 and 7%) and Vmax (10 and 15%), respectively. This information suggests that these diverging mechanistic qualities (Fmax and Vmax) can be improved simultaneously via complex SHB and SLB training, which in turn should result in significant adaptations in CMBT Pmax^[37, 109]. Significant upward shifts (12 to 15%) in Pmax output along with 1RM bench press (4 to 9%) were observed following the SHB and SLB training; a similar phenomenon was also observed in highly trained rugby league players over a two year period; as the players gained strength (8%) Pmax also increased (15%)^[296]. It appears that improvements in strength and Pmax are interconnected when utilising a long-term linear (off-season) and wave-like (in-season) periodised strength and power programme.

In the present study, 1RM bench press and CMBT Pmax were not interconnected as indicated by a low correlation; therefore increases in Pmax may be due to the ballistic high velocity/power stimulus received during training. There were no significant changes in Pmax CMBT load, as it occurred consistently between 40 and 50% 1RM prior to and following both complex training interventions. Similar Pmax loads were also observed in a number of other studies utilising highly trained rugby players [29, 31, 32, 54, 246, 296].

8.4.3.2 Ballistic Lower Body Adaptations

Adhering to the principle of specificity, the SLB training produced its largest shifts in PF (11 to 15%), PV (19 to 22%) and PP (25 to 34%) utilising the lighter ballistic loads (body mass/0, 15 and 30% 1RM). The SHB training caused large to very large improvements in CMJ PF (13 to 20%), PV (18 to 33%) and PP (28 to 46%) across all loads, with the largest increases occurring at body mass. Previous strength, power and sprint training studies also observed smaller scale improvements in vertical jump performance (e.g. jump height and PP) in highly training rugby-football code athletes [46-48, 95, 104, 109]. Ronnestad et al.^[95] found very large improvements in loaded (i.e. 20, 35 and 50 kg) SJ PP (7 to 11%) in professional soccer players following seven weeks of strength-only training and strength training contrasted with plyometrics. No significant group differences were observed in SJ PP possibly due to the ballistic training stimulus received by both groups during the on-field training sessions. The above PP adaptations were slightly less than the PP improvements observed in the current study, possibly due to the lack of loaded ballistic stimuli received during contrast strength and plyometric training [95]. Other acute (five to eight weeks) training studies utilising combinations of strength, plyometric and sprint training found small to large increases in vertical jump height (3 to 12%) coupled with improvements in sprint performance in highly training rugby, Australian football and soccer players [88, 403, 468, 470]. A series of studies conducted by Hoffman and colleagues [46-48] also found a range of vertical jump adaptations, from trivial

reductions to very large improvements (-1 to 13%) in jump height and PP in collegiate American football players following ten to fifteen weeks of various off-season resistance training programmes (i.e. power-lifting, Olympic-lifting, linear, non-linear, block and complex training methods). Trivial to small CMJ adaptations (-1 to 4%) were observed in the linear, non-linear and power-lifting training programmes ^[46, 47]. In contrast, the complex (strength and squat jump) training and Olympic lifting programme lead greater improvements in CMJ height (5 to 12%), respectively ^[46, 48]. The ten weeks of Olympic-lifting training was significantly more effective at improving CMJ performance any of the other methods, due to the high force, velocity and subsequently greater power outputs produced during the Olympic lift variations (e.g. snatch pulls, clean pulls, power shrugs, power cleans and push jerks) utilised ^[46]. The above findings suggest that acute (< 10 weeks) Olympic-lifting and ballistic-only and complex training can be utilised to stimulate positive shifts in CMJ performance, with complex strength and loaded ballistic training eliciting slightly more prominent adaptations. It must be noted that the training periods (five weeks) utilise herein may not have been long enough to demonstrate the effectiveness of one training programme over the other; it has been suggested that training durations of eight or more weeks may be required to reflect differences between training programmes ^[104].

Current Fmax and Vmax findings reinforced these observations; as both complex training modalities lead to very large rightward/positive shifts in PV (Vmax = 57 to 67%). The SHB training caused a marked increase in Fmax (10%); whereas the SLB trained resulted in a small decrease in Fmax (-3.5%). This information suggests that SHB and SLB training may be implemented to effect very large positive shifts in CMJ velocity capabilities (rightward); and to a lesser extent elicit smaller shifts in PF (upward) ^[37]. It also seems that the full PF-PV spectrum can be improved simultaneously using SHB training, which in turn may have accounted for slightly larger increases in Pmax (46%)

in comparison to SLB training (36%). As expected the increase in Pmax were coupled with significant improvements in the 1RM squat (12 and 9%) due to SHB and SLB training. A similar phenomenon was also observed in highly trained rugby league players over a two year period, as the players gained strength (14%) SJ Pmax also increased (13%) ^[104]. These long term increases in strength and Pmax were highly correlated ($r = 0.96$), indicating that an increase in strength may cause an equivalent increase in Pmax utilising a combination of linear (off-season) and wavelike (in-season) programming within the yearly training plan ^[104]. Current acute adaptations in strength (~10%) and CMJ Pmax (~40%) were poorly correlated; therefore increases in Pmax were most likely due to the high velocity and power outputs generated during the loaded ballistic jump portion of the complex training.

Predicted Pmax loads shifted from 12% (20 kg) and 4% (7 kg) 1RM to -1.5% (1.2 kg) and -1.3% (-2.8 kg) 1RM in the SHB and SLB training groups, respectively. It has been suggested that CMJ and SJ Pmax loads can occur between body mass and 65% 1RM in highly trained rugby (union and league) players, depending on the testing protocol, apparatus and analysis (i.e. inclusion or exclusion of body mass) ^[27, 35, 36, 303, 321, 439]. Pmax loads are shifted upwards if body mass is excluded and downwards if it is included in data analysis ^[15, 201, 308]; the current vertical jump calculations were based on a system mass that included body mass and the external load in all calculations. There is minimal research investigating the effects of training on the CMJ Pmax load shifts; but the complex strength and ballistic training herein appeared to cause downward shifts in Pmax load regardless of the load utilised during training, the true mechanistic cause of this shift remains unclear, and requires further investigation.

8.5 Practical Applications

The present findings suggest that maximum bench press and squat strength, sprint ability and bench throw and vertical jump force, velocity and power capabilities can be improved simultaneously over the short-term utilising complex strength coupled with heavy and light load ballistic training in highly trained rugby union players. The strength and conditioning coach could possibly utilise these acute complex training modalities (SHB and SLB) as a pre-season stimulus to elicit positive upper and lower body adaptations across the entire force-velocity spectrum and improve maximum strength, power and speed specific to rugby performance.

The twenty session complex strength and ballistic training interventions herein included a number of different strength (e.g. bench press, back squats and split squats) and ballistic (e.g. loaded jumps, bench throws and power cleans) exercises that lead to beneficial adaptations in F_{max} , V_{max} and P_{max} . It is recommended that strength (85-98% 1RM) coupled with heavy ballistic loading (60-75% 1RM) be prescribed to induce worthwhile improvements in F_{max} ; and strength (85 – 98% 1RM) coupled with light ballistic loading (15-30% 1RM) to elicit beneficial increases in V_{max} . Both complex training modalities should lead to similar positive adaptations in bench throw and vertical jump P_{max} . It must also be noted that larger worthwhile more rapid improvements in sprint ability would most likely have transpired with the addition of a sprint training stimulus, but requires further investigation in elite rugby-football populations.

***EFFECTS OF A SIX WEEK OFF-SEASON ON STRENGTH, SPRINT
ABILITY AND BALLISTIC PERFORMANCE IN SEMI-
PROFESSIONAL RUGBY UNION PLAYERS***

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9.0 Prelude

In rugby there is often a four to six week off-season rest period, which allows the athletes to rest and recover after a lengthy competitive season. While the previous chapter (Chapter 8) investigated the effects of complex training on strength and ballistic performance, understanding the effects of detraining on these performance measures may also help determine the structure/focus of such off-season rest periods. Based on research addressing training-retaining-detraining principles, it can be hypothesised that up to four weeks of training cessation may have minimal effect on maximum strength; but a larger negative effect on sprint ability and ballistic performance. Such a contention requires further investigation on elite athletes, therefore the purpose of this chapter was to determine the residual effects of a six week off-season (resistance detraining) on maximum strength, sprint running ability and BTH and VJ force-velocity-power capabilities in a semi-professional rugby union players.

9.1 Introduction

In semi-professional rugby, a training year is divided into off-season, pre-season and in-season; in the southern hemisphere the rugby schedule is unique, as there are a number of overlapping competitions (club, provincial [semi-professional] and super rugby [professional]) a single professional player may be involved in. This can be a lengthy (~ 10 months) and physically demanding competition period with accumulative and possibly negative effects on performance; therefore athletes are generally given three to six weeks of active off-season rest free of any structured team training (no resistance) to allow the body to heal and repair.

When strength, sprint running and/or ballistic (i.e. power) training is ceased for an extended period, the decay rates in these performance variables are of great interest. Understanding the rate of decay of various performance attributes may allow us to determine the minimum and maximum duration strength and power training can be ceased before another training stimulus is required. The residual effects (the retention of strength, speed or power over a period of training cessation) and decay rates (a quantification of the speed at which performance qualities are lost over time) may provide crucial information that may allow strength and conditioning coaches to periodise the yearly training plan more effectively.

According to Issurin ^[475], elite athletes may be able to retain maximum strength and sprint ability/power qualities for up to 30 ± 5 and 5 ± 3 (mean \pm SD) days post-training, respectively. Acceleration, maximum speed and ballistic performance measures, such as bench throws and vertical jumps utilise the same energy system (alactic) and require similar neuromuscular activation processes, therefore should respond similar to detraining. Detraining data on elite athletes is scarce, but researchers utilising resistance trained individuals have reported that strength can be maintained for up to four weeks with more substantial losses occurring thereafter ^[59, 60, 363, 401, 476]; while there is

minimal research on the decay rates of speed and ballistic performance in elite rugby codes.

Based on current findings and detraining principles (decay rates and residual effects), it can be hypothesised that four or more weeks of training cessation may cause minimal (trivial/small) changes in strength qualities and moderate to large reductions in ballistic performance and sprint capabilities (increases in sprint times) in highly trained rugby union players. Given these hypotheses the purpose of this investigation was to determine the residual effects of a six week off-season on strength, sprint times and ballistic upper and lower body performance in a squad of semi-professional rugby union players.

9.2 Methods

9.2.1 Experimental Approach to the Problem

The players' experienced six weeks of complex strength and ballistic training prior to the six weeks of active off-season rest. Changes in strength, sprint ability and ballistic upper and lower body performance were quantified prior to and following the active rest. Paired t-tests, percent change and effect size calculations were used to determine significant differences and estimate the magnitude of change in the dependent variables due to active rest, which included hiking, jogging, running, cycling and stretching, but not resistance training approximately three to four days per week.

9.2.2 Subjects

Ten highly trained male rugby union players (mean \pm SD; age = 20.5 ± 1.4 years; mass = 96.4 ± 6.5 kg; height = 1.85 ± 0.04 m) participating in New Zealand's Provincial rugby union competition volunteered for this study, which was approved by AUT University's

Research Ethics Committee. Written informed consent was obtained from the subjects prior to study participation.

9.2.3 Procedures

Sprint times, strength, and ballistic upper and lower body testing sessions were conducted, one week following the complex training and the week following the six week period of active off-season rest. The testing week consisted of the three specific testing sessions. During session one, sprinting (10, 20 and 30 m) and one-repetition maximum (1RM) back squat and bench press strength was assessed. During the sprint testing, the athletes performed the following standardised warm-up in sequential order: light 400 m jog, ankling 40 m, A-skips 40 m, C-skips 40 m, high kicks 40 m, 10 walking lunges, 10 military push ups, 20 trunk rotations, 20 forward arm circles, two 30 m sprints at ~ 75% of maximal sprinting speed and one 30 m sprint at ~ 90% of maximal sprinting speed. Three minutes rest was then given, which was followed by three 30 m maximal sprint trials (3-5 min rest were given between each maximal sprint trial), starting in a split stance 50 cm behind the first set of timing lights (height of tripod = 25 cm). Sprint times were measured using dual beam infrared timing lights (Swift Performance, Lismore, Australia) at 10, 20 and 30 m splits (height of tripods = 50 cm). After the sprint testing athletes were given 30 min to recover before performing bench press (depth = bar-to-chest) and back squat (depth = thigh parallel-to-floor) testing as follows: 8 repetitions at ~50% of 1RM (2 min rest), 3-4 repetitions at ~ 70% 1RM (3 min rest), 1-2 repetitions at ~ 80% 1RM (3-5 min rest), 1 repetition at ~ 90% 1RM (3-5 min rest), 1 repetition at ~ 95-100% 1RM (3-5 min rest), 1 repetition at ~102-105% 1RM. Sessions two and three were dedicated to assessing countermovement bench throw (CMBT) and countermovement jump (CMJ) performance (Figure 9.1 and 9.2). CMBT (15, 30, 45, 60 and 75% 1RM) and CMJ (body mass/0, 15, 30, 45, 60 and 75% 1RM) performance were assessed across a spectrum of five and six relative loads, respectively. The ballistic testing protocols consisted of two

trials at each relative load performed in sequential non-randomised order. The testing sessions were performed in a power cage (Fitness Technology: FT700 power cage, Adelaide, South Australia) utilising a free-weight barbell with a single linear position transducer (Celesco PT5A-150, Chatsworth, CA) was securely fixed to the top of the power cage, the cord was attached to the bar directly above the players left acromioclavicular joint during the CMJ testing (Figure 9.1), and directly above the pectorialis major during the CMBT testing (Figure 9.2). The linear position transducer was connected to a computer interface (Fitness Technology: Ballistic Measurement Systems, Adelaide, South Australia) and sampled at a frequency of 400 Hz. A magnetic braking system (Fitness Technology: Magnetic Braking Unit [MBU], Adelaide, South Australia) was also attached to centre of the barbell and a spotter was positioned directly behind the athlete as safety precautions to decelerate the load once the bar-bell/athlete was projected into the air. Tension supplied by the breaking system cable was negligible (< 1 kg) and therefore not factored into the analysis.



