2007

A series of studies on professional rugby league players

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A series of studies on professional rugby league players, including:

1. Testing and the relationship of upper body muscular strength, power, speed and strength-endurance to playing position and status in professional rugby league players

2. Acute training methods that affect the development of upper body muscular power

and

3. Chronic adaptations ~ the nature, scope and methodology of long-term adaptations in upper body strength and power

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Date of Submission: September, 2006

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Abstract

Rugby league football is a popular game in Australia, which appears to rely heavily upon strength, power, speed and endurance due to the nature of the phyiscal contacts. In an effort to discern the importance of upper body strength, power speed and endurance to rugby league players a retrospective data analysis was performed. Three areas of investigation were: 1) the testing of upper body physical qualities of strength, power, speed and strength-endurance and their significance to playing status in the elite national first-division (NRL), second-division (SRL) and third-division (CRL), 2) the effect of acute training variable manipulations upon power output and 3) the nature, scope and magnitude of chronic adaptations in strength and power in a multi-year period in professional rugby league players.

The findings for the first part suggest that maximum pressing and pulling strength appear vitally important to NRL attainment. Maximum power and strength-endurance are only slightly less indicative of NRL attainment and appear as important as each other. Upper body speed appears to garner less importance. The major findings of this part of the thesis is that testing can determine the future training content of an athlete to a degree, but that initial training should be directed at increasing maximum strength which appears to underpin all other qualities. After adequate levels of maximum strength have been attained, the training can be directed (based upon test results) more appropriately at either maximum power or strength-endurance training; these qualities which require very different training variable manipulations (viz. repetitions, rest periods, etc).

The second part of the thesis looked at how power output could be acutely affected within a workout by different training variable manipulations. The first two papers addressed the power training methodology known as complex or contrast training. Previous upper body studies have not shown any benefit and equivocal results exist concerning lower body effects of such training strategies. However, in the current studies both an agonist strength exercise and an antagonist strength exercise alternated with the power exercise brought about a small but significant increase in power output. The difference between this and previous research is that the athletes in these investigations were stronger, more powerful and experienced in power training. As such it was concluded that complex training, using contrasting resistances and/or exercises, might be a valid power training method for advanced athletes. However, less experienced athletes may actually derive adverse outcomes from attempting to implement complex training.

A third study in this section looked at the effect that hypertrophy-oriented training may have upon power output within a training session. It was determined that a hypertrophy-oriented training bout, in this instance a small dose of 3 x 10 repetitions @ 65%1RM with short rest periods, severely suppressed power output by 17%. A considerable negative effect still lasted despite 7 minutes of passive rest and was more pronounced in the strongest athletes. Consequently coaches should be wary of hypertrophy-oriented strength training preceding power training within a training session.

The nature, scope and magnitude of chronic adaptations in strength and power in a multi-year period in professional rugby league players were

the final themes to be investigated. The two major findings were that 1) advanced athletes can still make gains in strength and power, however there exists a diminishing scope for improvements with increased strength and experience levels ~ the time frames over which changes may be seen may be quite lengthy. Also the age that regimented resistance training commences also appears to impact upon strength and power levels. Those who delay the start of such training until their early twenties do not possess the same strength and power levels as those who start in their late teenage years.

The last papers are review papers. The first paper is concerned with practical methods of enhancing the effectiveness of power training. By itself it could be seen as a summary paper of much of the work in this thesis as it contains a review of relevant power training literature coupled with practical recommendations for enhancing power training. The second paper is a review of the different periodization strategies used to vary training across a training cycle.

Acknowledgements

I would like to acknowledge the support of the Brisbane Broncos Rugby League Football Club. Especially I would like to thank the coaching staff for their assistance and support. In particular Wayne Bennett has been extremely supportive over 10 years of association. Not many strength and conditioning coaches get to work at the same club for 10 years straight, win three Premierships, a World Club Championship and make the finals each year. Ten years allows you to develop players from scratch and you can learn a lot that way. Of course the players must be acknowledged for being extremely hard-working and motivated trainers, which is what separates this thesis from those done using typical college students as subjects. No one trains harder than athletes whose livelihood depends largely upon their physical attributes and who are scrutinized by millions each week on television. More and more training studies must be done on elite athletes to discern the differences in their adaptations in comparison to lesser level athletes.

I would also like to thank my supervisor Professor Rob Newton for his patience and help in preparing this type of thesis. His desire to see research on elite athletes parallels my own and I know I could not get a start on a thesis like this without his support and enthusiasm.

I would also like to thank all the other athletes I have trained or trained with over the years. I learned something from each session, even if it was merely an affirmation of something I already knew or believed. Also to former power-lifting greats such as Glen Wazkiel, Wayne Scarffe, Dino Toci, Mason

Jardine and Robert Wilks for passing on practical bits of information and guidance concerning elite level strength training over the years.

Family and friends are the basis of all positive things that can happen in your life. Consequently I would like to thank my parents, Frank and Aline Baker, for providing me with a great upbringing, great education and great love of sport, which was only achieved through their sacrificing a lot to give their seven children something.

Finally, I would also like to thank my partner Sercia Caballes Hopkins for helping me over all the years. She is the most beautiful and funny woman I have ever met. Mahal kita ("I love you" in the Bisaya language of the Philippines).

Daniel Baker

List of Original Papers

1. Baker, D. & Newton, R. U. (2006): " Analyses of tests of upper body strength, power, speed and strength-endurance to describe and compare playing rank in professional rugby league players." **International Journal of Sports Physiology and Performance**, 1(4) December.

2. Baker, D. & Newton, R. U. (2004): "An analysis of the ratio and relationship between upper body pressing and pulling strength." **Journal of Strength and Conditioning Research**, 18(3):594-598.

3. Baker, D. (2004): "Predicting 1RM or sub-maximal strength levels from simple "reps to fatigue" (RTF) tests." **Strength and Conditioning Coach**, 12(4):19-24.

4. Baker, D. (2003): "Acute effect of alternating heavy and light resistances on power output during upper-body complex power training." **Journal of Strength and Conditioning Research,** 17(3):493 -497.

5. Baker, D. & Newton, R. U. (2005): "Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training." **Journal of Strength and Conditioning Research,** 19(1):202-205.

6. Baker, D. (2003): "Acute negative effect of a hypertrophy-oriented training

bout on subsequent upper-body power output." **Journal of Strength and Conditioning Research**, 17(3):527-530.

7**.** Baker, D. & Newton, R. U. (2006): "Adaptations in upper body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes." Daniel Baker and Robert U. Newton, **Journal of Strength and Conditioning Research,** 20(3):541-546.

8. Baker, D. (2005): "The effects of systematic strength and power training during the formative training years: A comparison between younger and older professional rugby league players." **Strength and Conditioning Coach.** 11(2):9–11.

9. Baker, D. & Newton, R. U. (2005): "Methods to increase the effectiveness of maximal power training for the upper body." **Strength and Conditioning Journal,** 27(6):24-32.

10. Baker, D. (2006):" Cycle-length variants in periodized strength/power training." **Strength and Conditioning Journal (**was accepted to be published on 6th September, 2006).

Abbreviations and Definitions

NRL = the elite, professional first-division national rugby league competition

SRL = A second-division intra-state based rugby league competition

CRL = A third-division intra-city based rugby league competition

Pmax = Maximum power

1RM = One Repetition Maximum (test of strength)

BP = Bench press

PU = Pull-up

BT = Bench throw

BT P20 = Bench throw test of upper body speed with a resistance of 20 kg

BT P40-80 = Bench throw tests of power with a resistances of 40-80 kg

Load-power curve = Graphic display of BT 40-80 testing

RTF BP 60 = Exhaustive test bench pressing 60 kg for as many repetitions to fatigue (RTF) as possible

Hypertrophy-oriented training = training with higher repetitions, moderate resistances and shorter rest periods to induce muscle growth

Strength-oriented training = training with lower repetitions, heavy resistances and longer rest periods to induce increases in muscle strength

Power-oriented training = training with lower repetitions, moderate resistances and longer rest periods to induce increases in power output

Strength-endurance training = training with very high repetitions, light to moderate resistances and shorter rest periods to increase strength-endurance capabilities

Chapter 1. Introduction

Rugby league football is an important professional sport in Australia. Currently the Australian national team is the world champions, a situation that has remained unchanged for a number of years. However, until recently a paucity of scientific data existed regarding the applied physiology of professional rugby league players. As rugby league entails brutal physical collisions, (requiring a large degree of strength, power speed and endurance) between opposing players, then any study examining these physical qualities is of interest. Pressing or pushing an opponent backwards/away is perhaps the most fundamental task in rugby league. Therfore studies examining the testing and training of upper body pressing/pushing strength, power speed and endurance and how they relate to players of differing playing status and training experience is of interest.

In an effort to discern the importance of upper body strength, power and speed to rugby league players, I have analyzed data that I have amassed during testing and training during my eleven years involvement in a professional rugby league club. This retrospective data analysis would have three main areas of focus. These three areas of investigation are 1) the testing of upper body physical qualities of strength, power, speed and strength-endurance, 2) the effect of acute training variable manipulations upon power output and 3) the nature, scope and magnitude of chronic adaptations in strength and power in a multi-year period in professional rugby league players.

First, a retrospective data analysis study would determine to what extent upper body maximum strength, power, speed and strength-endurance affect the playing position and status of professional rugby league players (Study 1). Specifically the extent to which these upper body physical qualities relate to playing status as participants in the elite national league (NRL),

second-division state league (SRL) or third-division intra-city league (CRL). While previous studies (Baker, 2001c, 2002) have shown that maximum strength is more important than upper body speed in determining playing status, the extent to which maximum power and strength-endurance impact upon playing status is less clear. Recent trends in playing and refereeing games appear to have increased the strength-endurance demands upon the players. It is of considerable interest if this belief is borne out in testing.

A second related study (Study 2) would examine the strength ratio between upper body pressing and pulling strength and again determine if this differed between NRL and SRL players. Very little data exists concerning the pulling strength of rugby league players and no data has been found that examines whether a strength ratio between pressing or pulling strength exists in any athletes, despite the widespread and commonly held edict that they should be equivalent (either in force or training dosages).

A brief data analysis study of the predictive value of repetitions to fatigue tests (RTF) to extrapolate 1RM performance is also included in this section (Study 3). Many studies have been performed using RTF tests to develop regression equations to estimate 1RM performance in exercises such as the squat and bench press. However regression equations, assuming a linear relationship between repetitions performed and sub-maximal strength levels, from which maximum levels are predicted, may be fundamentally flawed given that the relationship is actually curvi-linear or partly parabolic. Consequently in Study 3 a table of correction factors applicable to the repetitions performed and the corresponding sub-maximal strength levels is used in the bench press and pull-up exercise to extrapolate 1RM performance. A more accurate method of testing large numbers of less experienced athletes in a short period of time in these two key upper body tests would be of considerable interest to lower level coaches.

Overall these three studies will provide insightful data indicating the relevance of further training intervention studies. In particular they will provide normative data as to the actual relevance of each quality to successful participation in the NRL. Once this is known it is much easier to determine the nature of future training studies. For example, if upper body speed is found to be more important than strength-endurance in NRL attainment, then future longer-term training studies should focus upon upper body speed, rather than strength-endurance.

The second series of studies will consist of three training intervention studies that investigate how acute manipulations of training variables may affect upper body power output. Increasing muscular power output is of interest to many sports and considerable interest exists in specific methodologies that aim to do this. A number of these methods are quite common in the wider power training community, but have yet to be conclusively verified. One method is the use of contrasting exercises and resistances. The effect that alternating sets of a heavier strength exercise with sets of lighter power exercises (also known as "complex" training) has upon subsequent power output will be analyzed in Study 4. To date the results from complex training have been mixed for the lower body with no benefit elucidated yet for the upper body. Some of the research suggests the strength level and training experience of the athletes influences the outcomes of these studies (eg. Hakkinen, 1985).

A different form of complex training, whereby an antagonist exercise is alternated with the agonist power exercise will also be examined to observe if this procedure has any effect upon subsequent agonist power output (Study 5). Some previous work concerning agonist and antagonist muscle interplay suggests that this method warrants consideration as a power training method.

The hypertrophy of muscle is thought to offer possibly the only avenue of continued strength/power gain in elite, experienced athletes. However the

training variable manipulation suitable for hypertrophy is quite disparate, and perhaps contradictory, to that recommended for power training. Hypertrophy-oriented training typically precedes general strength/power and maximal strength/power training in a yearly-periodized training cycle. However, some recent trends entail a more holistic approach within a week (e.g., hypertrophy-oriented, strength-oriented and power-oriented training sections within each work-out). Given that high-volume energy system training has been shown to attenuate power output, the effect that high-volume hypertrophy-oriented resistance training may have if it precedes power training within a workout is of interest. Study 6 will investigate how upper body power output is affected by a high-volume, short-rest period training protocol that is often recommended to induce muscle hypertrophy.

The third theme to be analyzed will be the nature and scope of changes in upper body maximal strength and power across prolonged periods in professional rugby league players (Study 7). Long-term training observations of elite athletes are extremely rare, but in reality should be of the greatest interest to researchers. Of interest is the fact that the professional rugby league players, who could be grouped equally based upon years of training experience at the commencement of the study period, could provide data upon the concept of the diminishing scope for further strength/power progress that may occur with increased training experience. This concept is further illustrated by a short data analysis paper that compares the strength and power levels for matched NRL players who are differentiated not by how many years resistance training experience they have but by at what age did they commence serious periodized resistance training (Study 8).

From the series of retrospective data analysis and training intervention studies, a literature review and recommendations for training to develop maximum strength and power will be described (Studies 9 and 10).