Figure 9.1 Countermovement jump testing set-up with magnetic breaking system



Figure 9.2 Countermovement bench throw testing set-up with magnetic breaking system

9.2.4 Data Analysis

The use of position transducers in ballistic upper and lower body assessments have been previously validated with a high level of precision ($CV < 1.2\%$; $ICC > 0.99$) for the measured (i.e. displacement) and the derived variables (i.e. velocity, force and power) [17, 434]. The displacement-time data were filtered using a second order Butterworth filter (low pass) with a cut off frequency of 5 Hz. The displacement data was then single and double differentiated to determine the velocity and acceleration, respectively. Force was calculated as the sum of the system weight ($[\text{body mass} + \text{external load}] \times \text{gravity}$) and the system mass multiplied by the acceleration of the athlete-load during CMJ testing [36]. Body mass was removed from the formula when calculating force from the CMBT data. Power was calculated as the product of force and velocity. A quadratic was fitted to the individual and group peak power (PP) data across the loading spectrum to determine the load producing maximum power (P_{max}). Linear regression was utilised for the analysis of individual peak force (PF) - peak velocity (PV) curves to allow prediction of hypothetical CMBT and CMJ maximum force (F_{max}) and velocity (V_{max}).

9.2.5 Statistical Analysis

Means and standard deviations were used to represent centrality and spread of data. Percent change calculations were used to estimate the magnitude of change in the dependent variables due to detraining. Effect size ($ES = ([X_{post} - X_{pre}]/SD_{pre})$) calculations were included to determine the magnitude of change as well as account for the variance within group in turn providing a more accurate descriptions of the detraining effects^[157]. ES calculations were interpreted as trivial (0.00 – 0.25), small (0.25 – 0.50), moderate (0.50 – 1.00), large (1.00 – 1.50) and very large (> 1.50). Paired t-tests were also used to determine if there were significant strength, sprint time and ballistic (CMBT and CMJ) performance differences ($p < 0.05$) pre and post active rest.

9.3 Results

There were trivial and small non-significant decreases in upper and lower body strength, respectively as a result of active rest. Whereas large and very large significant decrements in 10 m ($ES = 1.08$) and 30 m ($ES = 2.29$) sprint times were observed over these six weeks (Table 9.1).

Table 9.1 Effects of six weeks active rest on strength and sprint ability in semi-professional union rugby players

Variable	Pre	Post	%	ES	P-value
1RM BP (kg)	131 ± 20	128 ± 16	-1.3	-0.12	0.44
1RM Squat (kg)	165 ± 22	154 ± 19	-6.2	-0.49	0.10
10 m (s)	1.72 ± 0.04	1.77 ± 0.04	2.8	1.08	0.01
20 m (s)	3.00 ± 0.03	3.08 ± 0.03	2.7	2.39	0.001
30 m (s)	4.19 ± 0.03	4.26 ± 0.04	1.5	2.29	0.008

1RM BP = one-repetition maximum bench press; **1RM Squat** = one-repetition maximum parallel back squat; **10 m – 20 m – 30m** = 10, 20 and 30 metre sprint times.

9.3.1 Ballistic Upper Body Adaptations

There were trivial to small non-significant reductions in CMBT Pmax, Fmax and Vmax following the six weeks of active off-season rest (Table 9.2). There were also trivial to

small decreases (-2 to -5%; ES = -0.18 to -0.36) in CMBT PP across the loading spectrum (Figure 9.3a). Similarly, trivial to moderate (ES = -0.02 to -0.47) non-significant reductions (-0.3 to -6%) in CMBT performance were observed from the PF-PV curve (Figure 9.3b). The PV decrements were amplified (-2 to -8%) with increasing load (15 to 75% 1RM); whereas the opposite effect was observed with PF (-5 to 0.5%).

Table 9.2 Effects of six weeks rest on countermovement bench throw performance in semi-professional rugby union players

Variable	Pre	Post	%	ES	P-value
Pmax (W)	769 ± 150	723 ± 139	-6.0	-0.31	0.34
Pmax %1RM	46.7 ± 4.0	46.3 ± 3.5	-0.4	-0.10	0.77
Pmax load (kg)	60.7 ± 9.0	59.0 ± 6.3	-2.8	-0.19	0.53
Fmax (N)	1480 ± 233	1448 ± 158	-2.2	-0.14	0.59
Vmax (m/s)	3.04 ± 0.51	2.92 ± 0.52	-3.9	-0.23	0.38
Sfv	493 ± 79	503 ± 68	2.1	0.13	0.60

Pmax = maximum predicted peak power output in watts; **Pmax %1RM** = percent 1RM load where Pmax occurred; **Pmax load** = load in kg where Pmax occurred; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax.

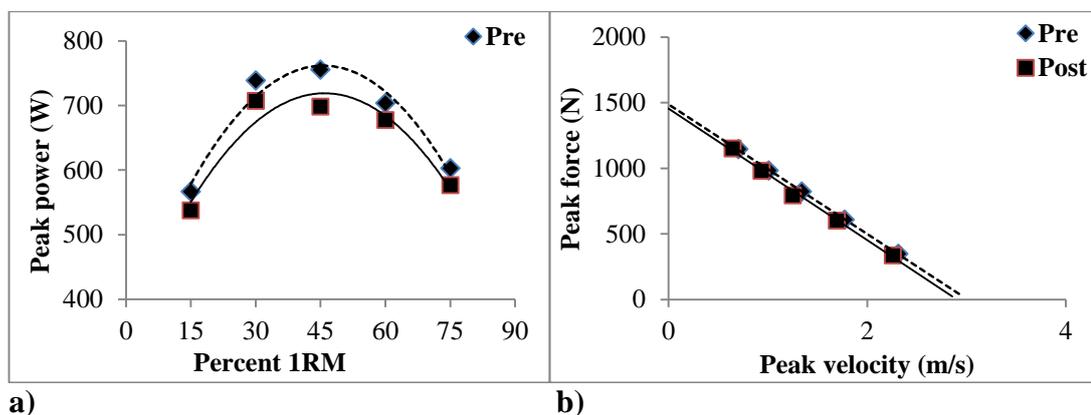


Figure 9.3 Effects of six weeks active rest on countermovement bench throw a) peak power-load and b) force-velocity curve changes in semi-professional rugby union players

9.3.2 Ballistic Lower Body Adaptations

There was a very large (ES = -2.19) reduction in CMJ Pmax (Table 9.3) due to a six week active off-season rest. In addition, very large (ES_{body mass} = -2.24) to trivial (ES_{60% 1RM} = -0.21) reductions (-14 to -2%) in PP with increasing load (Figure 9.4a) were observed. There was a moderate decrease (ES = -0.73; -35%) in Vmax and a small (ES = 0.43) increase (9%) in Fmax (Table 9.3). Large to very large (ES = -1.21 to -2.36) decrements

in PF and PV using the lighter loads (-7 to -9%) were observed; whereas trivial to moderate (ES = -0.02 to -0.71) non-significant reductions using the heavier loads (-0.1 to -5%) were detected (Figure 9.4b).

Table 9.3 Effects of six weeks active rest on countermovement jump performance in semi-professional rugby union players

Variable	Pre	Post	%	ES	P-value
Pmax (W)	5088 ± 328	4369 ± 609	-14	-2.19	0.07
Pmax 1RM (%)	-9 ± 12	17 ± 31	27	-2.18	0.09
Pmax load (kg)	-14 ± 18	29 ± 53	43	2.44	0.11
Fmax (N)	3683 ± 759	4007 ± 595	9	0.43	0.11
Vmax (m/s)	11.03 ± 5.36	7.13 ± 2.37	-35	-0.73	0.06
Sfv (N/m/s)	425 ± 261	638 ± 277	50	0.82	0.09

Pmax = maximum predicted peak power output in watts; **Pmax 1RM** = percentage 1RM load where Pmax occurred; **Pmax load** = load in kg where Pmax occurred; **Fmax** = hypothetical maximum force capabilities at zero velocity; **Vmax** = hypothetical maximum velocity capabilities at zero force; **Sfv** = Fmax/Vmax

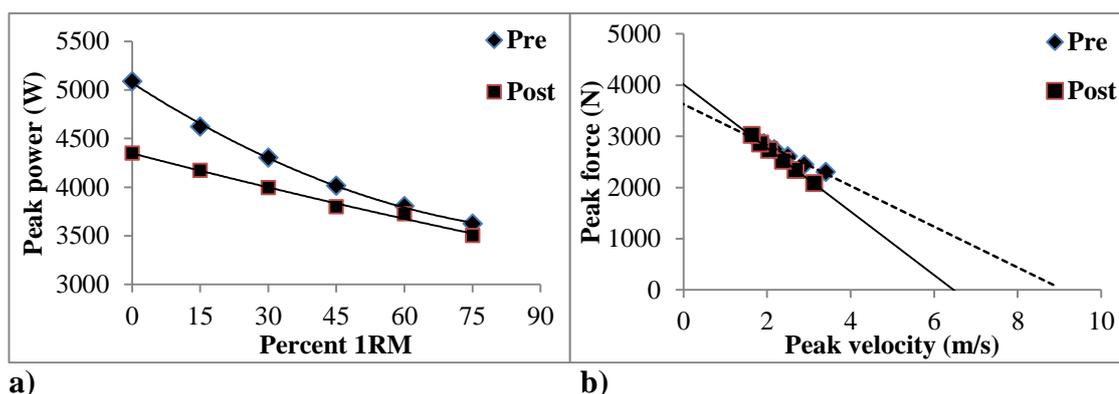


Figure 9.4 Effects of six weeks active rest on countermovement jump a) peak power-load and b) force-velocity changes in semi-professional rugby union players

9.4 Discussion

It was hypothesised that six weeks of resistance training cessation would result in minimal changes in strength and moderate to large losses in ballistic and sprint capabilities in semi-professional rugby union players. Previous research investigating the residual effects of periods of resistance training cessation on strength, running sprint ability and power in elite rugby union is non-existent; however comparisons can be made to other rugby-football codes. The six-week off-season period consisted of active rest, but no resistance training. This off-season rest had trivial to small negative effects on the 1RM bench press

(-1%) and 1RM squat (-6%) and trivial effects on heavy load (60-75% 1RM) CMBT (-0.3 to 0.5%) and CMJ (0.2 to 1.7%) PF. These small reductions in strength are similar to the trends reported by other researchers studying retention and detraining [59, 60, 362, 369, 389, 401]. Due to the heterogeneity of the rugby union squad, ES calculations may have underestimated the true effects of active rest on maximum strength, specifically 1RM back squat as there was a decrease of 6% (11 kg) following the resistance detraining. The trivial negative and small positive adaptations in upper (-2%) and lower body Fmax (9%) provide some support for the proposed maximum strength retention rates and large residuals of highly trained athletes [380]. Izquierdo et al. [60] found slightly larger upper (-6%) and lower body (-9%) strength decreases during a four week detraining period in national level Basque-ball players; other studies examining the effects of resistance detraining (two to three weeks) in strength and power trained athletes also found trivial upper and lower strength decreases (-1 to -2%) [59, 389]. Based on the data from past and current research, it can be speculated that maximum strength and Fmax in highly trained rugby union players can be retained for up to four to six weeks without resistance training. However, these findings may not be generalized to all sports, as other highly training athletes appear to require a low frequency dose of resistance training to retain strength and power. Only one strength or/and heavy ballistic training stimuli may be required every two weeks during off-season rest periods (four to six weeks) if retention of maximum strength and force is the focus [165].

In terms of ballistic upper body capabilities, CMBT Pmax decreases (-6%) were small with little to no shift in bench throw Pmax load, which occurred at 46-47% 1RM. There were also trivial reductions on CMBT Fmax (-2%) and Vmax (-4%) due to six weeks of active off-season rest. Research investigating the effects of detraining on CMBT and ballistic upper body performance is scarce; however, one group of researchers investigated the effects of a five week detraining period in elite athletes (kayakers) and

found very large decreases (-9 to -13%) in PV during a 45% 1RM speed bench press ^[165]; which is slightly larger than the current CMBT PV reductions (-7%) using the same relative load. Two other studies examining the effects of four and six weeks of resistance detraining on recreational athletes found trivial reductions in overhead medicine ball throw distance (-1%) ^[62, 477]. Researchers investigating the effects of detraining on elite handball players also found small (-3%; ES = -0.31) and moderate decreases (-4 to -9%; ES = -0.52 to -0.91) in throwing velocity after seven and eight weeks of detraining ^[61, 63]. Based on our finding and those of previous researchers, it appears that ballistic upper body capabilities can be retained with only small decrements for up to seven weeks post training cessation. However, it may be inferred from our results that velocity capabilities may decrease at a slightly greater rate than force capabilities. These ballistic upper body qualities would most likely be fully retained if a training stimulus was received every two weeks ^[165, 460].

Moderate and very large reductions were observed in CMJ Pmax (-14%), which occurred slightly below body mass (-9% 1RM) prior to and at a slightly larger load (17% 1RM) following the off-season rest period. This shift in predicted Pmax load during the CMJ might be attributed to the large reductions in PP at body mass and the minimal reductions in PP at the heavier loads, resulting in an upward shift in the estimated Pmax load. Reinforcing these contentions, were large to very large negative shifts in CMJ PP (-7 to -14%) using the lighter loads (body mass/0% and 15% 1RM) with minimal changes in heavy load power performance (-5 to 0%). It would seem that PP decay rates using lighter loads would be greater in comparison to heavy loads i.e. high velocity vs low velocity peak powers. These differential decay rates may be attributed to their governing mechanisms (high velocity vs. high force) as evidenced by the small positive shifts in Fmax (9%) and large negative shifts in Vmax (-35%).

Hermassi et al. ^[63] also found very large decreases in CMJ PV (-43%) after eight weeks of in-season resistance detraining in highly trained handball players, which was in agreement to current Vmax findings in semi-professional rugby players. Of note, previous researchers found that body mass CMJ height could be retained (-2.0 to 0.5%) during acute periods of resistance detraining (six to seven weeks) in elite rugby union players, professional handball players and recreational athletes ^[50, 61, 461]. Hortobagyi et al. ^[59] reported that CMJ height improved by 3% with two weeks of detraining. Based on the above studies it appears that a two-week taper can elicit improvements in CMJ height and retain these qualities for four weeks. It seems that CMJ height and the associated take-off velocity are less sensitive to decay than the PV of the movement.

Large to very large increases were also evident in sprint times over 10 (3%), 20 (3%) and 30 (1.5%) m. Hermassi et al. ^[63] reported small to moderate reductions in 5 m sprint acceleration (-5%) and maximum sprinting speed (-3%) between 25 and 30 m after eight weeks of in-season resistance detraining in highly trained handball players. A study by Bissas et al. ^[478] also found a trivial decrease (-1.3%) in maximum running velocity as a result of three weeks of detraining in recreational athletes. Current findings, coupled with related research suggest the acute periods (three to six weeks) of off-season rest may also be detrimental to body mass and light load (15% 1RM) vertical jump performance and sprint capabilities (10 to 30 m).

Based on the current findings and the purported mechanistic-neuromuscular adaptations, it can be concluded that off-season-detraining periods of up to six weeks should result in trivial to small rates of decay in strength and heavy load (high force) ballistic performance, moderate decay in medium load (Pmax) ballistic performance and large to very large decrements in light load (high velocity) ballistic performance and sprint capabilities. However, the practitioner must be cognisant of the benefits and limitations when using percentage change and/or ES calculations, as training and

detraining effects may be over- and under-estimated in homogeneous (i.e. small within group variance for a given performance measure) and heterogeneous (i.e. large within group variance for a given performance measure) populations, respectively. Percentage change calculations can overestimate the performance changes and ES calculations can underestimate the performance changes in heterogeneous groups, respectively and vice versa. If decay rates and residual effects are to be effectively quantified, further investigations looking at weekly/biweekly strength, speed and ballistic performance changes over these off-season/detraining periods are recommended.

9.5 Practical Applications

It would seem from the findings of this study, coupled with related research, that these acute periods (three to six weeks) of off-season rest may also be detrimental to body mass and light load (15% 1RM) vertical jump performance and sprinting capabilities (10 to 30m). Therefore, it is recommended that ballistic and sprint maintenance stimuli (e.g. body weight and loaded squat jumps, bench throws and assisted, body weight and resisted 5 to 30 metre sprints) be prescribed every five to ten days during this off-season period to prevent any harmful effects that could carry into the pre-season competition. However, maximum squat and bench press strength and high force loaded ballistic movement patterns (60-75% 1RM) were far less affected by the off-season rest period, therefore low frequency strength training stimulus (i.e. every 12 to 15 days) may be needed during the off-season to retain maximum upper and lower body strength. Immediately following the competition season (early off-season) rest is vital to restoration and regeneration of the different systems (e.g. central nervous, musculoskeletal and neuromuscular systems), therefore small non-significant losses in strength, ballistic performance and sprint ability due to resistance detraining may be necessary to allow the body to heal and repair, and in turn prevent future injuries the following season. Based on current strength and ballistic

retention findings, it is recommended that sprint, ballistic and strength training stimuli be received approximately every five, ten and fifteen days, respectively following the first two weeks of off-season rest to prevent decay. These findings could also possibly be applied to other strength and power based teams sport utilising similar yearly training structures.

***MONITORING BALLISTIC IN-SEASON RECOVERY PATTERNS IN
SEMI-PROFESSIONAL RUGBY UNION PLAYERS***

**Daniel Travis McMaster, Daniel Smart, Nicholas Gill, John Cronin and
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**National Strength and Conditioning Association Conference
Oral Presentation (Appendix 4i)**

**Journal of Science and Medicine in Sport
In Review (Appendix 4i)**

10.0 Prelude

The rigors and demands of a rugby union match and competition can have an acute and accumulative effect on neuromuscular fatigue. A number of studies have used neuromuscular performance tests pre- and post- match, but few studies have assessed the accumulative effects of a rugby competition on ballistic performance. Previous chapters examined the effects of training (Chapter 8) and detraining (Chapter 9) on strength and ballistic performance; therefore the purpose of the current chapter was to monitor the acute effects of a single match and the accumulative effects of a rugby union competition on VJ recovery patterns.

10.1 Introduction

In contact sports the rigors and demands of a match and competition can have an acute and accumulative effect on neuromuscular fatigue. ^[54, 57, 58] This accumulation of fatigue may lead to performance decrement and/or injury if suitable monitoring methods and recovery modalities are not in place. ^[436, 479, 480] In contact sports such as rugby union, the match demands and training loads may cause a certain amount of muscle damage, neuromuscular fatigue and decreased performance during maximum strength, speed and ballistic tasks. ^[58, 436, 481] Training programmes have been successfully implemented to prevent decay and even improve strength and neuromuscular performance throughout the competitive season in elite rugby-football codes. ^[39, 397, 482] Various biological and performance markers have been used to track and quantify the amount of muscle damage and neuromuscular fatigue following rugby matches and training sessions. ^[32, 54, 483] Key biological markers include: creatine kinase (marker of muscle damage), cortisol (catabolic hormone) and testosterone (anabolic hormone). ^[54, 481] Studies have shown elevated serum creatine kinase and cortisol concentrations and reduced testosterone levels for up to five days post-match, indicating increased muscle breakdown and possibly inhibited neuromuscular performance for up to 96 hours. ^[58, 483, 484]

Small to moderate correlations between the biological and neuromuscular performance markers of fatigue and muscle damage have been reported previously. ^[32, 58, 439] The vertical jump and its variations (i.e. static squat jumps [SJ], countermovement jumps [CMJ] and drop jumps) are the most commonly used movements to assess and monitor ballistic lower body (neuromuscular) fatigue and recovery. ^[27, 56, 297] Peak power is often reported as the primary monitoring variable ^[54, 57, 58]; while some studies have also reported jump height^[56], flight time^[147], contraction time^[439], peak velocity^[56], peak force^[58] and rate of force development. ^[58, 485] Peak power (CV < 3.6%), jump height (CV < 5.3%), flight time (CV < 5.3%), the ratio of flight time to contraction time (CV < 6.2%),

peak velocity (CV < 3.5%) and peak force (CV < 3.6%) have been used effectively assess vertical jump performance and detect fatigue and recovery patterns over-time; [58, 147, 208, 485] whereas the rate dependent variables (CV > 16%) were not as accurate due to large inter-trial and inter-day variability.[58, 485]

A number of studies have measured key biological markers and neuromuscular performance tests pre- and post- match, but few studies have assessed the accumulative effects of a rugby competition on vertical jump performance. [54, 439, 483] Furthermore, no research has monitored the changes in the derivatives of peak power (force at peak power and velocity at peak power) and their contribution to the changes in vertical jump performance (fatigue and recovery). Since peak power is the primary variable used to assess and monitor ballistic lower body performance adaptations in elite rugby union players [27, 31, 32], the purpose of this study was to track the time course changes in vertical jump peak power, force at peak power and velocity at peak power throughout a nine week rugby union competition to quantify the weekly recovery patterns in vertical jump performance the days following each rugby match.

10.2 Methods

10.2.1 Experimental Approach to the Problem

The Ballistic lower body changes were monitored across nine weeks to assess the acute and accumulative effects of an elite rugby union competition on vertical jump fatigue and recovery patterns. Measurement of peak power, force at peak power and velocity at peak power during body weight CMJs and SJs were performed on a portable tri-axial force plate at baseline (pre-season) and pre- (58 ± 2 hrs) and post-match (41 ± 10 hrs) for nine consecutive weeks. The testing sessions were conducted prior to scheduled sessions two mornings per week during long match turn around weeks (i.e. ≥ 7 days between matches) and one morning per week during short match turn around week (i.e. ≤ 6 days between

matches); the sessions were used to track vertical jump fatigue post-match (beginning of week) and recovery (end of week) prior to the following match. Understanding individual vertical jump recovery patterns (post- and pre- match) week to week and across a competitive season may be important in the implementation of suitable recovery modalities and managing weekly training workloads to reduce the risk of injury and subsequently optimise ballistic performance.

10.2.2 Subjects

Eighteen semi-professional rugby players (age = 23.9 ± 2.9 yrs; height = 184 ± 7.2 cm; body mass = 103 ± 12.4 kg) were recruited from a representative team competing in New Zealand's Provincial rugby competition. The players volunteered to participate in the study, which was approved by the university's ethics committee. Written informed consent was obtained prior to study participation.

10.2.3 Procedures

The players completed two to three on-field and two to three resistance training sessions each week, depending on the length of the pre-match training week. The in-season/competition resistance training programme followed a three week undulating mixed methods loading scheme designed to retain strength, power and speed during this period. Training consisted of complex strength (week 1 [5 sets of 3 reps at ~90% 1RM], week 2 [4 sets of 6 reps at ~85% 1RM], week 3 [6 sets of 2 reps at ~95% 1RM]), power (week 1 [5 sets of 5 reps at ~0% 1RM], week 2 [4 sets of 5 reps at ~50% 1RM], week 3 [6 sets of 5 reps at ~-10% 1RM]), and speed (week 1 sled towing [5 sets of 20 m at ~10% body mass], week 2 reaction sprints [4 sets of 10-30 m at body mass], week 3 overspeed [6 sets of 30 m with bungies]) sessions.

The players undertook a total of fourteen vertical jump testing sessions across a ten week period (one week of pre-competition and nine weeks of in-competition). Baseline testing was conducted two weeks prior to the first regular season fixture. All post-match (41 ± 10 hours post-match) and pre-match (58 ± 2 hours pre-match) testing was conducted between 06:00 and 07:30 h prior to the daily recovery, resistance or speed training session. Due to match fixture scheduling conflicts (i.e. mid-week matches) and changes in weekly training schedules, five scheduled testing sessions were not completed.

The players performed two acyclic vertical CMJ and two vertical SJ with a lightweight wooden dowel (<0.25 kg) placed across the upper traps and shoulders at each testing session standing on a portable tri-axial force plate (Accupower, AMTI, Watertown, MA). The force plate was zeroed prior to data collection for each athlete; the athlete was then weighed using the force plate. The tri-axial force plate was connected to a computer interface (Accupower Software, Watertown, MA) and sampled at a frequency of 400 Hz. During the CMJ the athletes performed an initial eccentric (squatting down to ~ 120 degree knee angle) contraction to a self-selected depth, immediately followed by an explosive concentric (upward movement) contraction and subsequent flight phase. During the SJ the athletes initially squatted down to a self-selected depth (~ 120 degrees), followed by a 3 second pause, which was immediately followed by an explosive concentric contraction and subsequent flight phase. The athletes were given thirty seconds rest between jumps and jump order was randomised across the fourteen sessions to minimize any potentiation effects.

10.2.4 Data Analysis

The use of portable force plates in ballistic lower body assessments have been previously validated with a high level of precision ($CV < 1.2$ %) for the measured (ground reaction force) and integrated variables.^[26, 183] The force-time data were filtered using a second

order low-pass Butterworth filter with a cut off frequency of 16 Hz. Velocity and power were calculated using a customised data analysis programme (Labview 8.2; National Instruments). Centre of mass velocity was calculated by integrating the acceleration-time data using the Simpson rule algorithm:

$$\int_0^{N \cdot \Delta t} f(\tau) d\tau \approx f(0) + \frac{\Delta t}{6} \sum_{i=0}^{N-2} (f_i + 4f_{i+1} + f_{i+2})$$

Power was calculated as the product of the resultant force and centre of mass velocity; while jump height was calculated from the take-off velocity based on the laws of projectile motion. CMJ peak power (PP [CV < 5.5%; ICC > 0.91]), velocity at peak power (V@PP [CV < 5.0%; ICC > 0.86]) and force at peak power (F@PP [CV < 3.6%; ICC > 0.93]) were deemed highly reliable for assessing inter-trial and inter-day performance changes in the current squad of semi-professional rugby union players.

10.2.5 Statistical Analysis

All data were analyzed using an Excel spreadsheet for analysis of controlled trials, which was set at 95% confidence limits.^[437] Standardised mean differences in performance were used to assess magnitudes of effects by dividing the appropriate between-player standard deviation. Standardised effects were defined as using a modified Cohen scale: <0.25 = trivial, 0.25 - 0.50 = small, 0.51 - 1.00 = moderate, 1.01 - 1.50 = large, > 1.50 = very large.^[438] Pearson product correlation coefficients were calculated to detect if pre-match vertical jump performance was related to match outcome (expressed as a positive or negative value based on the score differential). Pearson product correlation coefficients were calculated to determine the relationship between the changes in vertical jump performance and the number of post-game rest days prior to testing. Correlations were classified as small (0.10 - 0.29), moderate (0.30 - 0.49), large (0.50 - 0.69) and very large (0.70 - 0.89).^[486]

10.3 Results

The results were based on fourteen testing sessions conducted across ten weeks of pre- (week 0) and in- (weeks 1 to 9) competition. Average pre- and post- game PP, V@PP and F@PP are shown in Table 10.1. Since CMJ and SJ provided almost identical diagnostic information ($r = 0.90 - 0.99$) only the outcomes of the CMJ data were reported. Small CMJ significant ($p < 0.001$) differences between post-game and pre-game occurred for PP (3.7%) and V@PP (2.9%).

Table 10.1. Pre and post match testing of body mass countermovement jumps

Dependent variable	Post-Game (Mean \pm SD)	Pre-Game (Mean \pm SD)	%	ES	P-value
Peak Power (W)	5087 \pm 587	5275 \pm 562	3.7	0.32	0.0004
Velocity at Peak Power (ms^{-1})	2.31 \pm 0.18	2.38 \pm 0.20	2.9	0.37	0.001
Force at Peak Power (N)	2339 \pm 317	2364 \pm 334	1.1	0.08	0.46

Post-match testing (~ 41 hours post) and pre-match testing (~58 hours prior).

There were small differences between baseline CMJ and post-game PP (~-2.7%; ES = -0.25 – Figure 10.1) and V@PP (~-2.3%; ES = -0.29), while differences between baseline and pre-game were trivial (<1%; ES < 0.12). The differences between baseline and F@PP for post-game and pre-game were trivial. There were small increases from the first two weeks of competition to the last two weeks in CMJ PP (2.4%) and CMJ V@PP (5.9%); while there were small decreases in CMJ F@PP (-3.7%) from the first two weeks to the last two weeks.