Purposes

The most basic purposes of this research are to determine the extent to which levels of upper body strength, power, speed and endurance relate to rugby league players from different playing positions and different status levels and the factors that affect the development of strength and power. The factors that affect strength and more particularly power are will be examined in both acute (within a work-out) and chronic (4-years) periods.

Rugby league is an important professional sport in Australia, which, due to the high impact force physical contact it entails, appears to rely heavily upon high levels of strength, power, speed and endurance. Therefore testing of these physical qualities and the training methods that impact upon them are of interest. This increased understanding of the role of strength, power, speed and endurance play in the development of rugby league players would benefit not only rugby league players and coaching staff but also broaden our understanding of the field of applied sports physiology. While maximum strength appears to be adequately researched over the last 40 years, little research has been conducted upon upper body power in comparison, especially using experienced athletes. For example, most studies conducted at universities use university students as subjects and extrapolate these results to other populations such as elite athletes. This methodology is continually questioned, especially in the field of sports physiology and coaching. The issue of complex power training (an acute manipulation of training) stands out. It has been illustrated that differences exist in the nature of the adaptation to complex training, based upon initial strength levels and

training experience. As yet, complex training has not been verified as an effective power training method, despite its seemingly widespread acceptance in the wider training community. Complex training may be either an invalid training method, as some research suggests or perhaps a valid method that has yet to be fully understood due to the relative inexperience and low levels of strength of subjects used in previous research. The question is “will using much stronger, powerful and experienced athletes garner different results to previous upper body complex training studies”? The papers concerning complex training in this thesis may provide data that resolve the issues of the veracity of complex training.

Also by investigating younger college-aged CRL players, SRL players and comparing them to elite NRL professionals, differences in the extent and scope of adaptations to training can be identified and more readily explained. Furthermore the examination of changes in strength and power over a 4-year period has rarely been reported for any athletes, let alone elite professional athletes. This thesis will report the nature and scope of changes in strength and power across this long-term time period with special reference to different training variable manipulations.

Statement of the problem

Because a paucity of data exists concerning the applied physiology and biomechanics of rugby league, confusion exists concerning the relative importance of strength, power and speed to playing status in the game. Furthermore it has not been determined if strength, power, speed and endurance are more important to some positional playing groups. The purpose of this research is to determine a) the importance of upper body

strength, power, speed and endurance to professional rugby league players, b) how power output can be impacted by different training variable manipulations and c) the nature and scope of changes in strength and power across long-term time periods in experienced trainers.

Specific Research questions

This series of studies will examine a number of questions pertinent to the development of strength, power, speed and endurance in professional rugby league players.

1. What is the extent to which levels of upper body strength, power, speed and endurance relate to rugby league players from different playing positions and different status levels?
2. Is there a difference in the strength ratio between pressing and pulling strength between players of different status levels?
3. Can simple Repetitions to Fatigue (RTF) testing accurately predict upper body 1RM pulling and pressing strength?
4. How is upper body power output impacted upon by contrasting resistances during "complex" training including a traditional heavier strength-oriented training set alternated with a lighter power set?
5. How is upper body power output impacted by a non-traditional method whereby the contrast provided is in the form of alternating agonist and antagonist exercises in the complex?
6. How is upper body power output impacted by different resistance training variable manipulations such as high volume hypertrophy-oriented training?
7. What is the scope and nature of changes in upper body strength and power across a 4-year time period in professional rugby league players?

8. Does the chronological starting age possibly affect the scope, nature and magnitude of changes in upper body strength and power?

9. Based upon this and other relevant literature, what practical methods of enhancing power training can be recommended?

10. What are the variations of periodized strength/power training that may be utilized by rugby league players or other strength/power athletes?

Limitations

The results of this series of studies may be limited to rugby league players or athletes with considerable training experience. It is not known if other athletes who are not used to performing resistance, speed and endurance training concurrently would exhibit the same responses or adaptations. Clearly the training experience of athletes affects the nature and scope of adaptations and this should be taken into account when extrapolating the results of this series of studies.

Furthermore, the results and conclusions from this series of studies were limited to the chosen upper body tests. This does not preclude other tests or other physical qualities (eg. running endurance) from also being of great importance to the success of rugby league athletes.

Chapter 2. Review of the literature.

Introduction

This literature review will address aspects of upper body muscular functioning as related to the sport of rugby league, in particular maximal strength and power. Firstly strength and power will be defined, using common definitions used in the literature. The related qualities of speed and strength-endurance, although not the main focus of this thesis, will also be defined.

The second part of this review will address the neuromuscular basis of strength and power. Specifically the relative (and sometimes theoretical) role that neural mechanisms such as increased central drive and decreased disinhibition have upon strength and power adaptations will be reviewed. The role, nature and scope of the hypertrophy of muscle and its effect upon ongoing strength/power gain in long-term training will also be reviewed. It is hoped that a greater understanding of the role of these two broad avenues of force regulation, but in particular the neural mechanisms, may give rise to the development of specific acute training strategies that may enhance power output.

The third part of this chapter will review the interplay between neural and hypertrophic adaptations to resistance training and how these two broad avenues of force regulation are affected by different training variable configurations. Specifically training methods to develop strength and power, including programming considerations, the concept of training periodization and specific advanced strategies will also be reviewed.

The fourth part of this chapter will address how the different upper body

muscular qualities of strength, power, speed and strength-endurance are assessed in the athlete and in particular, rugby league players. An important reason for testing of muscular functioning is to determine if testing identifies trends in the team grading (a measure of performance) or positional grouping of rugby league players. This question will be reviewed in regards some of the common tests currently used or recommended. This area of the review will provide insight as to which tests may prove most useful when assessing the upper body muscular functioning of rugby league players.

2a. Definitions of strength and power.

For the purpose of this thesis strength will defined as the ability to apply force, irrespective of time constraints. The ability to apply maximal force, irrespective of time constraints, can be defined as maximal strength (Knuttgen & Kraemer, 1987). However in most sporting situations force must be applied rapidly or under some time constraint (eg. in rowing, the stroke rate may be 40 per minute, so this is the time constraint under which force must be applied). The parameter that describes a force being applied over a given distance (work performed) in a given time is power. For the purpose of this thesis power will be defined as force x distance/time (also work/time). Maximal power (Pmax) will be defined as the highest average power output during the concentric phase of a muscular contraction (Baker, 2001a). Speed will be defined as the distance-time, based upon the time taken to move between two points (ASCA, 2006). Strength-endurance will be defined as the ability to continue to apply force at a designated level or the ability to apply

force with minimal diminishment, for longer periods (typically greater than 30 s) (ASCA, 2006).

2b. Neuromuscular basis of strength and power.

It has long been known that progressive over-loading of muscle brings about an increase in strength. However, it is not yet fully understood how this occurs. The interaction of neural factors, hypertrophy and hormonal activity plays an important role in increasing strength and power (Hakkinen, 1985; 1989). This review will only briefly examine the roles of neural adaptations and hypertrophic responses in improving strength and power functioning but it is felt necessary to gain a better understanding of the rationale of some specific strategies currently being used. In particular periodization of resistance training is largely based upon having periods of training primarily addressing strength and power either through the avenue of hypertrophy of muscle and/or altering contractile properties or through periods addressing the neural control of muscle. Furthermore some specific advanced power training strategies currently being used require an in depth understanding of the neural interplay involved in force regulation.

2bi. Neural Adaptations to Strength Training

As force output is largely regulated by neural control, some basic understanding of the neural mechanisms of force control and how resistance training may impact them is required. This review is not intended to be extensive, but merely to provide a general insight into how neural control strategies may be impacted by resistance training.

The fact that large increases in strength are observable shortly after the commencement of strength training in beginners without any discernible hypertrophy has led researchers to believe that other factors may contribute to strength gains (Thorstensson et al., 1976; Costill et al., 1979; Dons et al.,

1979; Moritani and DeVries, 1979). Muscle activation can be measured by electromyography (EMG) and the recorded signal is often integrated for further quantification. Increased integrated myoelectrical activity (IEMG) (Moritani and DeVries, 1979; Hakkinen and Komi, 1983), motor unit synchronization (Milner-Brown et al., 1975; Moritani et al., 1987; Moritani, 1993) and skill learning/coordination (Rutherford and Jones, 1986) have consequently been hypothesized to account for these rapid increases in strength.

Before further elaborating on the neural responses to strength training a short discussion on the role of motor unit recruitment and firing rate in grading muscle force production is warranted. A muscle can increase its force via increased recruitment of motor units and/or an increased firing rate (rate coding) of neural impulses in the motor neuron that controls the motor unit (Milner-Brown et al., 1973; Desmedt and Godaux, 1978). The relative contribution of motor unit recruitment and firing rate to muscular force production varies according to the muscle (DeLuca et al., 1982), the level of force required (Milner-Brown et al., 1973; Desmedt and Godaux, 1977) and possibly the type of muscle contraction (Person, 1974; Desmedt and Godaux, 1981).

In muscular contractions it has been hypothesized that the size principle of motor unit recruitment applies (Henneman et al., 1965). This principle suggests that force output increases initially by recruiting the small motor units, followed by the larger, higher threshold motor units. However, there may be a "ceiling" of recruitment after which the firing rate may be more critical for increasing force (Belanger and Comas, 1981; Kukulka and Clamann, 1981). The initial effect of strength training may be to facilitate the recruitment of these higher threshold motor units as well as the enhancement of the firing rate (Sale, 1986). How this "functional reserve" of

neural output is accessed and at what level of the nervous system this occurs is not fully understood.

The tripartite model of motor control (Wetzel and Stuart, 1977) has been hypothesized to account for the neural processes that regulate force production and motor control at different levels of the nervous system. This model proposes three levels of nervous system control of muscle from which neural output and hence force could be increased. The three levels of control of the tripartite model are the high-level controller (supraspinal centres), the low-level controller (spinal cord) and the peripheral receptors (muscle spindle, Golgi tendon organ) (Wetzel and Stuart, 1977).

The low-level controller contains neural circuitry responsible for the performance of a motor skill, for example, the lifting of a barbell. Such a movement also requires the high-level controller to initiate this action by descending commands and feedback from the peripheral receptors to regulate and modify the motor skill. Consequently performance by the neuromuscular system is dependant on the interaction of the input and output at these different levels of the nervous system. Importantly the level of excitation of the various interneurones within the spinal cord (low-level controller) that receive and integrate inhibitory input and excitatory output from the various levels of the tripartite model may be a major factor in regulating muscle force production (Stuart, 1987a; 1987b). Consequently before ascribing "neural adaptations" as the mechanism of increased strength it is necessary to review the processes by which the nervous system might influence the neural activity of muscle.

2bii. Increased central drive/descending activity.

The increased central drive of the supraspinal centres (high-level controller) has been postulated to partly account for the large initial increases in voluntary strength observed upon the commencement of strength training

or as a result of extraordinary arousal (Ikai and Steinhaus, 1961; Milner-Brown et al., 1975; Shelton and Mahoney, 1978; Moritani and De Vries, 1979; Hakkinen and Komi, 1983; Narici et al., 1989). There may be inhibition occurring at the higher motor centres as varying types of arousal strategies can precipitate immediate and large increases in strength (Ikai and Steinhaus, 1961). Various arousal strategies such as hypnosis, shouting, loud noises (gunshot) and positive affirmations have been hypothesized to have the effect of increasing the descending activity of the higher cortical centres. This may increase neural input to the muscle and hence facilitate force production (Ikai and Steinhaus, 1961). Such a scenario could result in the over-riding of the inhibitory effects of the peripheral receptors', such as the Golgi tendon organ, and the central interneurones, such as the Renshaw cell, resulting in an increase in net neural input to the muscle. Ikai and Steinhaus (1961) demonstrated that the actual increases in strength following the arousal techniques seemed to correspond to the "intensity" of the arousal strategy. This may indicate that increased descending activity of the supraspinal centres may precipitate a greater excitatory state in the facilitatory interneurones that integrate the various neural signals, resulting in increased net excitatory output.

Most research has focused on level of neural output measured in a prime mover muscle group during an isometric contraction (eg. Moritani and De Vries, 1979; Hakkinen and Komi, 1983; Narici et al., 1989). However, as performance of strength skills, either isometric or dynamic, depends to a large extent on synergist muscle activity (Rutherford and Jones, 1986), it would appear prudent to assume that the increased descending activity of the supraspinal centres encompasses these muscles as well. It has been suggested that improved neural activation of synergists would result from strength training (Hakkinen et al., 1993). Conceivably the output of the synergists would add favourably to the total force output of the movement or

test of strength, however this assumption has not yet been investigated during strength training.

Increased descending activity would not only apply to prime movers and synergists but also to the antagonist muscle group. The fact that supraspinal excitatory signals have been sent to the prime movers would result in a reciprocal inhibitory signal being sent to the antagonist muscles. This may occur through interneurones that serve to integrate the intensity of the supraspinal signals with the feedback signals (Baldissera et al., 1981). By inhibiting the antagonist muscles the net activity to the agonist muscles would be increased.

Therefore, the recruitment and rate coding of motor units and consequent strength of muscle contraction may be effected by the higher motor centres increasing their descending activity so there is an enhanced excitatory output to prime mover muscle and synergist muscles and increased inhibition of antagonist muscle. However, the sum neural output to a muscle would depend on the effects of coupling the supraspinal excitatory output with inhibitory feedback mechanisms existing in the peripheral and low-level controller areas of the nervous system. Therefore the roles of the inhibitory mechanisms in regulating force production must be reviewed.

2biii. Disinhibition.