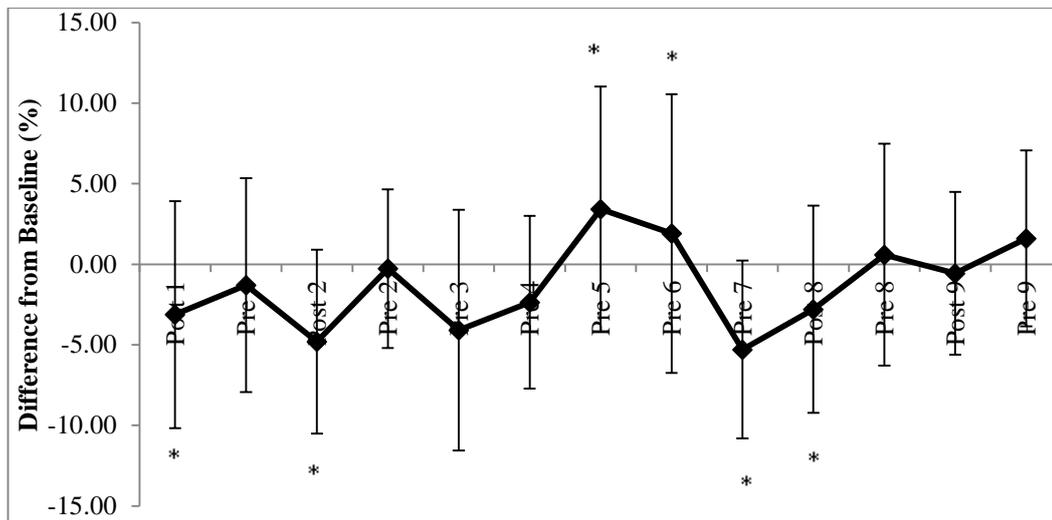


Figure 10.1. Weekly differences (%) in countermovement jump peak power from baseline. Error bars indicate 90% confidence limits. * Small difference from baseline.

CMJ PP ($r = 0.72$) and V@PP ($r = 0.62$) were very large and largely correlated to the number of hours jump testing occurred post-match (Figure 10.2), respectively. Moderate correlations were also observed between match result and pre-match CMJ PP ($r = 0.47$) and V@PP ($r = 0.52$).

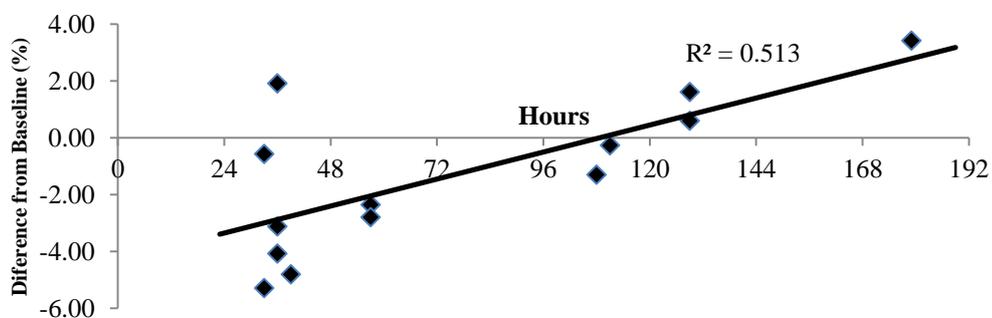


Figure 10.2. Difference of CMJ peak power from baseline in relation to the number of hours jump testing occurred post-match.

10.4 Discussion

Post-match neuromuscular fatigue in rugby football codes varies between codes, matches and individuals based on a number of factors, such as playing position, game time, total distance covered, running intensities and durations, the number of impacts per match and the force of each impact. [3, 11, 84] The small to moderate decreases in post-match PP and

V@PP from baseline (trivial differences in pre-match to baseline) was in agreement to past research on highly trained rugby football code players.^[54, 58, 439] Acute studies by McLean et al.^[57] and McLellan et al.^[58] found that vertical jump flight time (ES = - 1.67), PP (-25%; ES = -1.20) and PF (-13.9%; ES = -0.89) were significantly reduced 24 hours post-match in elite rugby league. Cormack et al.^[147] also found significant reductions (-3.5 to -17.1%) in the ratio of flight time to contraction time during body mass vertical jumps for up to 72 hours post-match in professional Australian Rules football players. The time course changes in vertical jump performances the week following a match and the week leading up to the next match may provide coaches with valuable information that may influence the weekly training plan (i.e. recovery, weight training, tactical and contact sessions).

Small increases in PP (~ 3.5%) and V@PP (~ 2.6 %) over the course of the training week (post-match vs. pre-match) indicate a recovery from impaired neuromuscular function post rugby match. These findings were reinforced by a very large ($r = 0.72$) correlation between CMJ PP and the number of hours post-match jump testing took place. The outcomes revealed that CMJ performance is often diminished for up to 110 (~ 4.5 days) hours following a semi-professional rugby union match; which is also in agreement to previous literature.^[57, 58] McLellan et al.^[58] found that PP CMJ returned to pre-match levels within 72 hours post-match and was maximized around the 96 hour mark. Similarly, McLean et al.^[57] reported that neuromuscular fatigue measures returned to baseline within 96 hours post-match in rugby league players. Therefore, it appears that between 72 to 110 hours (3-5 days) is required for total muscular and neuromuscular recovery following an Australian Rules football, rugby league or rugby union match and is most likely influenced by the previously mentioned game related stressors.^[58, 439, 481] Moderate to large correlations ($r = 0.47 - 0.52$) between enhanced pre-game CMJ performance (PP and V@PP) and match outcome were observed, reinforcing the need to

physically prepare players for upcoming matches through effective post-game recovery modalities and possibly advanced pre-game potentiation strategies. Monitoring weekly vertical jump recovery patterns throughout a season may provide coaches with an indication of any existing accumulative fatigue effects on the neuromuscular system.

Current findings provided minimal evidence to support the theory of accumulative neuromuscular fatigue across a rugby-football competition, as there were no definitive trends of increased decay in CMJ performance as the season progressed from week one to week nine, only temporary post-game reductions in performance were observed. Cormack et al.^[147] also found little evidence to support the theory of accumulative fatigue across a twenty-two week Australian football rules competition^[439]. Some studies found small decreases in neuromuscular performance between the start and end of the competitive season.^[54, 401] Argus et al.^[54] reported a small overall decrease (-3.3%) in jump squat performance in elite rugby union players across a thirteen week competition; Schneider et al.^[401] also reported a small overall decrease in vertical jump performance of - 4.6% in Canadian university football players over a sixteen week competition. It would seem that that lower body power can be maintained and under the right training stimulus even improved throughout a competitive season. In the present study, a trivial increase (2.4%) was also observed in peak power over the nine weeks indicating a training effect, highlighting the need to possibly retest baselines on a regular basis in order to understand the true performance decrement as a result of a rugby union match. A shifting baseline or regression analysis with a correction factor might help compensate for improvements in performance throughout the season.

There were no substantial differences between baseline, post-match and pre-match in F@PP, whereas V@PP was significantly reduced post-game (-2.3%) and returned back to baseline levels prior to the next game (1%); indicating the changes in PP were most likely due to changes in velocity. This may suggest that PP and V@PP may be better

indices of fatigue than force, due to their sensitivity in detecting weekly changes in CMJ performance. It is also important to select the most sensitive variables to detect those changes in performance, such as PP, PV, flight time, contraction type, and possibly mean power and mean velocity. If reliable, eccentric-concentric ratios and rate of force development could also be valuable monitoring variables, but requires further investigation.

10.5 Practical Applications

Monitoring the rates of neuromuscular recovery following a rugby match through regular vertical jump testing, provides coaches with valuable information regarding the individual and squad's level of neuromuscular fatigue, which in turn should influence the planning of weekly in-season recovery and training sessions. For strength and conditioners, a single body mass CMJ may be adequate to monitor CMJ recovery patterns across a competitive season. It seems that vertical jump PP output may be diminished for up to 110 hours post-match; therefore practitioners should be cognisant of these reductions when planning weekly training sessions. Reduced pre-game CMJ PP was related to poor match performance; therefore implementing more effective recovery modalities early in the competition week may result in more rapid recovery rates and in turn enhance the quality of in-season training and match preparation. There were no definitive accumulative effects of a nine week rugby competition on neuromuscular lower body performance; seemingly PP can be retained in semi-professional rugby union players throughout a competitive season utilising mixed method strength, speed and ballistic training, performed two to three times per week.

***SUMMARY, PRACTICAL APPLICATIONS AND FUTURE
RESEARCH DIRECTIONS***

11.1 General Summary

This doctoral thesis by publication was conducted to enhance the understanding of strength and ballistic performance; particularly around assessments to create comprehensive profiles for rugby union athletes through novel analytical approaches. The underlying objective was to improve current methods of assessment, monitoring and programming in semi-professional rugby union. Two reviews covering strength and ballistic assessment, development, retention and decay in highly trained rugby-football populations were compiled, providing a comprehensive overview and subsequent directions for current and future research.

Based on the gaps in the literature, current objectives were to validate wireless accelerometry (Chapter 4) for its practicality in assessing ballistic performance in athletic environments, and secondly to create comprehensive ballistic (BTH and VJ) performance profiling protocols utilising new analytical approaches (Chapters 5, 6 and 7). These ballistic performance assessment protocols along with maximum strength and sprint running performance were then utilised to respectively assess the training, detraining and in-season effects of acute complex strength and ballistic training (Chapter 8), resistance detraining (Chapter 9) and a competitive season (Chapter 10) on semi-professional rugby union players. Subsequent discussion articulates the outcomes of these key research aims.

For a measurement system to be implemented into a practical setting it must be reliable and the validity established against a “gold standard” system. Of interest to this research was the utilisation of wireless accelerometry for the purpose of assessing ballistic movements (VJ and BTH) due to the practicality of this system over other laboratory-based systems. The objectives of Chapter four, were to assess the reliability and validity of accelerometry and the relationships between the kinematics and kinetics of the following three measurement systems during the VJ: hip acceleration (accelerometer attached to the hip), bar acceleration (accelerometer attached to bar) and centre of mass

acceleration (force plate). In comparison to the force plate, the bar accelerometer revealed similar PV and PP (2%), but predicted significantly greater PF (24%) during the concentric phase; while the hip accelerometer predicted similar PF (2%) but significantly under-predicted PV (21%) and PP (24%) during the concentric phase. As expected, the force plate (gold standard) was found to be very stable within and across testing sessions for the concentric phase variables ($M_{diff} \leq 1.1\%$, $ICC \geq 0.81$, $CV \leq 5\%$). Both accelerometer attachments were also deemed reliable for assessing PF ($ICC > 0.80$; $CV < 13\%$), but were low to moderately reliable for monitoring PV ($ICC > 0.35$) and PP ($CV < 23\%$). Based on these reliability outcomes, and the large discrepancies between the force plate and accelerometer set-ups, subsequent studies in this PhD utilised force plate technology and previously validated linear position transducers. It is recommended that researchers and strength and conditioning coaches continue to use established measurement systems, such as force plates and linear position transducers for ballistic performance assessments until the stability of wireless accelerometry set-ups are improved.

Before a ballistic profiling protocol is used as a monitoring or assessment tool it must also prove to be valid and reliable. Chapter five assessed the reliability of BTH and VJ incremental relative load profiles (body mass/0% to 75% 1RM) using a linear position transducer due to the high validity and practicality of the device for the purpose of assessing the changes in performance. BTH and VJ profiles were assessed using relative incremental loading. The BTH and VJ profiling protocols herein were relatively stable and reliable ($ICC > 0.79$; $CV < 11\%$) for measuring and detecting the following parenthesised changes in concentric PF (> 98 N), PV (> 0.13 m/s) and PP (> 224 W) within and across testing sessions. The VJ and BTH profiling protocols herein are valid to detect and therefore assess and monitor concentric PF, PV and PP adaptations greater than these respective thresholds.

There is a necessary evolution of ballistic assessment methods in elite sport, as is required to continually improve the physical qualities of these respective athletes to match the growing sport and position specific performance demands. The second part of this series of investigations focused on applying novel analytical approaches to previously collected BTH and VJ data (Chapter 5) assessing the underlying effects of upper body strength on BTH (Chapter 6) and lower body strength and sprint ability on VJ (Chapter 7) capabilities of semi-professional rugby union players. The overall aim was to provide a greater mechanical understanding of these ballistic movements. This analysis compared the differences in BTH and VJ performance between strong and weak and fast and slow rugby players. The stronger players produced significantly larger BTH P_{max} and F_{max} , whereas the weaker players produced non-significantly larger V_{max} . The VJ analysis revealed that the faster players produced larger P_{max} and V_{max} , whereas the stronger players produced larger F_{max} and P_{max} in comparison to their slower, weaker counterparts. Certain inferences can be drawn from the above findings; stronger and faster players will most likely produce a higher VJ and BTH F_{max} and V_{max} , respectively. These findings can also be used to inform programming of an athlete's mechanical deficient areas, where specific strength and ballistic training modalities can then be prescribed to shift the various portions of individual force-velocity curves, and possibly increase P_{max} . Players with a lower F_{max} , could attempt to improve their force-velocity profile using heavier strength/ballistic loads; while players with lower V_{max} , could attempt to improve their force-velocity profiles using lighter ballistic loads.

In the previous chapters it has been established using cross-sectional designs that maximum strength and sprint ability may affect the resultant BTH and VJ force-velocity-power capabilities. The next three chapters use the major findings of these studies in longitudinal designs. This next phase of research (Chapter 8) implemented a complex training intervention, where a strength exercise is followed by a heavy or light ballistic

exercise in order to potentiate the performance of the ballistic exercise. The athletes completed two different, five week complex training interventions (strength + heavy ballistic [SHB]; strength + light ballistic [SLB]) utilising a within group cross-over design. The cross-over design was utilised to allow for a smaller sample size to be utilised while still providing data for comparisons of group and individual responses to both interventions. Both interventions followed a four day complex training week with the same strength and ballistic exercises. SHB and SLB training caused small to moderate improvements in the 1RM bench press (4 – 9%) and 1RM squat (9 – 12%); as well as small to moderate reductions in sprint running times (0.5 - 1.5%) over 10, 20 and 30 m. SHB training also lead to significant increases in BTH and VJ Fmax (6 and 10%); whereas the SLB training caused significant increases in Vmax (15 and 68%). Therefore it appears that SHB and SLB training were most beneficial at increasing Pmax (12 and 46%) through the improvement of force and velocity capabilities, respectively. The complex training modalities prescribed herein may be implemented to elicit positive adaptations in VJ and BTH Fmax, Vmax and Pmax, while simultaneously improving maximum squat and bench strength and sprinting ability in highly trained rugby union players.