The neuromuscular system has a number of in-built feedback mechanisms that regulate the production of muscular force through the net balance of inhibitory and excitatory neural impulses. One of these inhibitory mechanisms is the Golgi tendon organ (GTO) (McGrouch et al., 1950), which is sensitive to the level of tension produced in the musculature. The GTO is found in the musculotendinous junction and throughout the perimysial connective tissues. It lies in series with the skeletal muscle fibers and is

sensitive to the production of tension via muscular activity. It is believed that the GTO is an important peripheral source of inhibition, through the inverse myotatic reflex, that protects the muscle from too great an overload that potentially could result in injury to the muscle or tendon (Granit, 1950). Thus if excessive tension is perceived by the neural system an inhibitory signal is sent by the GTO along the sensory nerve fibre, via a connecting inhibitory synaptic knob in the spinal cord (interneurone), to the motor nerve. This results in the reduction of neural input for further motor unit discharge and consequently force output is moderated (Granit, 1950).

The Renshaw cell is a central feedback loop mechanism that also moderates neural output, and hence force output, through its property of an inhibitory synaptic knob. This central negative feedback loop operates via a recurrent axon collateral when an alpha efferent neuron fires. The discharge information of the alpha neuron that is initiating the contraction is fed back within the spinal cord to reduce further recruitment that may result in injurious levels of force production. The Renshaw cell exists centrally and acts to inhibit the further recruitment of motor units which otherwise may make the contraction too strong. The GTO operates peripherally to moderate the current force levels.

The strength of the signals sent by these inhibitory afferents and how they are acted upon may dictate the resultant neural signals, and hence force output of the muscle (Baldissera et al., 1981). Therefore muscular strength and power are potentially limited to a considerable degree by the central inhibition of the Renshaw cell and the peripheral inhibition of the

GTO, which both operate to dampen neural output and thus limit the potential force production of the muscle. Learning to disinhibit these mechanisms by progressively exposing them to increasing levels of tension and loading (via resistance or speed), thereby reducing their sensitivity, may be an important aspect of strength and power training (Hakkinen and Komi, 1983). Further, reducing their inhibitory effect at the interneurone level, in the low level controller, by increased descending activity of the higher supraspinal centres, may be a concurrent process with increased central drive from the supraspinal centres. The net effect of these occurrences is an increased neural input to muscle (Milner-Brown et al., 1975; Burke, 1985)

It is believed that the initial stages of strength training involve the reduction of inhibition so that the higher threshold motor units are preferentially recruited (Milner-Brown et al., 1973; Narici et al., 1989) and the maximal firing rate is increased (Kulkulka and Clamann, 1981). Due to neural inhibition it has been hypothesized that there exists a deficit between the potential force production capabilities of the muscle, based on the cross-sectional area, and the actual maximal voluntary force output (Schmidtbleicher, 1985). This difference between the potential and actual strength capabilities has been termed the "strength deficit" by Schmidtbleicher (1985) and estimated as the difference between the maximum eccentric and isometric strength. Tidow (1990) has stated that the strength deficit may be as high as 45% in untrained individuals, who cannot readily access the high threshold motor units or fire them at maximal frequencies due to neural inhibition. This is in accordance with the

hypothesis of Sale (1986) that a functional reserve of neural activity exists which untrained people have difficulty accessing, even during maximum voluntary contractions. In contrast, Tidow (1990) suggests that trained athletes who are regularly exposed to high levels of tension may have strength deficits of only 5%. The sensitivity of these inhibitory mechanisms is such that Schmidtbleicher (1985) suggested that the state of inhibition or disinhibition is considered to be a relatively temporary state and would constantly alter in accordance with the loads used in training (or the training state of the athlete). Schmidtbleicher (1985) stated that when the strength deficit is high, the musculature is relatively inhibited to high levels of force production or high loads. Consequently strength may be increased, without hypertrophy, by using high intensity/low volume training that serves to disinhibit the GTO and Renshaw cells so that motor unit recruitment and firing rate are enhanced. When the deficit is low Schmidtbleicher (1985) recommends that further strength gains may best be acquired by morphological changes to the muscle through the use of higher volume/lower intensity training. Schmidtbleicher (1985) has stated that this is the fundamental rationale for the periodization of strength training.

As yet it is unclear to what degree the reduction of inhibitory signals (GTO and Renshaw cell) from the prime movers play in increasing strength and much of the theories of Schmidtbleicher (1985) are conjecture. Increased strength and/or neural output have been observed in untrained contra lateral limbs as a result of strength training. This tends to indicate that much of the enhanced neural output must stem from central mechanisms

such as increased descending activity and/or reduced Renshaw cell inhibition (Darcus and Salter, 1955; Moritani and De Vries, 1979). The GTO of the untrained limb would theoretically not have been disinhibited and as a result, would not have influenced the increased neural and force output observed in the untrained limb that occurred as a result of training.

The conclusion is that the relative contributions of the different levels of the nervous system to increased neural output during muscular work are not fully understood. It has been hypothesized that the interaction of the various neural impulses in the interneurones (excitatory output coupled with inhibitory input), rather than the motor neurones, dictates to a large extent the neural and force output (Baldissera et al., 1981; Stuart, 1987a; 1987b). How these neural control strategies are altered by different resistance training variable manipulations and at different levels of training adaptation, are of interest. While this thesis does not include a mechanistic investigation into the realms of neural control and resistance training adaptations, the above review does provide a theoretical basis for attempting some training interventions. Given this basis of muscle-force control reviewed above, some quite distinct practical training methods capable of enhancing power output (temporarily at least), presumably through some neural based mechanism(s), will be investigated in this thesis (Studies 4 and 5).

2biv. Hypertrophy

An increase in the size of a muscle, subject to exercise or loading, is a clearly observable and well-established phenomenon (Hakkinen et al., 1981; Young et al., 1983; Schmidtbleicher and Buehrle, 1987; Narici et al., 1989).

However the exact mechanisms that trigger this hypertrophy of muscle are still not fully understood (McDonagh and Davies, 1984). It is known that the muscle hypertrophies due to a net increase in protein synthesis (Goldberg, 1975) that results in an increased size of individual muscle fibers (Thorstensson et al, 1976; Haggmark et al., 1978; Dons et al., 1979; Hakkinen et al., 1981). The increase in individual fibre size is results from an increased myofibrillar volume (Luthi et al., 1986). The biochemical processes that precipitate these occurrences warrant further investigation as clearly the processes of muscle tissue remodeling/hypertrophy are linked to hormonal regulation (Florini, 1985, 1987; Kuoppasalmi and Aldercreutz, 1985). However this review will concentrate more on the macro level adaptations consequent to different training variable manipulations during strength and power training, which are of interest to rugby league players.

McDonagh and Davies (1984) hypothesized that the tensile strain in the myosin and actin filaments may precipitate hypertrophy. If the level of strain, caused by loading and stretching, was the main mechanism for the initiation of hypertrophic responses, then eccentric training, which utilizes the highest loads under stretch, should conceivably precipitate the greatest responses in hypertrophy and strength. However the highest loading (strain) does not seem to produce the greatest hypertrophy or strength (Hakkinen and Komi, 1981). Nonetheless the load utilized would seem important (Atha, 1981; McDonagh and Davies, 1984). The forces produced by high loads are translated to the muscle fibre and cell membrane causing a "disruption in muscle fibers which are crucial for the initiation of a remodeling process in

muscle" (Kraemer, 1992). The repair mechanisms consequent to this load induced disruption of muscle fibre are different to those that are caused by injury (Clarkson and Tremblay, 1988). The mechanical forces translated to the muscle could be expected to differ with varying movements (Narici et al., 1989). This may cause a preferential recruitment of fibres for certain tasks (Caldwell et al., 1993), which might result in certain muscles or aspects of a muscle preferentially hypertrophied (Narici et al., 1989). Further, different training variable manipulations such as load intensity, exercise, volume/duration of the contraction stimulus and rest period, could cause different myogenic adaptations (Kraemer, 1992; Schmidtbleicher and Buerhle, 1987).

The importance of hypertrophy to continual strength improvement lie in the fact that hypertrophy is almost, but not always (Sale et al, 1992) associated with a long-term increase in force producing capabilities (Ikai and Fukunga, 1970). Early researchers utilized simple girth measures to assess limb hypertrophy or lean body mass changes to assess whole body hypertrophic responses (eg. O'Shea, 1966; Alexeeyev & Roman, 1976). This progressed to the cross-sectional or total surface area of muscle being calculated using ultra-sound scanning (Ikai and Fukunga, 1968) and then computer tomography (Haggmark et al., 1978; Shantz et al., 1981; Schmidtbleicher & Buehrle, 1987). Over the last twenty years or so nuclear magnetic resonance imaging seems to have become the standard for assessing hypertrophy of muscle (eg. Hinshaw et al., 1979; Narici et al., 1989). Both cross-sectional and longitudinal experimental paradigms have

been utilized to examine hypertrophy in response to strength training, but the longitudinal training studies afford a much greater or conclusive understanding of how hypertrophy progresses and how it is affected by training variable manipulations.

Cross-sectional studies clearly indicate that strength trained athletes possess significantly greater muscle size than controls (Katch et al., 1980; Pipes, 1974; Tesch and Larsson, 1982), especially in fast twitch muscle fibers (Edstrom and Ekblom, 1972; Prince et al., 1976; Tesch and Karlsson, 1985) but also across all fibre types (Shantz et al., 1981). The number of fast twitch fibers may not be increased by resistance training (Dons et al., 1979; Costill et al., 1979), though this is by no means unequivocal. More importantly, the fast twitch fibre area within the muscle is increased significantly (Thorstensson et al., 1976; McDougall et al., 1980; Hakkinen and Komi, 1985; Tesch and Karlsson, 1985). These adaptations may be observed within 2 to 3 months after the initiation of a heavy training program (Thorstensson et al., 1976; Hakkinen et al., 1981), but the rate of hypertrophic response tends to slow down after this period (Hakkinen et al., 1985). Changes in body mass or lean body mass over this initial 2-3 month period appear in the range of 1.2% (Hakkinen and Komi, 1981) to 5.8% (Gater et al., 1992) in male athletes. Baker et al. (1994b) and Baker (1995c) identified that changes in LBM were the statistically most significant factor relating to changes in whole body strength (1RM squat + bench press totals) in young males accustomed to resistance training during 9-12 week training cycles.

After the initial large improvement in beginners there is a more limited scope for training induced improvement in muscle fibre size or lean body mass (Baker et al., 1994b, Hakkinen et al., 1985a,b, 1987, 1988). Sale (1986) has suggested that this may, in part, explain the avid interest in anabolic steroids by experienced strength athletes. Alen et al. (1984) have demonstrated that athletes using these drugs experienced a significantly greater increase in fibre area and strength than control subjects performing the same training regime. In intermediate level athletes not using anabolic drugs small changes in hypertrophy are still achievable, but reduced in scope and magnitude in comparison to less experienced athletes (Hakkinen, 1985). Elite level strength athletes possess even less scope for improvements in hypertrophy. In elite weight-lifters no significant hypertrophy could be detected, via muscle biopsy and computer tomography or changes in lean body mass, over the course of one year of intense training (Hakkinen et al., 1987). As a result no changes occurred in dynamic or isometric strength levels. However, over a two year period, a small, significant increase in lean body mass (2%) occurred corresponding with a small but significant increase in weight-lifting strength (2.8%) (Hakkinen et al., 1988). Again no increase in fibre size was detected indicating the difficulty of achieving hypertrophic responses via this method in elite athletes. Based on this observation it would appear that changes in lean body mass would offer an important mechanism for continual strength development, especially in athletes with an extensive strength training background.

The conclusion from this data is that the time frame for changes in LBM varies with training history and with it, the potential for greater strength gains. For example, a 2% increase in body mass was achieved in 12 weeks by non-competitive subjects (Hakkinen and Komi, 1981) versus a 2% improvement in 2 years for elite weight-lifters (Hakkinen et al., 1988). The relative increase in strength was tenfold for the novice subjects compared to the elite lifters in these two studies.

The "type" of hypertrophy developed by different training variable manipulations may affect strength and power functioning quite differently (Hakkinen et al, 1984a; Hakkinen et al, 1986; Blazevich et al., 2003). It has been theorized that hypertrophy induced by body building methods (10-15RM, short rest periods of 1 minute) may be less beneficial, in regards to strength and power functioning, than hypertrophy developed by more intense loads (Kraemer, 1992). In particular power-training exercises seem to affect the muscle architecture in a different way as compared to heavy strength exercises (Blazevich et al., 2003). Such differences may explain some neuromuscular differences between body-builders and other strength athletes (Hakkinen et al., 1986). As a result tissue remodeling/hypertrophy may differ in nature over the long term training history of an athlete as modes of resistance training vary. Given that Blazevich et al (2003) identified differences in neural and muscle architecture in response to different types of training (hypertrophy versus power training), strength coaches may need to be aware of the limitations of traditional hypertrophy methods being used for prolonged periods by power athletes.

In summary, the data from the above research clearly indicates that hypertrophy is best produced by higher volume (8-20 RM, 3-5 sets), medium intensity training (66-80% of maximum). A minimum load of 66-70% may be needed to stimulate an adequate number of motor units (McDonagh and Davies, 1984). More intense loads may stimulate more motor units, but the duration of stimulus is decreased as fewer repetitions are possible with greater intensity loads (Bryzcki, 1993; Baker, 1995d; Chapman et al., 1998). The duration of the training stimulus (i.e. how long the load acts upon the muscle) would appear to be an important factor (McDonagh and Davies, 1984). This may in part explain why higher repetitions are more effective in producing hypertrophy than the more intense loads (1-3RM loads) (Berger, 1962) as the total time under stimulus is enhanced by higher repetitions. Poliquin and King (1992) believe that the load intensity and the time the load acts upon the muscle (an alternative measure of training volume to repetitions), are important variables that affect hypertrophy and consequently strength.