In rugby there is often a four to six week off-season rest period, which allows the athletes to rest and recover after a lengthy competition season. The effects of complex training on strength and ballistic performance were investigated previously but understanding the effects of rest on these performance measures may also help determine the structure and training content for this phase of the training cycle. The effects of detraining on the strength and ballistic capabilities in rugby union are of great interest, as the decay rates and residual effects of training cessation can aid the practitioner with better informed planning and prescription off-season and in-season training loads. Chapter 9 investigated the effects of six weeks of resistance detraining on strength, sprint ability and ballistic performance. This resistance detraining period resulted in trivial to

small reductions in 1RM bench press (-1%), 1RM squat (-6%) and heavy load PF production (-2%); there were also significant increases in sprint times (2-3%). Small to very large reductions in BTH and VJ Vmax (4 and 35%) and Pmax (6 and 14%) were also observed across the six weeks. Based on these findings, off-season resistance detraining periods of up to six weeks may result in trivial to small reductions in maximum strength and heavy load (high force) ballistic performance, small to moderate decay in medium load ballistic performance and large to very large decrements in light load (high velocity) ballistic performance and sprint capabilities. This information suggests that a strength and heavy ballistic training stimulus may not be needed to retain these force/strength specific qualities during acute off-season rest; conversely light ballistic load and sprint training is recommended to help retain these velocity/speed specific capabilities in highly trained rugby union players.

In rugby the rigors and demands of a match and a lengthy competition season can have an acute and accumulative effect on neuromuscular fatigue. Studies within this thesis have examined the effects of training (Chapter 8) and detraining (Chapter 9) on ballistic performance; therefore the purpose of the final study (Chapter 10) was to track the time course changes in VJ performance throughout a competitive season. The acute effects of a single match and the accumulative effects of a rugby union competition on VJ recovery patterns were evaluated. Body mass VJ performance was monitored pre- (58 ± 2 hrs) and post- (41 ± 10 hrs) match to assess weekly ballistic recovery patterns. Small decreases in post-match PP (-2%) in comparison to baseline and small increases in pre-match PP (4%) and V@PP (3%) in comparison to post-match were observed. This suggests that there are short-term reductions in PP due to the demands of a single match, but values return to baseline prior to the next match. Furthermore, a large correlation was observed between PP ($r = 0.72$) and the number of hours post-match jump testing took place, a trendline fitted to this data suggests that PP may be reduced for up to 110 hrs post match. There

were also small increases in PP (2%) and V@PP (6%) from the first two weeks of competition to the last two weeks, suggesting that the mixed method strength, power and sprint training performed two to three times per week throughout the competition period may be sufficient to maintain VJ PP. Assessing pre- and post-game CMJ performance in proportion to the week prior and baseline may be used to guide daily and weekly training loads throughout the season. This information has provided a greater understanding of current in-season ballistic (neuromuscular) recovery patterns rugby union competition; and in turn may allow for more informed planning (e.g. recovery modalities and weekly training load management) throughout future competitive seasons.

The research outcomes as a whole were progressive and innovation in expanding current methods of assessing, monitoring and developing strength and ballistic qualities of highly trained rugby union players. Even with the inconsistency of the kinematic and kinetic outputs from current wireless accelerometers in comparison to force plate technology, the potential to develop valid wireless accelerometers for the assessment of ballistic movements remains high based on the current rate of micro-mechanical technological advancements. The addition of Fmax and Vmax to typical power-load BTH and VJ profiles provided a more holistic mechanical representation of the athlete's ballistic capabilities. The analysis of BTH and VJ force-velocity and power-load changes along with sprint ability and maximum strength prior to, during and following i) complex training, ii) resistance detraining and iii) a competitive season revealed: i) moderate (strength and sprint ability) to large (Fmax, Vmax and Pmax) increases, ii) trivial (strength and Fmax) to very large (sprint ability and Vmax) decreases and iii) acute decreases (24-48 hours post-match) and increases (96 to 110 hours post-match), respectively. Furthermore no accumulative effects on VJ were observed across a competitive season.

11.2 Delimitations and Limitations

The yearly training structure of a semi-professional/representative rugby union squad is complex and may have many underlying factors affecting an individual's and squad's performance. There are a number of intrinsic (motivation, adherence, genetics, etc...) and extrinsic factors (support staff, training quality, equipment, sleep, fatigue, injuries etc...) that can influence an individual's physical development and performance throughout the yearly training cycle, which are difficult to take into account during the various assessment, training and monitoring sessions.

Chapters five through nine utilised a single linear position transducer (valid) for all ballistic assessments; whereas chapters four (accelerometry validation) and ten (in-season monitoring) utilised wireless accelerometers (unreliable/invalid) and force plates (valid), respectively. Therefore comparisons of the force, velocity and power outputs from the different measurement systems (across these studies) are not recommended [15, 17, 19].

Ballistic profiles (Pmax, Fmax and Vmax) herein were created from a relative percentage 1RM free-weight loading scheme (body mass/0, 15, 30, 45, 60 and 75% 1RM) during acyclic BTH and VJ; therefore comparisons to previous research utilising cyclical repetitions, Smith machines, supine squat machines and absolute and relative body mass loading schemes were difficult.

The measurement system (Chapter 4), protocol validation (Chapters 5-7) and in-season monitoring (Chapter 10) studies utilised adequate sample sizes (n = 18 and 20); whereas the training (Chapter 8) and detraining (Chapter 9) interventions samples were smaller (n = 10 - 14) due to issues of injury, adherence and off-season acquisitions. The sample could have been expanded to include surrounding club level players and in turn increase the statistical power, but would have compromised the validity of the findings. Furthermore, no control group, athlete and/or experimenter blinding were administered

due to the ethical issues to using semi-professional athletes as subjects. Any positive and/or negative adaptations resulting from current complex training modalities, off-season detraining periods and in-season match/training loads should be interpreted in context with respect to the individual athlete, training status (highly trained) and current rugby squad (participating in New Zealand's provincial rugby union competition).

11.3 Practical Applications

Upper and lower body strength and ballistic capabilities and inevitably sprinting ability are paramount to excelling in contact/collisions sports, such as rugby. The principal applications of this thesis for sports scientists and strength and conditioners are i) integrating performance technology ii) to create comprehensive ballistic profiles and iii) enhance data analysis techniques to better inform iv) strength and ballistic programming; in addition to tracking physical performance changes v) throughout the off-season and vi) within the competitive-season to quantify acute and chronic recovery patterns and decay rates of highly trained team sport athletes (e.g. rugby union players).

- I. The measurement system (force plate, accelerometer or linear position transducer) and attachment site (centre-of-mass, hip or bar) utilised during bench throw and vertical jump assessments greatly affect the kinematic and kinetic outputs. Force plates detect changes in ground reaction force, which are directly related to the changes in acceleration of the centre-of-mass; while the wireless accelerometers and linear position transducers detect changes in acceleration and displacement, respectively at their point of attachment (i.e. bar and hip). These devices should not be used interchangeably to monitor ballistic performance due to the large differences in the outcome measures (PV, PF and PP) between devices. It is currently recommended that force plates or linear position transducers be used to monitor changes in VJ and BTH performance; until the stability and precision of wireless accelerometers are improved. It is also highly recommended that the

reliability of the testing protocol and dependent variables of interest be established for each group of athletes being assessed.

- II. Along with the measurement system, the apparatus/set-up utilised during ballistic assessments must be carefully selected. The use of relative versus absolute incremental loading during profiling should be considered for logistical purposes when working with individual or team sports. The VJ and BTH profiling protocols using relative 1RM loads (body mass/0, 15, 30, 45, 60 and 75% 1RM) developed herein as measured via a single linear position transducer may be implemented to accurately assess and monitor changes in concentric peak and mean force, velocity and power capabilities. However, due to the high variability of the eccentric phase variables, discretion is advised if using these variables for assessment purposes.
- III. The addition of Fmax and Vmax to the conventional BTH and VJ power-load profiling (Pmax), has provided a more holistic mechanical understanding of ballistic performance; which in turn may have a marked effect on programming. The findings suggest that Fmax, Vmax and Sfv can be used to detect individual areas of deficiency along the peak force-peak velocity curve (force deficient, velocity deficient or force-velocity deficient). As hypothesised the current analysis revealed that stronger players produce the largest Fmax and faster players generated the highest Vmax; the large and small Sfv associated with the stronger and faster player, respectively reinforced these findings. These observations suggest that possessing and improving strength and sprint ability in rugby union players may influence Fmax and Vmax capabilities and vice versa. Based on these acute comparisons, various sprint, strength and ballistic lower body loading schemes could possibly be prescribed to rectify these deficiencies.
- IV. The acute complex strength and ballistic training interventions (SHB and SLB) included a number of different strength (e.g. bench press, weighted pull-ups, back

squats and split squats) and ballistic (e.g. loaded-unloaded jumps, bench throws, high pulls and power cleans) exercises that lead to beneficial adaptations in strength, sprint ability and BTH and VJ performance (F_{max} , V_{max} and P_{max}). It is recommended that complex training with strength (85-98% 1RM) and heavy ballistic loading (60-75% 1RM) be prescribed to induce beneficial improvements in F_{max} ; and strength (85 – 98% 1RM) be coupled with light ballistic loading (15-30% 1RM) to elicit increases in V_{max} . Contrary to the principle of specificity, it appears that both complex training modes can be implemented to elicit beneficial adaptations in bench throw and vertical jump peak force, peak velocity and peak power across the entire loading spectrum (0 to 75% 1RM) in highly trained rugby players.

- V. Six weeks of resistance detraining appears to be detrimental to light load VJ performance and sprinting capabilities. However, 1RM and heavy load PF, PP and PV were far less affected. It is recommended that speed and light ballistic maintenance stimuli be prescribed during the off-season period to prevent these harmful reductions in performance that could possibly affect pre-season match performance. Conversely, it seems that little to no strength training stimulus may be needed during the off-season to retain strength qualities, but if a stimulus was received all upper and lower body maximum strength and force capabilities would most likely be retained. These findings could also possibly be applied to other strength and power based teams sport utilising similar yearly training structures.
- VI. Practitioners may use a single body mass CMJ, as a simple method to track weekly and long-term ballistic performance changes. Practitioners may use PP and $V@PP$ to detect acute fluctuations in VJ performance due to their heightened sensitivity. The in-season weekly VJ monitoring revealed post-match reductions in PP for up to 110 hrs in highly trained rugby union players. Reduced pre-game PP was

moderately related to poor match performance; therefore implementing more effective recovery modalities early in the competition week may result in more rapid recovery rates and in turn enhance the quality of in-season training and match preparation. There were no definitive accumulative effects of a nine week rugby competition on neuromuscular lower body performance; seemingly PP can be retained with as little as two mixed method strength and ballistic training session per week throughout a competitive season.

11.4 Future Research Directions

The studies in this thesis have resolved a number of issues with the assessment and development of strength, sprint and ballistic performance in highly trained rugby union players. These findings have also opened a number of future research avenues that may further expand our understanding and continue to evolve the practice of strength and conditioning research.

The design of current and future methodologies must be carefully considered. Strength, sprint ability and ballistic assessments should not be limited to the current designs. Future research should continue to assess the reliability and validity of wireless accelerometry and other innovative performance technologies, such as three dimensional magnetometers, gyroscopes and other micro-electromechanical measurement systems for the purpose of monitoring and assessing movement mechanics due to the practicality and logistical simplicity/ease of these micro-sized devices.

Maximum strength assessments, such as the 1RM bench press and 1RM back squat provide non-specific measurements of maximum strength, but may not provide a true representation of the required rugby specific strength qualities. Strength testing methods in rugby union could be improved upon by assessing maximum force capabilities of rugby specific tasks, such as scrummaging, tackling and fending to provide a more

representative measure of maximum rugby specific strength. Analysing the peak and mean force, rate of force development along with mean and peak power generated could provide greater insight into the required strength, force and power outputs of these rugby specific tasks.

Ballistic assessments should not be limited to the current dependent variables, testing protocols and movement patterns. This thesis analysed the ballistic maximums (i.e. F_{max} , V_{max} and P_{max}) produced during the concentric phase; future investigations could focus on a number of different and possibly equally important dependent variables including: rate dependent variables, ratio analyses and eccentric phase variables to further expand our mechanical understanding. Various loading schemes, such as absolute, relative and assisted (anti-gravity) should also be compared to determine how force, velocity and power are affected. Movement patterns must be selected based on reliability and sports specificity, for example the use of cyclic vs acyclic, horizontal vs vertical, double vs single arm/leg, power lifts vs Olympic lifts, pulling vs pushing. Future investigations should focus on creating comprehensive ballistic profiles that encompass the loading schemes and movement patterns specific to the sport/discipline of interest with the underlying objectives of better informing programming and improving performance.

The future utilisation of F_{max} , V_{max} and P_{max} is in the individualisation of programming to shift and correct individual deficiencies and to further develop current strengths. There is also a need to develop sport and position specific requirements/normative data to improve and guide strength and ballistic training strategies. Investigating the effects of different ballistic loading schemes on F_{max} and V_{max} may help in determining which protocols maximise these respective hypothetical outputs. Enhancing F_{max} , V_{max} and P_{max} may also transfer to improved scrummaging, mauling and tackling force production, fending power, and kicking and passing velocity;

and possibly lead to reductions in accumulative lower and upper body fatigue throughout the course of a rugby match. These match specific qualities were not measured; therefore require further investigation.

The complex training interventions in this thesis addressed many of the previous methodological issues around equal volume loading, group splitting, and training design. This intervention focused on acute changes in strength and ballistic capabilities (Fmax, Vmax and Pmax), which provided a detailed understanding of the mechanical adaptations with minimal focus on the hormonal, physiological and micro-mechanical adaptations. Current mechanical investigations could be improved by taking a closer look at the hormonal, physiological and micro-mechanical adaptations to complex, conjugate and block type strength and ballistic training. Current methods of complex strength and ballistic training should also be compared to a) complex strength and sprint training, b) complex ballistic and sprint training, along with other methods of training (e.g. conjugate and block training) to determine the acute benefits of each method. These short term studies do not address the long-term mechanical training adaptations, therefore further research tracking the longitudinal changes in physical performance across a number of years may provide practitioners with valuable information regarding squad changes and individual responses occurring with professional experience, maturity and age.

Maximum strength and ballistic adaptations due to resistance detraining was assessed prior to and following six week rest period to quantify the residual effects. If decay rates and residual effects are to be monitored more effectively, further investigations should look at the biweekly changes strength, sprint ability and ballistic performance. The inclusion of important hormonal, physiological and micro-mechanical measurements would also provide possible support and explanations for the various mechanical changes during this period.

The addition of the above measurements to current in-season ballistic monitoring would provide practitioners with greater detail around post-match neuromuscular fatigue and weekly recovery patterns. The retention of VJ PP across the nine-week rugby competition also highlights the need to possibly normalise the data (divide by body mass) or retest baselines on a regular basis in order to understand the true performance decrement as a result of a single rugby union match. Future research could also implement shifting baselines or regression analysis with a correction factor to help compensate for possible ballistic improvements throughout the season. When monitoring acute/low frequency mechanical changes, it is important to select the most sensitive movement patterns and variables to detect those changes, such as peak power, peak velocity, flight time and contraction type; if reliable, eccentric-concentric ratios, rate of force development and power absorptions ratio could also be valuable monitoring variables, but also requires further investigation.

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APPENDICES

Appendix 1. Ethics Approval Forms

Appendix 1a. Ethics Application Number 10/184

(Chapters 4 and 10)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Nicholas Gill
From: **Dr Rosemary Godbold** Executive Secretary, AUTEC
Date: 11 October 2011
Subject: Ethics Application Number 10/184 **Validation and reliability of a wireless accelerometer to assess changes in kinematics and kinetics during various jumps.**

Dear Nicholas

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 August 2010 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 31 October 2011.

Your ethics application is approved for a period of three years until 10 October 2014.

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

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 10 October 2014;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 10 October 2014 or on completion of the project, whichever comes sooner;

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

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

necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902.

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

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Appendix 1b. Ethics Application Number 10/183

(Chapters 5 and 7)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Nicholas Gill
From: **Dr Rosemary Godbold** Executive Secretary, AUTEC
Date: 11 October 2011
Subject: Ethics Application Number 10/183 **Reliability of lower body force-velocity-power profiling.**

Dear Nicholas

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 August 2010 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 31 October 2011.

Your ethics application is approved for a period of three years until 10 October 2014.

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

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 10 October 2014;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 10 October 2014 or on completion of the project, whichever comes sooner;

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

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

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902.

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

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Appendix 1c. Ethics Application Number 12/220

(Chapters 5 and 6)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Nicholas Gill
From: Rosemary Godbold, Executive Secretary, AUTEC
Date: 6 September 2012
Subject: Ethics Application Number **12/220 Reliability and validity of upper body power profiling.**

Dear Nicholas

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 27 August 2012 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement by AUTEC at its meeting on 24 September 2012.

Your ethics application is approved for a period of three years until 6 September 2015.

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

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 6 September 2015;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 6 September 2015 or on completion of the project, whichever comes sooner;

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

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

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTEC Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at <http://www.aut.ac.nz/research/research-ethics/ethics>).

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

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Appendix 1d. Ethics Application Number 12/213

(Chapters 8 and 9)



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Nicholas Gill
From: Rosemary Godbold, Executive Secretary, AUTEC
Date: 6 September 2012
Subject: Ethics Application Number **12/213 The effects of complex resistance training on ballistic performance in elite rugby players.**

Dear Nicholas

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 27 August 2012 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement by AUTEC at its meeting on 24 September 2012.

Your ethics application is approved for a period of three years until 6 September 2015.

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

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 6 September 2015;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 6 September 2015 or on completion of the project, whichever comes sooner;

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

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

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTEC Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at <http://www.aut.ac.nz/research/research-ethics/ethics>).

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

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Appendix 2. Consent Forms

Appendix 2a. Validation of Wireless Accelerometry

<h1>Consent Form</h1>	 <p>AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU</p>
-----------------------	---

Project title: Validity and reliability of a wireless accelerometer to assess changes in kinematics and kinetics during various jumps

Project Supervisor: Dr Nicholas Gill

Researcher: Travis McMaster

- I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw from this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I do not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection
- I agree to take part in this research.
- I wish to receive a copy of my individual results from this research project (please tick one):
Yes No

Participant's name:

Participant's signature:.....

Email:.....

Date:.....

Approved by the Auckland University of Technology Ethics Committee on 11 October, 2011. AUTEK Reference number 10/184

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

Appendix 2b. Reliability of Lower Body Ballistic Profiling

<h1>Consent Form</h1>	 <p>AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU</p>
-----------------------	---

Project title: Reliability of lower body force-velocity-power profiling

Project Supervisor: Dr Nicholas Gill

Researcher: Travis McMaster

- I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw from this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I do not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection
- I agree to take part in this research.
- I wish to receive a copy of my individual results from this research project (please tick one):
Yes No

Participant's name:.....

Participant's signature:.....

Email:.....

Date:.....

Approved by the Auckland University of Technology Ethics Committee on 11 October 2011. AUTEK Reference number 10/183

Appendix 2c. Reliability of Upper Body Ballistic Profiling

<h1>Consent Form</h1>	 <p>AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU</p>
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Project title: Reliability and validity of upper body force-velocity-power profiling

Project Supervisor: Dr Nicholas Gill

Researcher: Travis McMaster

- I have read and understood the information provided about this research project in the Information Sheet dated 3 September 2012.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw from this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I do not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection
- I agree to take part in this research.
- I wish to receive a copy of my individual results from this research project (please tick one):
Yes No

Participant's name:.....

Participant's signature:.....

Email:.....

Date:.....

Approved by the Auckland University of Technology Ethics Committee on 6 September 2012. AUTEK Reference number 12/220

Appendix 2d. Complex Strength and Ballistic Training Intervention

<h1>Consent Form</h1>	 <p>AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU</p>
-----------------------	---

Project title: Effects of complex resistance training on ballistic performance in elite rugby players

Project Supervisor: Dr Nicholas Gill

Researcher: Travis McMaster

- I have read and understood the information provided about this research project in the Information Sheet dated 3 September 2012.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw from this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I do not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection
- I agree to take part in this research.
- I wish to receive a copy of my individual results from this research project (please tick one):
Yes No

Participant's name:.....

Participant's signature:.....

Email:.....

Date:.....

Approved by the Auckland University of Technology Ethics Committee on 6 September 2012. AUTEK Reference number 12/213.

Appendix 3. Study Information Sheets

Appendix 3a. Validation of Wireless Accelerometry

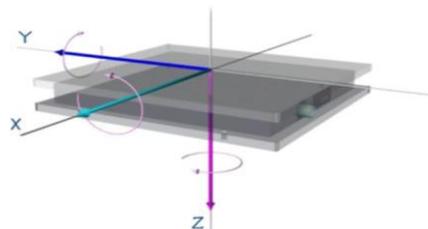
Study Information Sheet

Date Information Sheet Produced:

13 July 2011

Project Title

Validity and reliability of a wireless accelerometer to assess changes in kinematics and kinetics during various jumps



An Invitation

I, Travis McMaster, am a Doctoral candidate at the AUT University in Auckland, as well as an Assistant Strength and Conditioning Coach for the New Zealand Rugby and North Harbour Rugby Unions.

I would like to invite you to participate in a research study using new and innovative wireless technology to assess performance. Participation is entirely voluntary and you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

The primary purpose of this study is to determine the validity and reliability of the Myotest[®] accelerometer in assessing force, velocity, work, power, impulse and vertical displacement during squat type movements.

What will happen in this research?



You will be assessed on four occasions using a force plate and two wireless accelerometers. You will receive a familiarization session of the jumps performed during training. The testing sessions will take place every Monday and Thursday morning over a 2 week period. Performance tests will include three unweighted countermovement jumps (CMJ), three unweighted static squat jumps (SJ), three weighted (50 kg) CMJ and three weighted (50 kg) SJ with 30 s recovery between jumps and 2 min between sets. Prior

to testing, you will undertake a 10-minute standardised warm-up consisting of a series of dynamic movements (e.g. focusing on hip, knee and ankle mobility). The testing session will take approximately 10 min excluding the warm-up.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing are less than that of your regular North Harbour training and testing sessions. You may experience a mild soreness in your legs; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, you are unlikely to get DOMS after testing, as you will have enough time to recover in between trials.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedures.

If you do not feel you are able to complete the test requested, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher, if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains must be reported, specifically to the hip, knee and ankle.

What are the benefits?

By participating in this study, you will help assess the validity and reliability of wireless accelerometry, which may allow for more accessible and practical performance monitoring and assessment methods.

What compensation is available for injury or negligence?

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

How will your privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (Travis McMaster) and the primary supervisor (Dr. Nicholas Gill) will analyze your results.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time (~80 min) to be available for testing.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to Travis McMaster prior to participating in any of the tests.

If you do not wish to participate in this research, please notify the researcher and understand that you may withdraw at any time without any prejudice.

Will I receive feedback on the results of this research?

Yes, you can receive a summary of individual results once the information is ready for distribution (around end December 2011). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I contact for further information about this research?

Please contact the student researcher, Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 6248 050.

Student Researcher Contact Details:

Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 6248 050.

Project Supervisor Contact Details:

Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699

**Approved by the Auckland University of Technology Ethics Committee on: 11 October 2011.
AUTEK Reference number 10/184.**

Study Information Sheet

Date Information Sheet Produced:

15 July 2011

Project Title

Reliability of lower body force-velocity-power profiling

An Invitation

I, Travis McMaster, am a Doctoral candidate at the AUT University in Auckland, as well as an Assistant Strength and Conditioning Coach for the New Zealand and North Harbour Rugby Unions.

I would like to invite you to participate in a research study using new and innovative wireless technology and testing methods to assess profile athletic performance. Participation is entirely voluntary and you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

The purpose of this study is to determine the reliability the lower body force, velocity, power profile.

What will happen in this research?

Participants performing the reliability protocols will be assessed over four testing sessions; sessions one and two will be dedicated to creating a countermovement jump (CMJ) profile and sessions three and four will be dedicated to creating a squat jump (SJ) profile. You will perform a total of 12 jumps each testing session using loads ranging from 0 to 75 % of your one-repetition maximum parallel back squat. Session order will be randomised to minimise the effects of learning. Prior to testing, you will undertake a 10-minute standardised dynamic warm-up consisting of a series of dynamic movements (e.g. A's, C's, ankling, lunges, carioca and high kicks). Each testing session will take approximately 20 min.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing are less than that of your regular North Harbour training and testing sessions. You may experience a mild soreness in your legs; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, you are unlikely to get DOMS after testing, as you will have enough time to recover in between trials.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedures.

If you do not feel you are able to complete the test requested, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher, if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains of the hip, knee and ankle.

What are the benefits?

By participating in this study, you will help assess the reliability of an in-depth lower body force-velocity-power profile; which may lead to improved performance analysis techniques.

What compensation is available for injury or negligence?

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

How will your privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (Travis McMaster) and the primary supervisor (Dr. Nicholas Gill) will analyze your results.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for testing.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to Travis McMaster prior to participating in any of the tests.

If you do not wish to participate in this research, please notify the researcher and understand that you may withdraw at any time without prejudice.

Will I receive feedback on the results of this research?

Yes, I can receive a summary of individual results once the information is ready for distribution (around end December 2011). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I contact for further information about this research?

Please contact the student researcher, Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 6248 050.

Student Researcher Contact Details:

Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 6248 050.

Project Supervisor Contact Details:

Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699

Approved by the Auckland University of Technology Ethics Committee on: 11 October 2011.
AUTEC Reference number 10/183.

Appendix 3c. Upper Body Ballistic Profile

Study Information Sheet

Date Information Sheet Produced:

31 August 2012

Project Title

Reliability and validity of upper body force-velocity-power profiling
An Invitation

The Sport Performance Research Institute of New Zealand (AUT University) in collaboration with the New Zealand Rugby Union campus would like to invite you as representative players of the North Harbour Rugby Union to participate in a research study using new and innovative wireless technology and testing methods to assess profile athletic performance. Participation is entirely voluntary and you may withdraw at any time.

What is the purpose of this research?

The purpose of this study is to determine the reliability a ballistic upper body force, velocity, power profile to further improve rugby specific assessment protocols and add to the growing body of rugby research in New Zealand and beyond.

What will happen in this research?

As participants, your upper body power will be assessed across four testing sessions by a member of the SPRINZ research team external to the North Harbour Rugby Union to eliminate any conflicts of interest that may arise between the researcher and you (the athlete). Sessions one and two will be dedicated to assessing the countermovement bench throw and sessions three and four will be dedicated to assessing the concentric only bench throw. Session order will be randomised to minimise the effects of learning. Each session will take approximately 30 min, where you will perform 2 bench press throws at each of the following loads in ascending order: 15, 30, 45, 60 and 75% of your 1RM bench press.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing are less than that of your regular North Harbour training and testing sessions. You may experience a mild soreness in your legs; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, you are unlikely to get DOMS after testing, as you will have enough time to recover in between trials.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the testing procedures.

If you do not feel you are able to complete the test requested, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher, if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required activity; as only athletes that can perform maximally will be able to participate. For example, any strains and sprains of the back, hips, knees and ankles.

What are the benefits?

By participating in this study, you will help assess the reliability of an in-depth lower body force-velocity-power profile; which may lead to improved performance analysis techniques.

What compensation is available for injury or negligence?

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

How will your privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (Travis McMaster) and the primary supervisor (Dr. Nicholas Gill) will analyze your results.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for testing.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to Travis McMaster prior to participating in any of the tests.

If you do not wish to participate in this research, please notify the researcher and understand that you may withdraw at any time without prejudice.

Will I receive feedback on the results of this research?

Yes, I can receive a summary of individual results once the information is ready for distribution (end of November 2012). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project or conflicts of interests during participation in this project should be notified in the first instance to the primary researcher (Travis McMaster) and if an issue still exists, contact the Project Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699.