When high repetition training is done very quickly, reducing the time the load acts upon the muscle, the hypertrophic responses are considerably less (Schmidtbleicher and Buehrle, 1987). However the changes to the muscle architecture may be more favourable by this type of explosive training for power-oriented athletes (Blazevich et al., 2003). While some hypertrophy-oriented training may be required to induce greater force producing ability within the muscle, a necessary requirement for high power output, coaches should be careful in the prescription of hypertrophy-oriented

training as this may reduce the future ability to maximise power output. The long-term effects of large dosages of hypertrophy-oriented training upon maximal power output or fast force production (in comparison to other methods of inducing force producing abilities) is not known, but is hinted at in the cross-sectional analyses of Katch et al. (1980) and Hakkinen et al. (1986). In the analyses of Hakkinen et al. (1986), body-builders, whose resistance training was typically performed at slower speeds than weight-lifters, exhibited reduced muscle force-time and power output characteristics.

The conclusions to be drawn from this aspect of the review of the literature are that hypertrophy-oriented training appears necessary for ongoing strength gains in experienced athletes. However, prolonged periods of hypertrophy-oriented training may be detrimental to long-term power development (irrespective of neural adaptations) due to differences in muscle architecture or fibre (myosin heavy chain) responses to slow speed, short-rest period training. Given this conflict of a) hypertrophy is necessary for continued high force development in advanced athletes but b) hypertrophy-oriented training may not be most suitable for maximizing power output ~ then how do athletes such as rugby league players who require high levels of lean body mass/hypertrophy, maximal strength and maximal power manage training content. Consequently this thesis will investigate two main areas concerning hypertrophy-oriented training. First, what are the acute, short-term effects of one hypertrophy-oriented training dose upon power output within a workout (Study 6). Second, can elite athletes still increase strength

and power across multi-year periods with limited or no increases in body mass (Studies 7 and 8)?

2c. Development of strength and power.

2ci. Programming considerations

During the 1940's through to the 1980's recommendations for strength training followed a more dogmatic, non-varied prescription of training volume and intensity such as 3 sets of 10 repetitions (Delorme, 1945). The classical work of Berger (1962) indicated that a program that utilized three sets of six repetitions was most beneficial in developing strength. These recommendations were further supported by Atha (1981) who conducted an extensive review of the area. However throughout the 1960's and 1970's it became apparent that the world's strongest athletes, the competitive weight- and power-lifters, did not follow such non-varied prescriptions of training volume and intensity as recommended by Berger (1962). The domination of eastern bloc weightlifters and power athletes at international competitions during this era led to the belief that, among other aspects concerned with athlete preparation (e.g. pharmacological enhancement), they possessed superior methods of strength training. It appears the eastern bloc scientists and coaches of that era recognized that strength and power are increased by both morphological and neural adaptations and that the time frame over, and the stage of training/development at which these adaptations occur, differ (Matveyev, 1972; Vorobiev, 1978; Medvedev, 1988). Consequently they

sought methods that allow strength and force producing capabilities to be developed by hypertrophic/morphological adaptations, stimulated by high volume training, to be alternated with higher intensity training to stimulate the specific maximal strength or power capabilities, in some coherent manner. Therefore there would be different periods of training that mainly address different stimuli to strength and power adaptations. This structuring of training to emphasize different aspects of muscle adaptation at different times, is the basis of training periodization.

Consequently the concept of strength training periodization, as developed in the eastern bloc countries, became an area of intense interest to western athletes, coaches and scientists.

2cii. Periodization of strength and power training

A brief overview.

Periodization has been defined by Gambetta (NSCA Roundtable, 1986) as "the organization of training into a cyclic structure to attain the optimal development of an athlete's capacities" and is characterized by "periodic changes of the objectives, tasks and content of training". Although the concept of training periodization was first examined by the Russian researcher Matveyev during the 1950's-70's (Matveyev, 1972) it should not be viewed as a particularly new concept. It is known that Ancient Greek athletes utilized a crude form of periodization following a 10-month cycle in preparation for the Olympics. The last month was spent in specific competitive preparation in order to be fully "peaked" for competition. The

training week was also periodized into a four day cycle, known as the tetrad, which varied the tasks, content and objectives of training daily. This involved the manipulation of training intensity and volume such that there were heavy, light and medium effort training days (Sweet, 1987). Such training strategies are still common 2000 years later.

The pioneering work of Stone and colleagues introduced periodization of strength training to western literature in the early to mid-eighties (Stone et al.1981, 1982; Stowers et al. 1983). They basically proposed that training be divided into three main blocks, with each block encompassing methods that address hypertrophy; basic strength and power; and peak strength and power, respectively. Table 1 gives a basic outline of this model of training. Since that time the concept of periodization has undergone considerable study, with consequent debate concerning methods and effectiveness (eg. O'Bryant et al 1988; Poliquin, 1988; Baker ,1993, 1994, 1995c; Baker et al., 1994b; Balyi, 1995; Wilson & Baker, 1995a, b).

Table 1. Periodization model for strength training modified from Stone et al., (1981).

Weeks	1-4	5-8	9-12
Objective	Hypertrophy	Basic strength	Peak strength
Sets x Reps	3-5 x 8-12	3-5 x 4-6	1-5 x 1-3
Intensity (% 1RM)	60-75%	80-90%	90-100%

It is believed by experienced strength coaches that advanced athletes adapt more readily to imposed training stresses ~ therefore their training

content must be more varied (Pedemonte, 1982; Poliquin, 1988). This variation must occur during each week and across a training cycle (a training cycle is the combination of training blocks or the summation of training weeks). The purpose of within-week variation is to ensure that the training stimulus is presented in a non-habituating manner in the short-term and to allow for recovery within the training week (Pedemonte, 1982; Poliquin, 1988; ASCA, 2006). Therefore training is not always becoming harder, heavier, faster and so on, but there are variations in a number of the training variables such that training difficulty may move in a more varied manner within a week and also across a training block or group of weeks. It is thought that this approach allows for better adaptation and a more holistic approach to training (Pedemonte, 1982; Poliquin, 1998; Baker, 1993; Wilks, 1995; Stone et al., 1999a, b).

The Australian Strength & Conditioning Association (ASCA, 2006) has recognized nine main ways of varying or altering training load (volume-load) and difficulty within a training week, which are outlined in Table 2. It is thought that these methods ensure a more varied presentation of training stimuli on the 2-3 days/wk that most athletes typically resistance train a body area or movement pattern.

The first five methods apply mainly when training to address strength and hypertrophy, but not so much power, because they mainly address increasing training workload and time under tension, factors which are presumed to largely influence muscle contractile properties (McDonagh & Davies, 1984; Keogh et al., 1999). The sixth and seventh methods can be used for strength or power training as they reduce

workload and may also allow for greater lifting speeds (conducive to power training, Keogh et al., 1999). The remaining methods are presumed to work best when combining strength and power training due to their influence on markedly reducing workload and increasing speed of lifting/acceleration, factors favourable to enhancing power output (Newton et al., 1996; Baker, 1995b, 2001b).

Table 2. Nine methods ways of altering training load and difficulty within a training week.

Method of variation	Day 1 example	Day 2 example
1. Same exercises and other variables, increase repetitions and decrease resistance.	3x10 @ 70 kg	3x15 @ 60 kg
2. Same exercises and other variables, increase or decrease the number of sets.	Squat 4x10 @ 70 kg	Squat 2x10 @ 70 kg
3. Same exercises, sets and repetitions, reduce the lifting speed and resistance.	Squat 3x10 @ 70 kg (2s/rep)	Squat 3x10 @ 50 kg (4s/rep)
4. Same exercises and other variables, decrease rest periods and resistance	Squat 3x10 @ 70 kg (3m/rest)	Squat 3x10 @ 50 kg (1m/rest)
5. Same exercises and other variables, decrease resistance.	Squat 3x5 @ 100 kg	Squat 3x5 @ 80 kg
6.Same exercises and other variables, decrease repetitions.	Squat 3x 5 @ 100 kg	Squat 3x2 @ 100 kg
7.Different strength exercises, but same for all other variables (same %1RM).	Squat 3x10 @ 70 kg	Front squat 3x10 @ 55 kg
8. Perform a strength and power version of aligned exercises on different days.	Squat 3x5 @ 100 kg	Jump squat 3x5 @ 50 kg
9. Perform heavier and lighter versions of aligned power exercises on different days.	Power clean 3x5 @ 75 kg	Power snatch 3x5 @ 60 kg

All the methods above have been considered in isolation. In reality a strength coach could combine many of the methods above to further ensure that total workload, repetition volume, resistance in kg's and/or relative intensity, rest periods and/or workout density, power output per repetition and/or workout, speed of lifting and/or time under tension varied considerably within a training week. It is possible that the astute usage of the above methods may enable a strength coach of rugby league players to address strength, power, hypertrophy and strength-endurance effectively within a training week.

Different "cycle-length" variants or patterns of periodized strength training.

While the ability to vary training sessions within a week by utilizing methods such as those outlined in Table 2 appear well known to most coaches, descriptions of different cycle-length variants of periodized strength training appear less frequently in North American literature. The ASCA (2006) has outlined a number of different cycle-length (eg. 6-16+ weeks) variants of periodization that a strength coach may choose from, which have been identified from the literature and from analysis of current practices throughout the world (Baker, 1993; Bompa, 1996; Brown and Greewood, 2005; McNaughton, 1991; Pedemonte, 1982; Plisk and Stone, 2003; Poliquin, 1988; Stone et al., 1981, 1982, 1999a, 1999b). A few examples of these variants are described in Table 3. The nomenclature used by the ASCA, which is based upon the method of intensification, has been source of some debate, consternation or confusion (eg. Bradley-Popovich, 2001 versus Haff,

2001). Poliquin (1988) first proposed that a training cycle whereby the intensity (%1RM) is increased each week of the cycle should be designated as a “linear” method of intensification (see the first two examples in Table 3). This classification of “linear” is made irrespective of the fact that intensity, volume, workload (or training impulse) etc may be manipulated in an a non-linear manner within the week by methods such as those outlined in Table 2 (eg. heavy intensity or light intensity days, high or low load-volume days etc). “Non-linear” intensification entails not increasing training resistances each and every week of the training cycle (eg. with heavier and lighter weeks in intensity at certain weeks in the cycle, ASCA, 2006, Baker, 1993, 1994, 1995; Balyi, 1992; King and Poliquin, 1991; Stone et al., 1981, 1982, 1999a, 1999b). For the purposes of this review, if a variant does not entail increasing % 1RM or resistance each week, then it is not a linear intensification variant. This can be clearly seen in the two examples of variants of “block” periodization provided in Table 3 which are distinguished by either linear or non-linear intensification across 12-weeks. Figure 1 graphically illustrates differences between linear and non-linear intensification (Subtle Linear, Block (non-linear), Wave-like and Undulating periodized variants) while Figure 2 provides a more comparative example of training impulse (repetition-volume x relative intensity, % 1RM) between the Subtle Linear, Block (linear intensification), Block (non-linear intensification) and Wave-like periodized variants. Clearly most of the periodization strategies depicted are non-linear in the progression of intensification and training impulse, but linear progressions are still possible if the coach desires to configure training variables in a certain pattern.

When using this method of description, it should be noted that it is the method of intensification across the length of the cycle that is being refereed to, not the progression across the overall training year. A training year may contain a number of cycles such that overall the yearly progression is clearly non-linear, but this does not affect the description of the cycle-length pattern of progression.

By looking at week three from each of the specific variants in Tables 3, it can be seen that there are different prescriptions of sets, repetitions and resistances, despite all being examples of "periodized strength training". Great diversity exists in "periodized strength training" and coaches may wish to choose the variant(s) that they feel most appropriate to their circumstances (level of the athlete, period of the year etc).

Comparisons between different cycle-length patterns of progression

A paucity of data exists concerning comparisons upon the effects of different cycle-length patterns of progression as most research has tended to compare some form of periodized training to non-periodized training (O'Bryant et al., 1988, Stone et al., 1981, 1982; Stowers et al., 1983) or to "pre-intervention" data (ie. comparing "pre-" and "post-training" scores in muscular functioning in response to a specific periodized training pattern, eg. Baker, 1994, 1995, 1998, 2001). Baker et al. (1994) found that a block pattern with linear progression and an undulatory pattern of progression (changing repetition demands after every 2-weeks) provided similar benefits in maximal strength across 12-weeks. Rhea et al. (2002) found that a program that alternated training volumes and intensities within a week more effective than a

block method with linear intensification and no within-week variation. No other data has been found that directly compares different progression patterns of cycle-length periodized strength training in order to gauge the relative effectiveness of one pattern against another.

Possible reasons for a lack of comparative data

Given that resistance-training objectives can vary for different athletes (eg. hypertrophy of muscle, maximal power, absolute strength are different objectives requiring somewhat different training prescriptions), it is not known why research into the relative merits of different patterns of periodized progression has been so limited. The references contain many articles outlining debate and theory concerning periodization but it appears little of this theory has been tested, unless against non-periodized training. It is of interest to note that Stone et al. (2004) stated that the demise of sport science in the United States is in part attributable to Institutional Review Boards and academics not being “conceptually familiar with sports science”. This then reduces what they call “monitoring studies”, examples of which would be the analysis of the effects of different periodized variants/patterns of progression upon muscular functioning and sports performance. They also state that “politically correct” views of the academics may partly regulate research away from studies that investigate sports performance, to which comparative periodized strength training studies belong. For whatever reason, the level of research regarding the merits of different periodization variants/patterns has not equated with the overall theoretical literature on periodization.