Further concerns regarding the conduct of the research (i.e. unresolved conflicts) should be notified to the Executive Manager, AUTECH, Health Care Ethics, Rosemary Godbold PhD, R.N., rgodbold@aut.ac.nz telephone: 09 921 9999, extension 7772.

Whom do I contact for further information about this research?

Please contact the student researcher, Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 3136 630.

Student Researcher Contact Details:

Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 3136 630.

Project Supervisor Contact Details:

Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699

Approved by the Auckland University of Technology Ethics Committee on: 6 September 2012.
AUTEC Reference number 12/220

Appendix 3d. Complex Strength and Ballistic Training Intervention

Study Information Sheet

Date Information Sheet Produced:

31 August 2012

Project Title

Effects of complex resistance training on ballistic performance in elite rugby players

An Invitation

The Sport Performance Research Institute of New Zealand (AUT University) in collaboration with the New Zealand Rugby Union would like to invite you as representative players of the North Harbour Rugby Union to participate in a research study I would like to invite you to participate in a research study using innovative complex training methods to improve rugby specific performance. Participation is entirely voluntary and you may withdraw at any time.

What is the purpose of this research?

The purpose of this study is to investigate the effects of complex strength and power training on upper and lower body strength, velocity, power and force with the aim of improving rugby specific performance and further contribute to rugby research in New Zealand and beyond.

What will happen in this research?

As participants, you will partake in a 13 weeks of testing and training (the training interventions will replace your regular resistance training sessions). You will take part in 3 testing weeks (3 sessions per week of ~ 60 min) conducted by a member of the SPRINZ research team external to the North Harbour Rugby Union; and 10 training weeks (4 training session per week of ~ 60 min) supervised by the head strength and conditioning coach (Sam Pervan) to eliminated any conflicts of interest that may arise between the researcher and you (the athlete). The 10 weeks of complex training will combine strength and ballistic movements with the intent of simultaneously improving you strength, speed and power and in turn your on-field rugby performance.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing and training are similar to that of your regular rugby weight training and testing sessions. You may experience some soreness in your upper and lower body; this response is normal and triggered by the onset of any resistance training exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after training. DOMS occurs as a result of working and overloading your muscles, causing muscle breakdown and in turn forcing your body to repair your muscles to become stronger and more powerful.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarize yourself with the training programme. Post-training cold water immersion will also be available to aid in neuromuscular recovery.

If you do not feel you are able to complete the training requested, you should notify the researcher immediately and the training will be terminated.

Finally, you should notify the researcher, if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required activity; as only athletes that can perform maximally will be able to participate in this training study. For example, any strains and sprains of the back, hips, knees and ankles.

What are the benefits?

By participating in this study, you will gain strength and power in your upper and lower body, which may improve your speed and on-field performance.

What compensation is available for injury or negligence?

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

How will your privacy be protected?

The identity and results of each participant will be kept confidential. Only the researcher (Travis McMaster) and the primary supervisor (Dr. Nicholas Gill) will analyze your results.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for training and testing.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to Travis McMaster prior to participating in any of the training sessions.

If you do not wish to participate in this research, please notify the researcher and understand that you may withdraw at any time without prejudice.

Will I receive feedback on the results of this research?

Yes, I can receive a summary of individual results once the information is ready for distribution (early January, 2013). Please check the appropriate box on the *Consent Form* if you would like this information.

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

Any concerns regarding the nature of this project or conflicts of interests during participation in this project should be notified in the first instance to the primary researcher (Travis McMaster) and if an issue still exists, the Project Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699.

Further concerns regarding the conduct of the research (i.e. unresolved conflicts) should be notified to the Executive Manager, AUTECH, Health Care Ethics, Rosemary Godbold PhD, R.N., rgodbold@aut.ac.nz telephone: 09 921 9999, extension 7772.

Whom do I contact for further information about this research?

Please contact the student researcher, Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 3136 630.

Student Researcher Contact Details:

Travis McMaster, travis.mcmaster@aut.ac.nz, mobile 022 3136 630.

Project Supervisor Contact Details:

Supervisor, Dr Nicholas Gill, Nicholas.Gill@nzrugby.co.nz, telephone: 027 488 8699

**Approved by the Auckland University of Technology Ethics Committee on: 6 September 2012.
AUTEK Reference number 12/213**

Appendix 4. Abstracts of Chapters as Published, In Press or In Review

Appendix 4a. Chapter 2: Sports Medicine

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). A brief review of strength and ballistic assessment methodologies in sport. *Sport Medicine*, Accepted, January 14, 2014.
(Chapter 2)

An athletic profile should encompass the physiological, biomechanical, anthropometric and performance measures pertinent to the athlete's sport and discipline. The measurement systems and procedures used create these profiles are constantly evolving and becoming more precise and practical. This is a review of strength and ballistic assessment methodologies utilised in sport, a critique of current maximum strength (one-repetition maximum [1RM] and isometric strength) and ballistic performance [bench throw and jump capabilities]) assessments for the purpose of informing practitioners and evolving current assessment methodologies. The reliability of the various maximum strength and ballistic assessment methodologies were reported in the form of intra-class correlation coefficients (ICC) and coefficient of variation (%CV). Mean percent differences ($Mdiff = \left[\frac{|X_{method1} - X_{method2}|}{(X_{method1} + X_{method2})} \right] \times 100$) and effect size ($ES = [X_{method2} - X_{method1}] \div SD_{method1}$) calculations were used to assess the magnitude and spread of methodological differences for a given performance measure of the included studies. Studies were grouped and compared according to their respective performance measure and movement pattern. The various measurement systems (e.g. force plates, position transducers, accelerometers, jump mats, optical motion sensors and jump-and-reach apparatuses) and assessment procedures (i.e. warm-up strategies, loading schemes and rest periods) currently utilised to assess maximum isometric squat and mid-thigh pull strength (intra-class correlation coefficient [ICC] > 0.95; coefficient of variation [CV] < 2.0%), one-repetition maximum (1RM) bench press, back squat and clean strength (ICC > 0.91; CV < 4.3%), and ballistic (vertical jump and bench throw) capabilities (ICC > 0.82; CV < 6.5%) were deemed highly reliable. The measurement systems and assessment procedures employed to assess maximum isometric strength (MDiff = 2 – 71%; effect size [ES] = 0.13 – 4.37), 1RM strength (MDiff = 1 – 58%; ES = 0.01 – 5.43), vertical jump capabilities (MDiff = 2 – 57%; ES = 0.02 – 4.67) and bench throw capabilities (MDiff = 7 – 27%; ES = 0.49 – 2.77) varied greatly, producing trivial to very large effects on these respective measures. Recreational to highly trained athletes

produced maximum isometric squat and mid-thigh pull forces of 1000 to 4000 N ; and 1RM bench press, back squat and power clean values between 80 to 180 kg, 100 to 260 kg and 70 to 140 kg, respectively. Mean and peak power production across the various loads (body mass to 60% 1RM) ranges from between 300 to 1500 W during the bench throw and between 1500 to 9000 W during vertical jump. The large variations in maximum strength and power can be attributed to the wide range in physical characteristics between different sports and athletic disciplines, training and chronological age as well as the different measurement systems of the included studies. The reliability and validity outcomes suggest that a number of measurement systems and testing procedures can be implemented to accurately assess maximum strength and ballistic performance in recreational and elite athletes, alike. However, the reader needs to be cognisant of the inherent differences between measurement systems, as selection will inevitably affect the outcome measure. The strength and conditioning practitioner should also carefully consider the benefits and limitations of the different measurement systems, testing apparatuses, attachment sites, movement patterns (e.g. direction of movement, contraction type, depth), loading parameters (e.g. no load, single load, absolute load, relative load, incremental loading), warm-up strategies, inter-trial rest periods, dependent variables of interest (i.e. mean, peak and rate dependent variables) and data collection and processing techniques (i.e. sampling frequency, filtering and smoothing options).

Appendix 4b. Chapter 3: Sports Medicine

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). The development, retention and decay rates of strength and power in elite rugby union, rugby league and American football: a systematic review. *Sports Medicine*, 43 (5): 367-384.

(Chapter 3)

Background and aim: Strength and power are crucial components to excelling in all contact sports; and understanding how a player's strength and power levels fluctuate in response to various resistance training loads is of great interest, as it will inevitably dictate the loading parameters throughout a competitive season. This is a systematic review of training, maintenance and detraining studies, focusing on the development, retention and decay rates of strength and power measures in elite rugby union, rugby league and American football players.

Search strategies: A literature search using MEDLINE, EBSCO Host, Google Scholar, IngentaConnect, Ovid LWW, ProQuest Central, ScienceDirect Journals, SPORTDiscus and Wiley InterScience was conducted. References were also identified from other review articles and relevant textbooks. From 300 articles, twenty-seven met the inclusion criteria and were retained for further analysis.

Study quality: Study quality was assessed via a modified twenty-point scale created to evaluate research conducted in athletic based training environments. The mean quality rating of the included studies was 16.2 ± 1.9 ; the rating system revealed that the quality of future studies can be improved by randomly allocating subjects to training groups, providing greater description and detail of the interventions, and include control groups where possible.

Data analysis: Percent change, effect size ($ES = [Post X_{mean} - Pre X_{mean}] \div PreSD$) calculations and standard deviations (SD) were used to assess the magnitude and spread of strength and power changes in the included studies. The studies were grouped according to i) mean intensity relative volume ($IRV = sets \times repetitions \times intensity$) ii) weekly training frequency per muscle group and iii) detraining duration. IRV is the product of the number of sets, repetitions and intensity performed during a training set and session. The effects of weekly training frequencies were assessed by normalising the percent change values to represent the weekly changes in strength and power. During the

IRV analysis, the percent change values were normalised to represent the percent change per training session. The long term periodised training effects (12, 24 and 48 months) on strength and power were also investigated.

Results: Across the twenty-seven studies ($n = 1015$), 234 percent change and 230 ES calculations were performed. IRVs of eleven to thirty (i.e. 3-6 sets of 4-10 reps at 74-88% one-repetition maximum [1RM]) elicited strength and power increases of 0.42 and 0.07 % per training session, respectively. The following weekly strength changes were observed for two, three and four training sessions per muscle region/week: 0.9, 1.8 and 1.3 %, respectively. Similarly, the weekly power changes for two, three and four training sessions per muscle group/week were 0.1, 0.3 and 0.7 %, respectively. Mean decreases of 14.5 (ES = -0.64) and 0.4 (ES = - 0.10) % were observed in strength and power across mean detraining periods of 7.2 ± 5.8 and 7.6 ± 5.1 weeks, respectively. The long term training studies found strength increases of 7.1 ± 1.0 (ES = 0.55), 8.5 ± 3.3 (ES = 0.81) and 12.5 ± 6.8 (ES = 1.39) % over 12, 24 and 48 months, respectively; they also found power increases of 14.6 (ES = 1.30) and 12.2 (ES = 1.06) % at 24 and 48 months.

Conclusion: Based on current findings, training frequencies of two to four resistance training sessions per muscle group/week can be prescribed to develop upper and lower body strength and power. IRV's ranging from eleven to thirty (i.e. 3-6 sets of 4-10 reps of 70 to 88 % one-repetition maximum [1RM]) can be prescribed in a periodised manner to retain power and develop strength in the upper and lower body. Strength levels can be maintained for up to three weeks of detraining, but decay rates will increase thereafter (i.e. 5 to 16 weeks). The effect of explosive-ballistic training and detraining on pure power development and decay in elite rugby and American football players remain inconclusive. The long term effects of periodised resistance training programmes on strength and power seem to follow the law of diminishing returns, as training exposure increases beyond 12-24 months, adaptation rates are reduced.

Appendix 4c. Chapter 4: Sports Technology / SPRINZ Conference

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). Is wireless accelerometry a viable measurement system for assessing vertical jump performance? *Sports Technology*, Accepted June 14, 2013.
(Chapter 4)

The aim of this study was to assess the mechanical differences calculated from hip acceleration (accelerometer attached to the hip), bar acceleration (accelerometer attached to bar-bell) and centre of mass acceleration (force plate) during vertical countermovement jumps (CMJ) and the reliability of each system. 18 elite male rugby players served as participants. In relation to the force plate, the bar accelerometer revealed similar peak velocity (PV [2%]) and peak power (PP [2%]), but predicted greater peak force (PF [24%]) during the concentric phase; while the hip accelerometer predicted similar PF (2%); but under-predicted peak velocity (PV [21%]) and peak power (PP [24%]) during the concentric phase. Both accelerometer attachments were deemed reliable for assessing PF (ICC = 0.80 – 0.83; SEM = 3-13%); but were low/moderately reliable for monitoring PV and PP (ICC = 0.35 – 0.77; SEM = 11 – 23%). The eccentric phase variables were unreliable across all devices and attachment sites. The kinematics and kinetics measured with the three systems (hip accelerometer, bar accelerometer and force plate) varied significantly ($p < 0.05$). Based on the outcomes, it is recommended that the force plate be used as the primary means of assessing CMJ performance until the stability of wireless accelerometry set-ups and protocols are improved.

INTRODUCTION

Kinematic and kinetic measurement systems are constantly evolving and becoming smaller, lighter and more practical, which has led to the emergence and development of micro-electromechanical devices, such as force plates, position transducers and accelerometers.

The use of wireless accelerometry in force, velocity and power assessment has become more prominent in recent years^{1,2}. The purpose of this study was to validate two wireless tri-axial accelerometer attachment sites (see Figure 1) i.e. at the bar (A_{bar}) and the hip (A_{hip}).

METHODS

A total of 18 semi-professional rugby union players (age = 21.6 ± 2.9 yrs; body mass = 102 ± 14 kg; 1RM squat = 169 ± 21 kg) completed two countermovement jump testing sessions. Two tri-axial wireless accelerometers (Altores@, Sjön, Switzerland) and a bi-axial force plate (Advanced Mechanical Technology Inc., Acupuncture, Watertown, MA) were used during data collection.

Repeated measures analysis of variance with Holm-Sidak post hoc contrasts, percent differences in mean scores and Pearson product correlations were used to determine the criterion validity of the accelerometers. The reliability of the measures was assessed using intraclass correlation coefficients (ICC) and percent standard error of measurement (%SEM). ICC and %SEM were considered acceptable if the scores were > 0.70 and < 10 %^{3,4}.