Table 3. Different variants or patterns of strength training periodization applicable to a primary strength exercise over a twelve-week period. Assume the athlete increases strength by 3-5% across the twelve-week period. *The Accumulation/intensification pattern typically follows only an eight week cycle ~ however some initial higher repetition training may precede this type of cycle. S X R = sets x reps.

Type of cycle	Week #	1	2	3	4	5	6	7	8	9	10	11	12
Subtle Linear	S x R % 1RM	3 x 13 63%	3 x 12 66%	3 x 11 69%	3 x 10 72%	3 x 9 75%	3 x 8 78%	3 x 7 81%	3 x 6 84%	3 x 5 87%	3 x 4 90%	3 x 3 93%	3 x 2 96%
Block with Linear intensification	S x R % 1RM	4 x 10 60%	4 x 10 64%	4 x 10 68%	4 x 10 70%	4 x 5 78%	4 x 5 81%	4 x 5 83%	4 x 5 85%	3 x 3 88%	3 x 3 90%	3 x 3 92%	3 x 3 94%
Block with Non-Linear intensification	S x R % 1RM	4 x 10 64%	4 x 10 68%	4 x 10 70%	4 x 10 66%	4 x 5 80%	4 x 5 83%	4 x 5 85%	4 x 5 75%	3 x 3 90%	3 x 3 92%	3 x 3 94%	3 x 3 80%
Undulating	S x R % 1RM	4 x 10 64%	4 x 10 68%	4 x 6 76%	4 x 6 80%	4 x 8 72%	4 x 8 76%	4 x 4 84%	4 x 4 88%	3 x 6 82%	3 x 6 85%	3 x 3 92%	3 x 3 94%
Wave-like	S x R % 1RM	4 x 10 64%	4 x 8 70%	4 x 6 76%	4 x 4 82%	4 x 9 70%	4 x 7 76%	4 x 5 82%	4 x 3 88%	3 x 8 78%	3 x 6 84%	3 x 4 90%	3 x 3 94%
Accumulation & Intensification*	S x R % 1RM	*	*	*	*	6 x 3 80%	6 x 4 80%	6 x 5 80%	6 x 6 80%	5 x 5 85%	4 x 4 90%	3 x 3 95%	2 x 2 100%

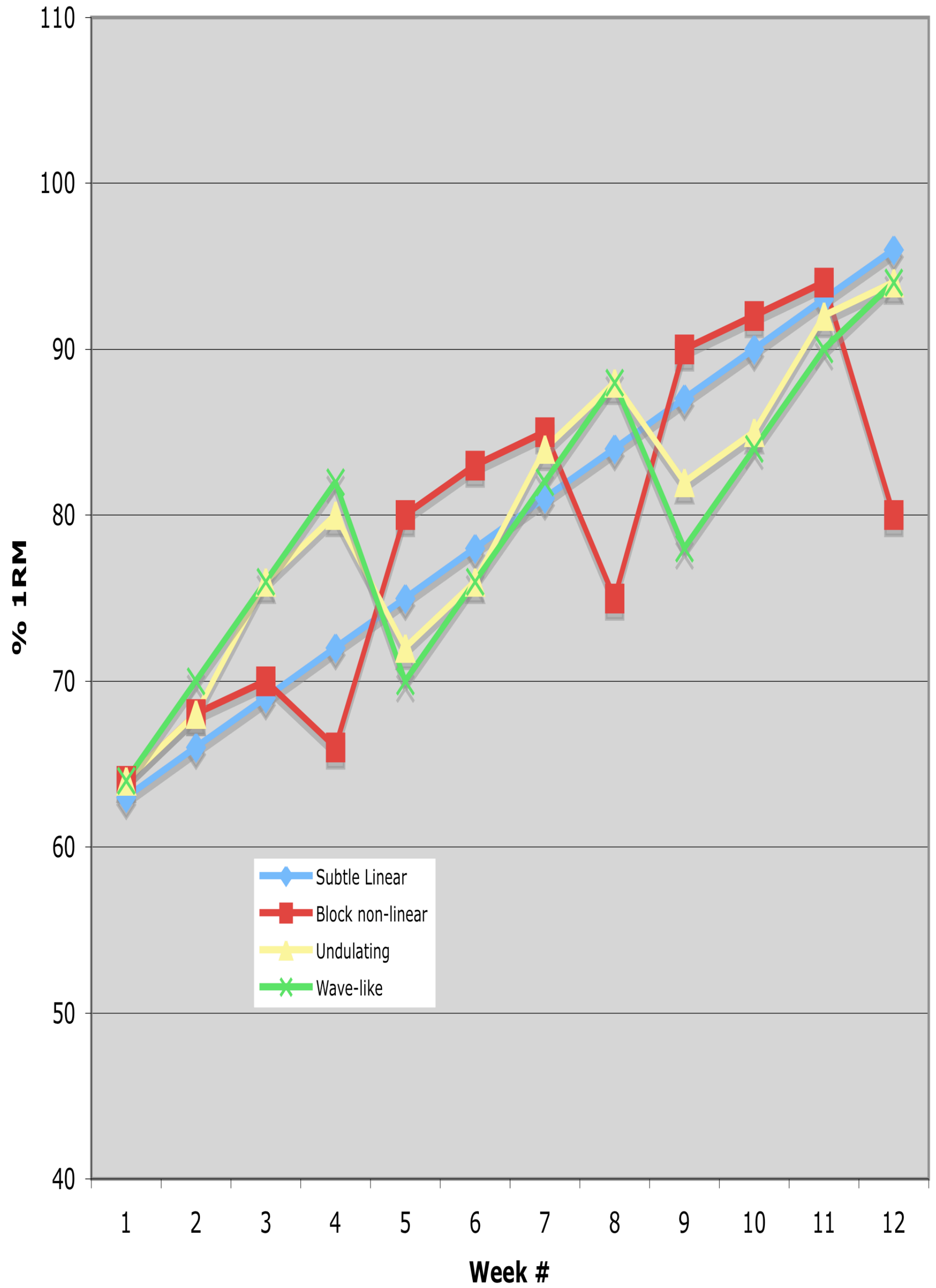

Figure 1. Different patterns of intensification of various periodized methods across a 12-week cycle.

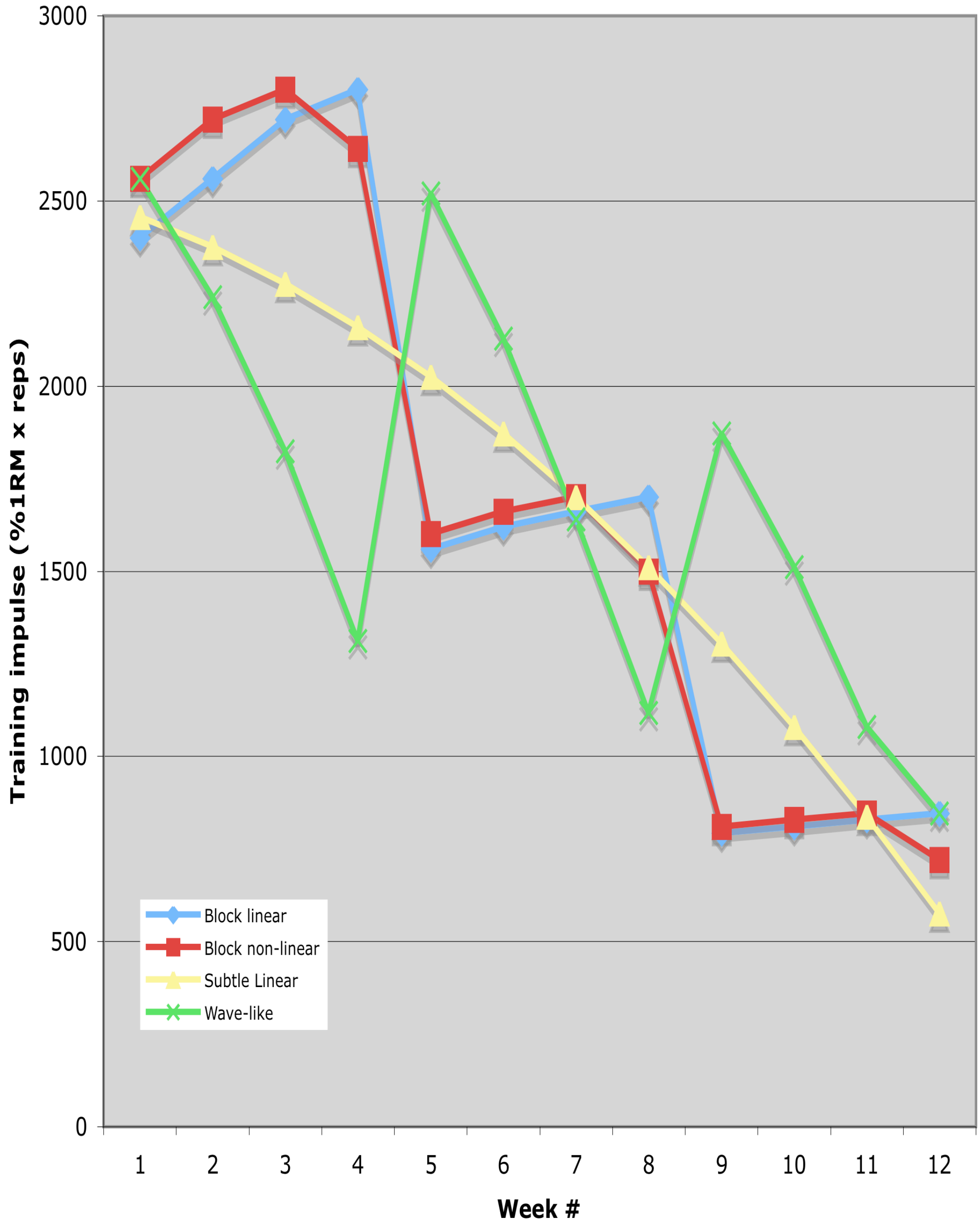

Figure 2. Graphic comparison of training impulse (total repetitions x % 1RM) different periodized methods across a 12-week cycle.

When and why a coach may choose different cycle-length variants of periodized strength/power training.

Given these deficiencies in the literature, the ASCA (2006) has made some generalizations regarding when and why a coach may choose different cycle-length variants of periodized strength/power training. These generalizations have been made mainly based upon the practical experiences of their elite coaches aligned with findings from the literature where possible and are summarized below.

Subtle linear-intensification patterns of progression. As these types of variants are characterized by fairly equivalent and small regular increments in training intensity each week (e.g. by $\leq$ 5% 1RM each week), it is thought these types of variants may be suited to novice and less experienced athletes who have not performed much periodized resistance training (Balyi, 1992; Baker, 1993, 1998b; Wilks, 1994, 1995). This is due to the fact that other variants are characterized by more pronounced alterations in intensity which may not be as easily managed by less experienced athletes whose exercise technique may deteriorate under such situations (Baker, 1998b,d; Pedemonte, 1982). Hence the subtle variations in intensity (and workload) enable a more stable technique acquisition/refinement environment (Pedemonte, 1982). Consequently these types of models may be best suited for lower level or less experienced athletes, irrespective of the training period (Preparation or Competitive Period) (Baker, 1998b).

Block or Step patterns of progression. The block or step patterns generally entail a training cycle being divided into three steps of repetition and intensity demands, each respectively signifying a hypertrophy block (a

traditional term, though now this block may also be referred to as a consolidated strength-endurance block or “muscle training” block), basic strength/power block and peak-strength/power block (Baker, 1993, Haff et al., 2004a,b; Kraemer, 1985; Kramer, et al., 1997; O’Bryant, 1988; Stone et al., 1981, 1982, 1999a, 1999b). As detailed in Table 3, the intensity progression could be linear or non-linear. As compared to subtle linear progressions, sharper drops in volume and rises in intensity when changing blocks characterize the block variants. These pronounced changes in volume and intensity may provide a beneficial stimulatory “shock” to experienced athletes and allow for a delayed training effect (Stone, et al., 1981, 1982; Wilks, 1994), but the pronounced intensity changes may be too severe for less experienced athletes to cope with (physiologically and exercise technique-wise) (Baker, 1998b; Pedemonte, 1982). Consequently the ASCA (2006) has recommended that these variants are generally recommended for use with more experienced athletes who possess stable exercise technique and predictable strength levels and who seem to benefit from the inherent marked variation. These types of variants can be seen as a progression from the subtle linear variants. Aside from competitive lifters, the block variants are generally used for the preparation period as high volume blocks of strength training are often not compatible with in-season training in a number of sports (ASCA, 2006)). The coach will also need to choose a linear or a non-linear intensity progression when implementing this variant.

Undulatory patterns of progression. The Undulatory variant in Table 3 is characterized by 2-week changes in repetition demands and concomitant alterations in intensity, which sees an undulatory progression in intensity as

training reverts from, lower intensity 2-week phases to higher-intensity 2-week phases back and forth, throughout the cycle (Baker, et al., 1994; Poliquin, 1988). It is not to be confused with simple within-week undulation of training such as having, high, medium and low volume training days (Rhea et al., 2002) (see Table 2).

These changes that typically occur after a 2-week time frame are generally greater (in workload, intensification) than for subtle linear methods, but less pronounced that block variants. Accordingly this type of variant may be beneficial as a progression for athletes who have habituated to subtle linear methods of intensity progression or for athletes who favour alternating 2-week phases of hypertrophy-oriented (eg. 3-4 sets x 8-12 repetitions) training with 2-week phases of general strength training (3-4 sets x 4-6 repetitions) on a continual basis.

Wave-like patterns of progression. The distinguishing difference between the undulatory and wave-like variants is the number of weeks that contain the variation. If the repetitions do not change till after every 2-weeks, then it is an undulatory model, as compared to every week for a “true” wave-like model used by a non-lifter (ASCA, 2006). This means there is less variation in volume, intensity and load-volume in an undulatory pattern as compared to a wave-like pattern.

Wave-like patterns derive from the sport of weightlifting, where earlier Soviet coaches advised that weekly volume-load should be presented in a wave-like fashion over a month (eg. the monthly 100% total is distributed 35-36%, 26-28%, 21-23% and 13-18% per week, or 42-44%, 32-33%, 22-26% for a 3-week “month”, (Baker, et al., 1987; Medvedev, 1987, 1988; Vorobiev,

1987). Even the order that each of these weekly workloads is to be presented is not constant and the earlier Soviet coaches provided examples of different orders that the workloads could be presented (Baker, et al., 1987; Medvedev, 1987, 1988; Vorobiev, 1987). Again the coach has to choose which workload order of the "wave" (ie. which variation of the wave-like pattern) would best suit their lifters (Baker, et al., 1987; Medvedev, 1987, 1988; Vorobiev, 1987).

The wave-like patterns have been adapted for use by non-lifters by mainly using the number of repetitions per set to alter weekly volume-load (Baker, 1993, 1994, 1995c, 1998a, 2000c, 2001d; Naughton, 1991; Poliquin, 1992), although additional sets can obviously affect volume-load (Naughton, 1991). In a basic wave-like pattern, the repetitions decrease weekly (with concomitant rises in intensity) for 3-4 weeks, whereby the general pattern is then repeated but at slightly higher intensities/lower repetitions as the athlete comes to the peaking phase (Baker, 1993, 1994, 1995c, 1998a, 2000c, 2001d; King and Poliquin, 1991; Naughton, 1991; Poliquin, 1992). A number of studies show that the wave-like variants are effective in maintaining or even increasing strength and power in both elite and moderately experienced athletes during long in-season periods (Baker, 1994, 1998a, 2000c, 2001d), though case studies also reported good results with its use in during preparation periods (Baker, 1995c; Poliquin, 1992).

Accumulation/intensification patterns of progression. Many introductory resistance-training programs can be loosely defined as, or based upon, the processes of accumulation/intensification. For example, an athlete may be prescribed a resistance they can lift for 3 x 10 repetitions and they do not increase the resistance (intensify training) until they have managed to perform

3 x 12 repetitions (ie. they have accumulated volume) with that constant resistance. Therefore these types of introductory programs are based upon the athlete accumulating training volume (volume-load) at a steady or designated resistance before training resistances are increased and the volume is reduced (intensification). This most basic type of accumulation/intensification used by beginners (eg. continually training within a narrow specified range of repetitions such as 3 x 10-12 etc) does not really embrace the concept of periodization and is not to be considered a periodized variant.

Table 3 details a certain example of the accumulation/intensification pattern that is a distinct cycle-length periodized variant. This program may be more familiar to coaches as the “Russian squat cycle” (although it was actually developed in the now separate country of Belarus) and was taken from the sport of weightlifting (Zeinalov, 1984). The original proponents stated that this particular variant was best suited to increasing maximal squat strength during the preparation period, presumably due to the high workloads involved (Zeinalov, 1984). Clearly this variant of accumulation/intensification was designed for competitive lifters and advanced athletes and may be less applicable to the vast majority of athletes or exercises due to its high intensities and workloads (ASCA, 2006). However, modifications such as more moderate volumes and intensities (eg. Accumulation => Wk1 = 70%/3x9, Wk2 = 70%/3x10, Wk3 = 70%/3x11, Wk4 = 70%/3x12, Intensification => Wk5 = 80%/3x7, Wk6 = 84%/3x6, Wk7 = 88/3x5, Wk8 = 92%/3x4) may make it more suitable to a wider range of athletes to use.

Integrating different models?

As described above, choosing a specific cycle-length variant/pattern of periodization may entail choosing a designated training variable configuration. Coaches may find some variants/patterns work well with certain athletes (eg. novice athletes and subtle linear-intensification patterns of progression) or certain times of the year (eg. wave-like patterns and in-season periods).

Another method is to prescribe patterns according to exercise classification. For example, Australian National Team Powerlifting Coach Robert Wilks proposed a block variant with linear intensity progressions for the three key powerlifts (but with large within-week variation in %1RM resistance and hence workload) and an undulatory approach for the assistance exercises (alternating between sets of 10 or sets of 6 repetitions every 2-3 weeks) (1994).

Accordingly a coach may ascribe to a philosophy of variant choice being determined by exercise classification, the training age/state of the athletes involved as well as the training period (General or Competitive periods). The overall periodized structure may reflect the integration of a number of different cycle-length variants.

2ciii. Periodization of resistance training for rugby league players.

While various authors have detailed different periodization strategies applicable to the training of rugby league players (Meir, 1993; Meir, 1994; Baker, 1995), little data has actually been published concerning the effects of different periodization models upon the strength and power of rugby league players. Baker detailed that the elite NRL players could maintain upper body

strength and power across lengthy in-season periods with the implementation of a wave-like cycle length training strategy as illustrated in Table 4 (2000c, 2001d). Moreover, younger SRL and CRL players could actually increase strength and maintain power during the in-season period. These results were achieved despite the high concurrent training volumes (eg. speed, conditioning, skill and tactical training) and game demands associated with the in-season period. As the goal of in-season training strategies is to maintain the physical qualities developed in the preparation periods, it was concluded that the wave-like strategy is a successful model and is recommended for use during in-season periods for rugby league players (Baker, 1998a). However it must be noted that these studies did not compare between different strategies, but rather could a wave-like training program maintain/increase the peak strength/power levels attained at the completion of an intensive preparation period. Thus it is not known if another strategy may have been more successful.

No data has been found that directly compares the effectiveness of different strategies upon strength and power levels in rugby league players. Also the long-term training effects are not known. For example, Balyi (1992, 1995; Balyi & Hamilton, 1998) has detailed a number of training stages applicable to the long-term athlete development (LTAD) of elite athletes. The latter LTAD stages include a “training to win” stage whereby sub-elite athletes aim to increase their physical capacities to the levels of the elite performers in their sport and a “training to maintain” stage whereby the elite performers

attempt to maintain their capacities while competing at the highest level (which takes precedence over developmental type of training).

As elite NRL rugby league players can experience lengthy careers spanning many years, it would be of interest to determine if they can still increase strength and power across this prolonged time period or at what time frame do strength and power gains stop/slow and accordingly, maintenance of these existing levels becomes the primary concern of training. Studies of this nature for any sport are very rare in the literature and currently non-existent in rugby league. To this end a long-term study investigating the changes in upper body strength and power across a multi-year period in professional rugby league players would be of interest. The scope and magnitude of the changes in upper body strength and power could also be tracked in accordance to the designation of whether the players were “sub-elite” (synonymous with Balyi’s “training to win” stage) or “elite” (synonymous with Balyi’s “training to maintain” stage) at the start of the study. These types of studies would provide data pertinent to the age that structured, heavy resistance training should commence for more optimal LTAD.

2civ. Advanced power training methods currently being used by elite rugby league players.

Power is the most desired physical quality for a number of sports because it entails both force (strength) and velocity (speed) aspects. For coaches and sports people it is more often described as strength x speed. Because both strength and speed can be improved by many different training variable manipulations, training to improve power output has been described as requiring a multi-faceted approach (Newton and Kraemer, 1994). However a cursory glance at many resistance training programs or recommendations aimed at increasing muscular power would typically reveal a high proportion of Olympic weightlifting (eg. power cleans, pulls) and plyometric exercises (eg. jumping, bounding) (eg. Haff et al., 2001). While Olympic weightlifting methods of training often produce tremendous increases in lower body power, other methods or exercises, especially for developing upper body power, appear less explored. For example, maximal upper body pressing/pushing power is of importance to rugby league to enhance the ability to push away opponents. However, most articles concerning power-training methods involve Olympic weightlifting exercises and lower body plyometrics, paying scant regard to the upper body requirements. Table 5 details some practical methods currently being implemented to enhance maximal power (Pmax) training in rugby league players. In this thesis a review paper outlining research findings and practical recommendations for the methods is included (Study 9). Primary attention will be given to how these methods can be used

to enhance upper body power, however many of the methods can be utilized for lower body power training as well.

Table 5. Practical methods to increase the effectiveness of maximal power training for rugby league players.

1. Include full acceleration exercises as power exercises.
2. Alter the kinetics of some strength exercises to more favorably affect rapid-force or power output.
3. Use complexes of contrasting resistances or exercises.
4. Periodize the presentation of power exercises and resistances.
5. Use low repetitions when maximizing power output.
6. Use "clusters", "rest-pause" or "breakdown" techniques for some strength or power exercises.
7. Use an ascending order of resistances when maximizing power output.

2d - Testing of strength and power in rugby league players.

2di. Types of tests

As rugby league is a collision-based sport, success would appear to be heavily reliant upon the players possessing an adequate degree of various physical fitness qualities such as strength, power, speed and endurance as well as the individual skill and team tactical abilities (Gabbett,

2005). Testing of these physical qualities could therefore be deemed to be of importance to rugby league players and coaching staff.

Testing of rugby league players has greatly increased during the past decade ~ principally due to the increased professionalism in the sport and the consequent determination to improve player talent identification and performance levels. While a number of researchers have utilized holistic test batteries running the gamut of physical conditioning (eg. Meir, 1993; Brewer et al., 1994; Brewer & Davis, 1995; O'Connor, 1996; Meir et al., 2001; Gabbett, 2000, 2002, 2006; Gabbett & Herzig, 2004) the purpose of this thesis is to concentrate principally upon the testing of upper body muscular functioning. In particular, upper body strength, power, speed and strength-endurance would appear to be of importance due to the large amount of tackling and grappling that occurs both in attack and defense during an 80-minute game. With respect to upper body testing, there is a distinct paucity of data prior to the early to mid-1990's.

Strength

Maximal strength levels appear to be important in rugby league. Traditionally methods of assessing strength, whether it is upper or lower body, have varied considerably (eg. isometric, dynamic, isokinetic etc). This variance often results in some training-induced adaptations being reflected in some tests, but not others (Baker et al., 1994a). Consequently it has been proposed that the method of strength testing be similar to the method of training (Baker et al., 1994a). Consequently researchers involved in the

testing of rugby league players have gravitated more towards the traditional free weight tests of maximal strength as were typically used in the American football system (eg. Fry & Kraemer, 1991; Ware et al., 1995; Chapman et al., 1998). Traditionally in the American football system, upper body strength was typically assessed using the bench press exercise (Fry & Kraemer, 1991; Ware et al., 1995; Chapman et al., 1998). Consequently from the early to mid-1990's onwards rugby league researchers have typically used the bench press (BP) to gauge strength levels via a 1 or 3-repetition maximum test (1RM or 3 RM BP) (Meir, 1993; Baker, 1995, O'Connor, 1996). It was presumed the bench press exercise represented the athlete's upper body capabilities in driving an opponent backwards, a fundamental task for players of all positions in both attack and defence in rugby league (Meir, 1993; Baker, 1995; O'Connor, 1996; Gabbett, 2005). Because of the simple nature of the test and almost universal availability of equipment and data for comparative purposes, it appears to have become an accepted measure of general upper body pressing strength used by rugby league players (eg. Meir, 1993 through to Keogh, 2004).

While pressing or pushing an opponent backwards/away is perhaps the most fundamental task in rugby league, there are a number of times that an opponent must be pulled to the ground in defense to halt their forward momentum or to slow down the "play the ball" situations. Consequently testing of upper body pulling strength appears warranted. Again there is a paucity of data concerning the measurement of pulling strength capabilities of rugby league players although this type of test has been used for over a

decade in rugby union players (eg. Baker, 1998a-d). Generally some simple test of pulling such as a pull-up (PU aka chin-up) test is performed with additional resistance added to ensure the test fulfills the criterion of a test of strength (high resistance, very few repetitions such as 1-5 RM, Kraemer et al., 2002) as opposed to the athlete performing multiple repetitions with their own body mass, which may be deemed more a test of strength-endurance. Keogh (2004) reported the pulling strength for SRL and CRL players from such a pull-up test. The pulling strength in this test was similar to the bench press scores. Baker (2000c) reported the percentage maintenance, but not the raw scores, of pull-up strength by rugby league players of various performance levels during an in-season period. No other data has been found that considers the upper body pulling strength of rugby league players. Therefore further research into the pulling strength of rugby league players, especially NRL players, appears warranted.

Power

Testing of upper body power did not appear for rugby league players until the late 1990's when power measurement technologies became more readily available for the testing and training of rugby league players. Baker and Nance (1999a, b), Baker, (2000a-c, 2001a, c, d) and Baker et al. (2001a) first reported the maximum upper body power of rugby league players by the testing of incline or flat bench press throws (BT) in a modified and calibrated Smith machine (Plyometric Power System). The bench press throw (or simply bench throw) in a Smith machine is used because this

exercise involves acceleration through the full range of movement, resulting in higher power outputs as compared to a traditionally performed bench press exercise (Newton et al., 1996). The testing procedures entailed the athletes performing three repetitions in the BT with a battery of absolute resistances (eg. 40, 50, 60, 70 and 80 kg). These resistances were chosen because they encompassed the resistance range of 30-60 % 1RM, which Newton et al. (1997) had shown maximized power output during BT's. Only the highest average concentric power output was recorded for each absolute resistance, with the highest power output overall designated as the Pmax. This testing also allowed for a load-power profile to be developed (see Figure 1 below), based upon the earlier work of Newton et al. (1997), which itself was influenced by the lower body jump squat load-power profiling research conducted by Hakkinen et al. (1985a,b). Based upon the research of these earlier investigators that reported distinct adaptations between strength-oriented and power-oriented training (Hakkinen et al. 1985a,b), it was recommended that the BT load-power profile could be used to aid training prescription (Baker, 2001c). For example, rugby league players with high strength levels but lower relative power levels could be prescribed more Pmax rather than strength training and vice versa (Baker, 2001c; Baker et al., 2001a, b).