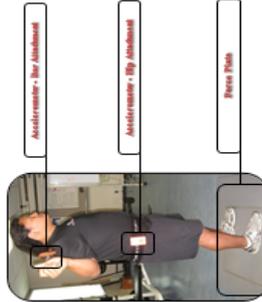


Figure 1. Accelerometer attachment sites and force plate during testing setup

RESULTS

In relation to the force plate, the A_{bar} over-predicted eccentric peak velocity and power by 42 and 82% concentric peak velocity and power by 2% and peak force by 24%. While the A_{hip} under-predicted eccentric peak velocity and power by 26 and 33% concentric peak velocity and power by 21 and 24% and peak force by 2%. Both accelerometer attachments were deemed reliable for assessing peak force (ICC = 0.80 – 0.83; SEM = 3.1-3%); but were low to moderately reliable for monitoring velocity and power (ICC = 0.55 – 0.77; SEM = 11 – 23%).

DISCUSSION

As expected, the location of the accelerometer attachment greatly affected the kinematic and kinetic outputs during jumping; and if the mechanics and movement paths associated with the hip, bar and/or centre of mass are of interest, then all three set-ups could be used in conjunction or independently for assessment and monitoring purposes. It must be noted, that the force plate was much more consistent between testing sessions than the two accelerometer set-ups. Therefore, it is suggested that the force plate should be used as the primary means of assessing and monitoring countermovement jump performance until the reliability of wireless accelerometry set-ups and protocols are improved.

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Appendix 4d. Chapter 5: Journal of Sports Science and Medicine

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). Quantifying Mechanical Variability across Upper and Lower Body Ballistic Movements. *Journal of Science and Medicine in Sport*, In 2nd Review. (Chapter 5)

The purpose of this investigation was to measure the mechanical variability associated with ballistic lower and upper body movements in semi-professional rugby union players. The players partook in four vertical jump and four bench throw sessions separated by three days. Vertical jump (countermovement jump [CMJ] and static squat jump [SJ]) and bench throw (countermovement bench throw [CMBT] and concentric only bench throw [COBT]) performances were assessed across six and five relative one-repetition maximum loads (0/body mass, 15, 30, 45, 60 and 75% 1RM), respectively. The kinematic and kinetic variable produced during the vertical jump and bench throw movement patterns displayed moderate to high inter-day reliability (ICC > 0.79 and CV < 10.6 %; ES < 0.73) during the concentric phase across the loading spectrum; the eccentric variables ranged from poorly to highly reliable (ICC > 0.50; CV < 17.2%; ES < 0.74). The upper and lower body ballistic profiling protocols described are relatively stable and reliable across testing sessions. Force, velocity and power can be used to assess and monitor ballistic jump and bench throw in the concentric phase if changes greater than 98 N, 0.13 m/s and 224 W respectively, across the loading spectrum are observed.

Appendix 4e. Chapter 6: Journal of Strength and Conditioning Research

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). Force-velocity-power assessment in semi-professional rugby union players. *Journal of Strength and Conditioning Research*, Accepted June 17, 2013. (Chapter 6)

There is a constant and necessary evolution of training and assessment methods in the elite contact sports; as is required to continually improve the physical qualities of these respective athletes to match the growing sport and position specific performance demands. Our aim was to examine the differences between ballistic upper body performance profiles and maximum upper body strength of elite rugby union forwards and backs. Twenty semi-professional male rugby union players (age = 21.1 ± 3.0 yrs; mass = 94.9 ± 9.7 kg) were assessed for maximum bench press strength (1RM bench press = 121.3 ± 21.8 kg) and maximum throw power (Pmax), force (Fmax) and velocity (Vmax) from an incremental relative load testing protocol (15, 30, 45, 60 and 75% 1RM). Player rankings were also included to identify individual strength and weaknesses. The forwards were moderately stronger (effect size [ES] = 0.96; $p = 0.01$), produced significantly greater Fmax (ES = 1.17 – 1.41; $p = 0.01$) and were more powerful (ES = 0.57 – 0.64; $p < 0.43$) than the backs. Vmax differences were trivial to small (ES = -0.32 - -0.65; $p > 0.15$). There were inherent differences in strength and Fmax between the forwards and backs most likely due to the physical demands of these respective positions. Improvements in upper body strength may in turn improve ballistic force and power production, but not necessarily velocity capabilities. From the Fmax and Vmax observations, the forwards appear to be more force dominant and the backs more velocity dominant. Pmax, Fmax and Vmax may be used to highlight proficient and deficient areas in ballistic upper body performance; the individual rankings could be further utilised to identify and possibly rectify individual deficiencies.

Appendix 4f. Chapter 7: Journal of Sports Science and Medicine

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). The effects of strength and sprint ability on ballistic lower body performance in semi-professional rugby union players. *Journal of Sports Science and Medicine*, In Review.

(Chapter 7)

The purpose of this investigation was to examine and identify mechanical lower body differences between strong and weak and fast and slow athletes. Eighteen semi-professional male rugby union players (age = 21.3 ± 3.3 yrs; mass = 93.2 ± 10.0 kg) were assessed for maximum back squat strength (1RM = 121.3 ± 21.8 kg), sprint ability (10, 20 and 30 m) and maximum vertical jump power (Pmax), force (Fmax) and velocity (Vmax) from an incremental relative load testing protocol (0, 15, 30, 45, 60 and 75% 1RM). Player rankings were also included to identify individual strength and weaknesses. The stronger players produced moderately (ES = 0.98) greater Fmax (10%) in comparison to the weaker players; whereas the faster players produced moderately higher (ES = 0.99) Vmax (19%) in comparison to the slower players. There were no significant differences in sprint ability and the 1RM squat between strong and weak players and fast and slow players, respectively. From the Fmax and Vmax observations, the stronger players appear to be more force dominant and the faster players more velocity dominant. Pmax, Fmax and Vmax may also be used to identify proficient and deficient areas in ballistic lower body performance; the individual rankings could be further utilised to identify and possibly rectify individual deficiencies.

Appendix 4g. Chapter 8: Journal of Australian Strength and Conditioning

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). Effects of complex strength and ballistic training on strength, sprint ability and force-velocity-power profiles of semi-professional rugby union players. *Journal of Australian Strength and Conditioning*, Accepted July 5, 2013.

(Chapter 8)

The primary purpose of this study was to determine the acute training effects of two different complex loading schemes on strength, speed and the ballistic force-velocity-power capabilities of fourteen semi-professional rugby union players (Mean \pm SD; age = 20.9 ± 1.6 years; mass = 95.2 ± 7.4 kg; height = 1.85 ± 0.05 m). The players completed two, five week (20 sessions) complex training interventions (strength + heavy ballistic [SHB]; strength + light ballistic [SLB]) utilising a cross-over design. Both interventions followed a four day complex training week with the same strength and power exercises. Both training interventions (SHB and SLB) produced small to moderate (ES = 0.34 – 0.98) significant ($p < 0.03$) adaptations in the 1RM bench press (4 – 9 %) and 1RM squat (9 – 12 %); as well as small to moderate (ES = -0.26 to -0.68) reductions in sprint times over 10 m (-1.2 to -1.6 %), 20 m (-1.0 to -1.2 %) and 30 m (-0.6 to -0.9 %). SHB training caused positive shifts in bench throw and vertical jump Fmax (6 and 10%), Vmax (10 and 57%) and in turn improved Pmax (12 and 46%); whereas the SLB training caused increases in Vmax (15 to 68%) and also enhanced Pmax (15 and 36%). Practitioners could implement these complex training modalities as acute stimuli to elicit positive adaptations across the entire force-velocity-power spectrum, while simultaneously improving maximum strength and sprint abilities.

Appendix 4h. Chapter 9: Journal of Australian Strength and Conditioning

McMaster, D., Gill, N., Cronin, J., and McGuigan, M. (2013). Effects of a six week off-season on strength, sprint ability and ballistic performance in semi-professional rugby union players. *Journal of Australian Strength and Conditioning*, Accepted (minor changes).

(Chapter 9)

The purpose of this investigation was to assess the effects of six weeks off-season rest on strength, sprint ability and ballistic upper and lower body performance in ten semi-professional rugby union players. There were trivial to small reductions in 1RM bench press (-1.5%; ES = -0.10), 1RM squat (-6 %; ES = -0.50) and heavy load (60-75% 1RM) peak force (PF [-1 to 2%; ES = -0.02 to -0.70]). Trivial to small decreases (-2 to -6%; ES = -0.20 to -0.35) in countermovement bench throw (CMBT) maximum force (Fmax [-2%]), maximum velocity (Vmax [-4%]) and maximum power (Pmax [-6%]). There were moderate (ES = 0.75; p = 0.06) and very large (ES = -2.30; p = 0.07) reductions in countermovement jump (CMJ) Vmax (-35%) and Pmax (-14%). There were also (ES = 1.10 – 2.30) increases in sprint times over 10, 20 and 30 m (2 to 3%). Current findings suggest that the decay rates using lighter loads are greater than that of heavy loads. Off-season rest periods of up to six weeks may result in trivial decay rates in strength and heavy load ballistic performance, moderate decay in medium load ballistic performance and larger decay in light load ballistic and sprint performance.

Appendix 4i. Chapter 10: National Strength and Conditioning Association Conference / Journal of Science and Medicine in Sport

McMaster, D., Gill, N., Smart, D., Cronin, J., and McGuigan, M. (2013). Monitoring weekly neuromuscular recovery patterns in semi-professional rugby union players. *National Strength and Conditioning Association Conference (Abstract)*: Oral Presentation, July 11, Las Vegas.

(Chapter 10)

PURPOSE: In elite rugby, the rigors and demands of a match and competition can have acute and accumulative effects on neuromuscular performance; various monitoring methods can be utilised to detect system fatigue and recovery. Vertical jump peak power is commonly used track and quantify neuromuscular fatigue and recovery following rugby matches. Few studies have fully assessed the accumulative effects of a rugby competition on vertical jump performance; furthermore no prior research has monitored the changes in the peak power derivatives (i.e. force at peak power and velocity at peak power) and their contribution to fatigue and recovery. The aim of the current study was to track the time course changes in vertical jump peak power, force at peak power and velocity at peak power to monitor the amount of acute and chronic neuromuscular fatigue and the weekly recovery rates in semi-professional rugby union players throughout a competitive season. **METHODS:** Vertical jump performance of eighteen semi-professional rugby union players (age = 23.9 ± 2.9 yr; height = 184.4 ± 7.2 cm; body mass = 103.1 ± 12.4 kg) was monitored at regular time points between games (pre [58 ± 2 hr] and post [41 ± 10 hr]) across a nine week period. Two body mass countermovement jumps (CMJ) and a portable force plate were used to measure peak power, velocity at peak power and force at peak power. **RESULTS:** There were small decreases in post-game peak power (-2.3%) and velocity at peak power (-2.7%) in comparison to baseline values; while differences between baseline and pre-game were trivial (<1.0%). Small increases in CMJ peak power and velocity at peak power (2.9 - 3.7 %) from post-game to pre-game were observed; whereas the pre- vs. post- game force at peak power changes were trivial (-0.5%; ES = 0.08). There were small increases in peak power ($2.4 \pm 2.6\%$) and velocity at peak power ($5.9 \pm 4.1\%$) and small decreases in CMJ force at peak power (-3.7%; $\pm 4.0\%$) from the first two weeks of competition to the last two weeks. Large and very large correlations were observed between velocity at peak power ($r = 0.62$), peak power ($r = 0.72$) and the number of hours post-match jump testing took place. There were also moderate correlations ($r = 0.47 - 0.52$) between enhanced pre-game CMJ performance

and match outcome (expressed as a positive or negative value based on score differential).

CONCLUSION: The results suggest that fluctuations in peak power were most-likely due to decreases and increases in velocity and not force, therefore velocity produced at peak power appears to be the limiting factor for assessing peak power decay and recovery rates. Neuromuscular performance (peak power) may be diminished for up to 110 hr post match from a neuromuscular fatigued state. **PRACTICAL APPLICATIONS:** The rate/amount of post-game fatigue (i.e. decrease in peak power and velocity at peak power) in proportion to the week prior and baseline may be used to guide daily and weekly training loads throughout the season. Peak power output can be maintained and under the right training stimulus even improved throughout a competitive season.

ACKNOWLEDGEMENTS: The investigators would like to thank the North Harbour Rugby Union staff and players for their support of and cooperation on this project.

McMaster, D., Gill, N., Smart, D., Cronin, J., and McGuigan, M. (2013). Monitoring weekly ballistic lower body recovery patterns in semi-professional rugby union players. *Journal of Science and Medicine in Sport: In Review*, May 28, 2013. (Chapter 10)

Objectives: The purpose of this investigation was to track the time course changes in vertical jump performance of semi-professional rugby union players throughout a 9-week competition.

Design: Repeated measures (weekly monitoring) within group design.

Methods: Vertical jump performance of eighteen semi-professional rugby players (age = 23.9 ± 2.9 yrs; height = 184 ± 7.2 cm; body mass = 103 ± 12.4 kg) were monitored pre- (58 ± 2 hrs) and post- (41 ± 10 hrs) game to assess neuromuscular performance. Two body mass countermovement jumps (CMJ) were used to measure peak power (PP), velocity at peak power (V@PP) and force at peak power (F@PP).

Results: Small decreases in post-game (-2.3%) in CMJ PP in comparison to baseline were observed; and small increases in pre-game CMJ (2.9 - 3.7 %) in comparison to post-game were observed. A very large correlation was observed between CMJ PP ($r = 0.72$) and the number of hours post-match jump testing took place. There were small increases in PP ($2.4 \pm 2.6\%$) and V@PP ($5.9 \pm 4.1\%$) from the first two weeks of competition to the last two weeks.

Conclusions: The results suggest that PP and V@PP were most sensitive to detecting CMJ changes and in turn neuromuscular recovery patterns. PP may be diminished for up to 110 hr post match from a fatigued state. Assessing pre- and post-game CMJ performance in proportion to the week prior and baseline may be used to guide daily and weekly training loads throughout the season.

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Appendix 5a. Chapter 3 Copyright Permission

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