Further research in the area of BT or incline BT power testing reported that these tests that were apparently sensitive to high volume training by rugby league players. Baker (2000c) reported a trend (p=0.08) towards decreased power (5.6%) during an extremely fatiguing portion of the in-

season. This trend was reversed with the resumption of normal playing and training loads. A follow up study (Baker, 2001d) also reported that the relationship between 1RM BP and BT Pmax was lower (r = 0.52 - 0.56) when a higher volume of upper body aerobic conditioning (swimming, arm grinding, wrestling etc) was concurrently being performed, however the relationship appeared also to revert back to “normal levels” (r= 0.75 – 0.77) with the cessation of this high volume training. The “normal levels” regarding the extent of the relationship between 1RM BP and BT Pmax were based upon the earlier relationships of that magnitude that were reported by Baker and Nance (1999b) and Baker et al. (2001a, c) with a large number of the same subjects. Various other researchers have also reported a strong cross-sectional relationship between maximum strength and power (Funato et al., 1996; Moss et al., 1997).

Upper body BT power testing has become more accepted in the testing of athletes and it appears to be a test that is sensitive to training and playing load interventions (eg. Drinkwater et al., 2005; Lawton et al., 2006). Consequently future research may focus more on how training and playing load interventions impact on the load-power profile and Pmax or even just 1-2 designated training resistances which may appear sensitive to such interventions (eg. how BT P40-60, power output during bench throws with 40-60 kg, is impacted, Drinkwater et al., 2005).

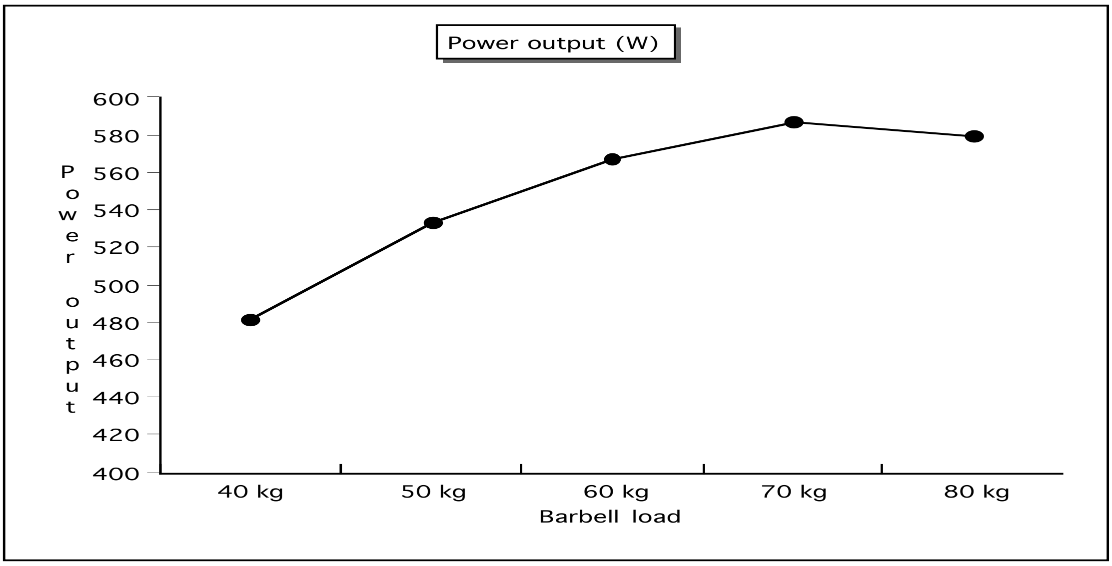

Figure 3. The load-power curve for various barbell resistances (40 to 80 kg) for professional and semi-professional rugby league players (From Baker, 2001c).

Speed

While running speed capabilities seem extensively reported in rugby league players of all different levels (Meir, 1993; Baker, 1999a; Baker and Nance, 1999a; Gabbett, 2000, 2002, 2006; Gabbett & Herzig, 2004), measures of upper body speed have not garnered much interest. As such it is not known if upper body movement speed is a factor of much importance to rugby league players. The first study to look at measuring upper body speed in rugby league players (players from NRL, SRL and CRL levels) utilized an incline BT with an empty 20 kg barbell in the Plyometric Power System (Baker, 2001c). Little difference in this measure was reported between the teams, however this data was collected in 1997 when rugby league players had typically not possessed an extensive background in

specific upper body speed training. Figure 2 (taken from Baker, 2001c) below depicts no difference between NRL and CRL players in the upper body speed test, but an increased percentage difference with increased resistances gravitating towards maximal strength. In an effort to amass more definitive data, a further comparative study was performed three years later in which the subjects were NRL, CRL and “talented” high-school rugby league players (ie. part of a Talent Identification process) who possessed varied resistance training backgrounds (Baker, 2002). The results of this study were more positive insofar as a flat BT test with 20 kg, designating upper body speed capabilities, could distinguish between NRL and lesser players, and therefore may be useful in rugby league talent identification. To date no other studies have investigated upper body speed in rugby league players.

Endurance

Due to the extensive amount of tackling and upper body grappling that occurs in tackles, it has long been thought that training and measuring upper body strength-endurance would be of benefit to rugby league players (Meir, 1993). Specifically the American College of Sports Medicine has recommended that strength-endurance training or testing entails the choice of a resistance in the range of 30-80% 1RM and should allow for the completion of at least 10-25 or more repetitions (Kraemer et al., 2002). The difficulty lies in choosing a test protocol that fulfills these requirements and is appropriate to the demands of the sport.

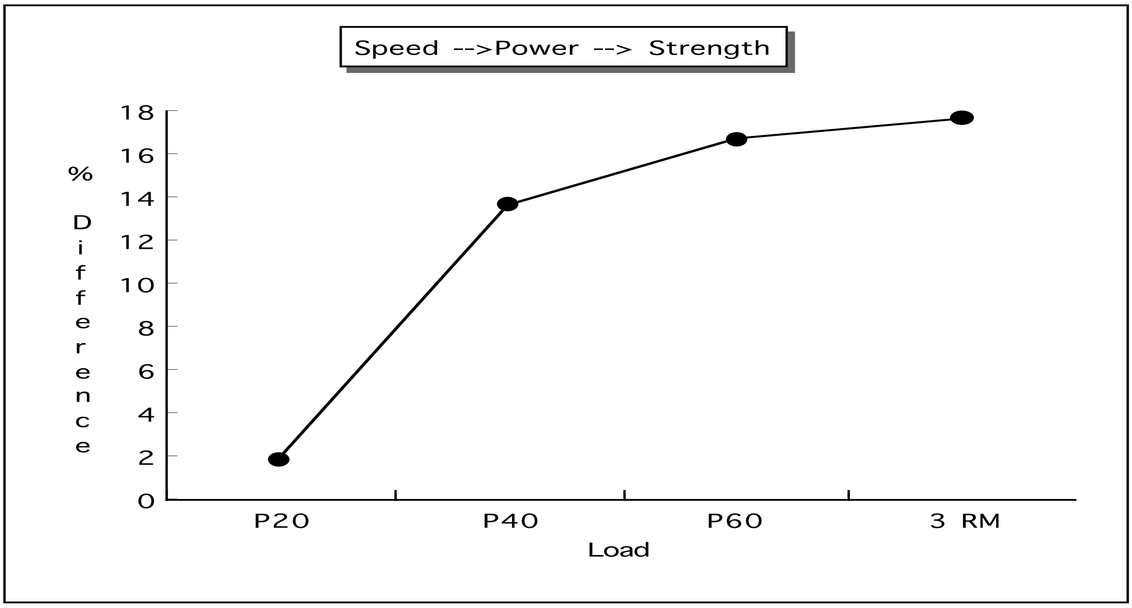

Figure 4. The percentage difference between professional (NRL) and college-aged (CRL) rugby league players in four loads of the speed-power-strength spectrum during upper body exercises. The difference in the Incline BT P20, representing the speed end of the spectrum, was not significantly different whilst differences in the other three loads were. From Baker, 2001c.

Meir (1993) and Meir et al. (2001b) were the first researchers to report an upper body strength-endurance test in rugby league players. They described a pushup test with the repetitions performed in a certain time period (eg. 60-s, Meir 1993) being the indicator of strength-endurance. While pushup tests have been used extensively in many settings such as the military to measure strength-endurance, typically the tests have not been normalized according to each subjects different body mass. Studies have shown that the actual resistance during a pushup is actually about BM x .67 (LaChance and Hortobagyi, 1994; Gouvali and Boudolos, 2005). Therefore

heavier subjects may perform less RTF, indicating less strength-endurance when analysed in this manner, but they may be actually performing more absolute work. The same situation applies when performing RTF pull-up tests with only the athlete's own body mass as resistance. In rugby league, defensive situations are thought to be the portion of the game most requiring strength-endurance (due to the upper body grappling occurring in the tackle) and in these defensive situations the onus is to perform work (work = mass x distance, ie., move the body mass of the opponent backwards or downwards). Therefore an upper body strength-endurance test that standardized the resistance to be overcome and measured the absolute work efforts based upon the RTF performed with that standardized resistance has been sought. A widely accepted and performed test in the American football system is a RTF BP test performed with a resistance of 102.5 kg (NFL 225 test,), which is used at the NFL draft combine (McGee & Burkett, 2003). Typically these athletes have high body mass levels and an extensive history of strength and power training (eg. 2-4 years at both high school and then college) ~ consequently the resistance of 102.5 kg allows for the completion of a high number of repetitions, fulfilling the ACSM (2002) guidelines regarding strength-endurance. However as rugby league players are talent identified and recruited by clubs at a younger age (Baker, 2002), with less resistance training experience, it must be presumed that this test would not fulfill the ACSM guidelines regarding strength-endurance. For example, in the research of Baker (2002), with the exception of the NRL squad, the NFL 225 test would be too heavy for the vast majority of younger

subjects to lift even once and for the remainder of the subjects capable of actually lifting this resistance, their performance of only 1-5 repetitions would invalidate it as a test of strength-endurance. Therefore while the NFL 225 test appears to be a valid test for strength-endurance (and for an extrapolated 1RM, eg. Ware et al., 1995; Chapman et al. 1998) in the American football system, this absolute resistance is too heavy for the vast majority of rugby league players. Consequently a strength-endurance test appropriate to the vast majority of adult rugby league players is sought.

2dii. Does testing identify trends in the team grading (a measure of performance) or positional grouping of rugby league players?

The most fundamental reasons to test the physical qualities of rugby league players are for the purposes of player talent identification and to provide a guide or rationale for adjusting training to improve playing performance levels through the enhancement of physical capabilities. Therefore tests should be able to discern differences in elite and non-elite performers in a sport. As an example, Secher had rowers of international, national and club level perform a number of tests of muscle strength and function in an effort to discern which tests were most capable of discriminating between the athletes at each of these levels (Secher, 1975). Only one test, an isometric pull in the start position of the rowing stroke was capable of identifying between the oarsmen (about 10% difference in force levels between each level of oarsmen). All the other standardized tests of

muscle strength and function were virtually useless for the purposes of identifying which athletes were elite or non-elite performers.

Sechers' study has become a benchmark for researchers looking to distinguish elite or more highly performed athletes from non-elite and lesser-performing athletes and as such this type of comparative study has been utilized in a number of sports ranging from kayaking (Fry & Morton, 1991) to American football (Fry & Kraemer, 1991) and volleyball (Fry et al., 1991). The testing of rugby league players should presumably follow this basis of testing being able to distinguish better performers in the sport from lesser skilled performers. However the first published studies concerning rugby league typically reported results for only one performance level of player (Meir, 1993; O'Connor, 1996). This provides information pertinent only to that one level of performance unlike the study of Secher, where a club level oarsman could see that an isometric pulling force of 1600 N was adequate for that level of competition but levels of 1800N and 2000N would be necessary to attain national and international level, respectively. It could be said that test studies that are aimed at identifying physical differences between elite and non-elite performers should include as many levels and/or ages of athlete as possible. This would allow for the generation of a talent identification/physical performance pathway from the lowest to highest levels (LTAD).

With regards upper body testing, the first study to do so was performed by Baker (2001c), who compared NRL, SRL and CRL upper body strength, power and speed capabilities. The difference in 1RM BP strength

between the three groups was in the order of 11-14% between each level whereas for power the differences were about 10%. There was no difference in the speed test. The basic result of that study was that the heavier the resistance used in a test procedure, the greater the difference between NRL, SRL and CRL players (see Figure 4).

A follow up study performed three years later found more profound differences between the 1RM BP levels of the CRL and NRL groups, which was attributed to greater resistance training experience of the NRL groups (Baker, 2002). The high-school rugby league players in this study were obviously less strong and possessed slower movement speed as compared to the NRL and CRL players (BT P20 test). This result concerning the high-school players was of course expected and that data was in reality collected for the purposes of establishing a talent identification/physical performance pathway ranging from junior to senior high-school, to CRL and finally NRL level. The fact that upper body speed differentiated the CRL group from the NRL, which was different to the previous result (Baker, 2001c) was interesting. It may be attributed to the increasing professionalism of elite NRL players and the growing sophistication of their training whereas the semi-professional CRL training standards and practices have perhaps remained less changed.

As yet no study has been performed that compares the strength-endurance capabilities of elite players to players of a lower performance level. Consequently it is not known if strength-endurance capabilities discriminate between rugby league players of a certain level and whether

testing strength-endurance would be useful in terms of talent identification or performance enhancement. Currently some commentators in the popular media believe that due to changes in, and interpretations of, the rules of the game (eg. concept of "dominant tackle" and "surrender tackle"), strength-endurance for the upper body and high-intensity running endurance for the lower body have become the dominant physical qualities required for success in rugby league. Obviously it is of interest to attempt to determine if upper body strength-endurance had surpassed maximal strength, power or upper body speed in importance, factors that had been shown to differentiate NRL, SRL and CRL, at least to some degree, prior to the "dominant tackle" rule changes.

Player Position

Studies of American football players clearly illustrate differences in strength and power levels not only between players of different performance levels (eg, starters and non-starters) but also according to the playing position of the players (Fry & Kraemer, 1991). As rugby league entails players having certain positional grouping requirements, it is possible that some of the upper body measures could also differ in importance. Therefore, analyzing the upper body capabilities according the positional grouping of the players appears warranted. Earlier studies testing rugby league players tended to use the two basic groupings of forwards and back-lines players (Meir, 1993; Brewer & Davis, 1995). However, this dichotomy oversimplifies the matter, as within these two groups are some player's tasks that overlap or may be quite different. Later researchers such as O'Connor

and Meir et al. (2001a,b) analysed players according to their distinct positional groupings (5-9 groups) and reported some differences between groups in maximal upper body strength (1 and 3RM). Meir et al. (2001b) labeled this more finite grouping as “the players position on the team”. Meir et al. also included the standard, simplified forwards versus backline analyses off upper body strength (forwards 10% > back-line players) and strength-endurance (back-line players performed 33.65 and forwards, 31.28 repetitions in a 30-s speed push-up test). No normalization for differences in body mass were taken into account for the strength-endurance test ~ therefore it is not known if differences truly existed in absolute workload performed as would be readily observable in a test that standardized absolute workload.

However, while Meir et al. (2001b) also analysed players into four sub-groups, which were labeled as forwards (props, second row players known as the “hit-up forwards”), outside backs (centres, wingers and fullbacks), ball distributors (hookers and half-backs) and adjustables (locks and five-eighths), none of the analysed tests were of upper body functioning (only sprint and 5-minute endurance running tests were analysed). This positional sub-grouping was based on current coaching strategies at the time. However, former Australian national team coach Wayne Bennett believes the analyses or training of players should be according to three sub-groupings with the adjustables and ball-players joined as their roles are linked and inter-changeable to a large degree (Wayne Bennett, personal communication, 1995 to present). Furthermore, the “style of play” of some

players in their "position on the team" should determine which sub-group they belong to, not simply "position on the team". For example, a fullback that is used in attack like a second five-eighth should be considered to be in the adjustable/distributors group whereas a fullback who is more of a ball-runner would be considered to be an outside back (Wayne Bennett, personal communication, 1995 to present). The same situation applies to the lock forward "position on the team" ~ their style of play may enable them to be in the adjustable/distributors group or in the hit-up forward group (Wayne Bennett, personal communication, 1995 to present).

In conclusion, irrespective of how players are grouped or sub-grouped there has been no study that has compared upper body maximal strength, power, strength-endurance or speed levels between playing positions or sub-groups from different performance levels. Maximum strength, power and upper body speed have been previously been show to differentiate between different performance levels (Baker, 2000a-c; 2001a, c, d; 2002), while maximum strength has been shown to differentiate to some degree between different "positions on the team" (O'Connor, 1996, Meir et al., 2001b). Strength-endurance has been analyzed in a simple forward versus back-line player comparison with no (Meir, 1993) or only minor differences (Meir et al., 2001b) in the repetitions performed in time constrained push-up tests. Absolute work was not assessed in either strength-endurance test, so this area of analyses remains devoid of definitive data.

Given the NRL salary cap and its strict enforcement, elite rugby league clubs in Australia must now focus on talent identification and physical

performance enhancement (Wayne Bennett, personal communication 2004 to present). As such rugby league clubs seek better talent identification protocols, including establishing norms for various upper body functioning tests for players of different positional sub-groupings at different levels of team performance (eg. NRL, SRL and CRL). Consequently the purposes of some of the studies within this thesis are to establish normative data for a number of upper body tests and to determine if these tests indeed discriminate between players from different performance levels or positional sub-groupings. The upper body tests would involve mainly standard tests used previously in rugby league players such as 1RM bench press and pull-up tests to assess maximum strength; BT power tests with a resistance battery of 40 to 80 kg to assess maximum power; BT P20 test to assess upper body speed; and a new strength-endurance test, the RTF BP60 (repetitions till fatigue bench pressing 60 kg) which is based upon the well accepted NFL 225 test, but modified to utilize a lighter resistance more appropriate to assessing the strength-endurance levels of rugby league players. Study 1 will investigate whether differences exist in upper body strength, power, speed and strength-endurance for players in three different positional groupings (hit-up forwards, outside backs and ball-distributors/adjustables) x team rankings (NRL, SRL and CRL). Study 2 will investigate pulling and pressing strength differences between SRL and NRL players. Study 3 will investigate whether high intensity RTF tests can be used to accurately predict 1RM BP and PU performance in rugby league players.

Summary and Implications of the Literature Review

This review of the literature has defined various qualities of upper body muscular functioning such as strength, power, speed and strength-endurance. The neural and muscle contractile basis for force output have also been reviewed. Theoretically in a high force sport such as rugby league football it could be assumed that testing of strength and power would be extensive and that strength and power may be prominent descriptors of performance level. However there is a paucity of data concerning upper body strength testing in rugby league players and even less data exists concerning power testing. Furthermore, given recent rule changes and current game trends, some debate exists as to whether strength and power are as important as strength-endurance. Therefore the purpose of Study 1 was to determine the relative importance to rugby league playing level of tests of upper body strength, power, speed and strength-endurance. The same movement pattern for each test must be used to limit chances of potential differences being ascribed to individuals' inter-test variance. Also a comparison between upper body pushing and pulling strength was deemed necessary as most strength studies tend to focus upon pushing/pressing strength. Given the large amount of pulling that occurs in defense (pulling an opponent to the ground etc), it was posited that this measure of strength should not be neglected when assessing the strength of rugby league players (Study 2). If pulling strength was different between NRL players and lower level players, then pulling strength must addressed in the training content of these lower level players. As 1RM strength testing can be a difficult and time consuming process when dealing with a large number of athletes, especially those not greatly experienced in resistance training, a simplified version of extrapolating 1RM test scores suitable for lower level athletes was also deemed of interest (Study 3). The

results of these testing investigations should direct the training goals and content of rugby league players.

The review of neural control of force output has potentially identified a theoretical basis for some specific acute power training strategies. As power movements entail rapid muscular contractions, they rely upon finite interplay between various neural control mechanisms. If specific training variable configurations could influence this neural interplay, then conceivably power output could be enhanced. This review identified two methods of acutely favourably influencing power output ~ one through the use of alternating sets of a heavier load in the same movement with sets of the designated power training resistance (Study 4) and the other through alternating sets of an antagonist training movement with sets of the designated power training resistance (Study 5).

Hypertrophy of muscle (and/or changes in the contractile qualities of muscle) was also identified as one of the main avenues that experienced resistance trainers may use to increase maximal strength. However the high volume of training thought to favourably influence hypertrophy was also identified as not being conducive to power development. The possible deleterious effects that an acute hypertrophy-oriented training bout has upon power output needs to be investigated (Study 6).

Most resistance training studies in the literature are short-term studies (< 6 months) using college students as subjects (with little or moderate resistance training experience). How the results of any of these studies can be applied to long-term experienced resistance trainers has been questioned by a number of researchers and strength coaches alike. Furthermore the few long-term studies (up to 2-years) that exist in the literature have shown that the scope and magnitude for increases in strength and power appear to diminish with increased training experience. What the nature and scope of long-term resistance training adaptations in maximal strength and power in

experienced, professional athletes across even longer multi-year periods is a question that need to be addressed (Study 7).

In terms of Long-term Athlete Development (LTAD) ~ Is there any advantage in commencing regimented strength/power training in the latter teenage years as compared to the early twenties with regards the development of strength and power in professional rugby league players (Study 8)? This would appear to be an important question for professional coaches.

As well as the testing, intervention and long-term observation studies outlined above, this review of the literature has identified that there are acute and chronic training strategies that can affect resistance-training outcomes such as strength and power output. Consequently two papers detailing these acute and chronic strategies were published arising from this literature review.

Table 4. In-season model of periodization using Wave-like variants according to exercise classification as primary strength or power or assistant strength or power exercises (from Baker, 1998a, 2001d).

Exercise classification	Week #	1	2	3	4	5	6	7	8
Primary strength eg. SQ, BP, PU	S x R % 1RM	3 x 8 66%	8-6-5 66-72-77%	6-5-3 72-77-82%	5-3-2 77-82-87%	8-6-5 70-75-80%	6-5-3 75-80-85%	5-3-2 80-85-90%	2-1-1 85-90-95%
Assistant strength	S x R % 1RM	2 x 10 65%	2 x 8 70%	2 x 6 75%	2 x 5 80%	2 x 8 75%	2 x 6 80%	2 x 5 85%	2 x 5 87%
Primary power eg. PC, J, BT JS	S x R % 1RM	3 x 5 65%	3 x 5 70%	5-4-3 70-75-80%	4-3-2 75-80-85%	3 x 5 75%	5-4-3 75-80-85%	4-3-2 80-85-90%	3-2-2 85-90-95%
Assistant power	S x R % 1RM	3 x 6 65%	3 x 6 70%	3 x 5 75%	3 x 4 80%	3 x 6 75%	3 x 5 80%	3 x 4 85%	3 x 3 90%

S x R = Sets x Reps, %1RM = Percentage of one repetition maximum strength, BP = bench press, PU = pull-ups, SQ = squats, PC = power clean from hang, J = jerks, JS = jump squats, BT = bench throws. * For squats, reduce intensity by about 10% 1RM. Third set may be optional for squats. ** Assistant strength and power exercises can be performed for 2 or 3 sets. Assistant power exercises include pull variations (eg. pulls to waist, high pulls, power shrugs), push press and power press/throwing variations, loaded jumping exercises etc.

2civ. Advanced power training methods currently being used by elite rugby league players.

Power is the most desired physical quality for a number of sports because it entails both force (strength) and velocity (speed) aspects. For coaches and sports people it is more often described as strength x speed. Because both strength and speed can be improved by many different training variable manipulations, training to improve power output has been described as requiring a multi-faceted approach (Newton and Kraemer, 1994). However a cursory glance at many resistance training programs or recommendations aimed at increasing muscular power would typically reveal a high proportion of Olympic weightlifting (eg. power cleans, pulls) and plyometric exercises (eg. jumping, bounding) (eg. Haff et al., 2001). While Olympic weightlifting methods of training often produce tremendous increases in lower body power, other methods or exercises, especially for developing upper body power, appear less explored. For example, maximal upper body pressing/pushing power is of importance to rugby league to enhance the ability to push away opponents. However, most articles concerning power-training methods involve Olympic weightlifting exercises and lower body plyometrics, paying scant regard to the upper body requirements. Table 5 details some practical methods currently being implemented to enhance maximal power (Pmax) training in rugby league players. In this thesis a review paper outlining research findings and practical recommendations for the methods is included (Study 9). Primary attention will be given to how these methods can be used

to enhance upper body power, however many of the methods can be utilized for lower body power training as well.

Table 5. Practical methods to increase the effectiveness of maximal power training for rugby league players.

1. Include full acceleration exercises as power exercises.
2. Alter the kinetics of some strength exercises to more favorably affect rapid-force or power output.
3. Use complexes of contrasting resistances or exercises.
4. Periodize the presentation of power exercises and resistances.
5. Use low repetitions when maximizing power output.
6. Use “clusters”, “rest-pause” or “breakdown” techniques for some strength or power exercises.
7. Use an ascending order of resistances when maximizing power output.

2d - Testing of strength and power in rugby league players.

2di. Types of tests

As rugby league is a collision-based sport, success would appear to be heavily reliant upon the players possessing an adequate degree of various physical fitness qualities such as strength, power, speed and endurance as well as the individual skill and team tactical abilities (Gabbett,

2005). Testing of these physical qualities could therefore be deemed to be of importance to rugby league players and coaching staff.

Testing of rugby league players has greatly increased during the past decade ~ principally due to the increased professionalism in the sport and the consequent determination to improve player talent identification and performance levels. While a number of researchers have utilized holistic test batteries running the gamut of physical conditioning (eg. Meir, 1993; Brewer et al., 1994; Brewer & Davis, 1995; O'Connor, 1996; Meir et al., 2001; Gabbett, 2000, 2002, 2006; Gabbett & Herzig, 2004) the purpose of this thesis is to concentrate principally upon the testing of upper body muscular functioning. In particular, upper body strength, power, speed and strength-endurance would appear to be of importance due to the large amount of tackling and grappling that occurs both in attack and defense during an 80-minute game. With respect to upper body testing, there is a distinct paucity of data prior to the early to mid-1990's.

Strength

Maximal strength levels appear to be important in rugby league. Traditionally methods of assessing strength, whether it is upper or lower body, have varied considerably (eg. isometric, dynamic, isokinetic etc). This variance often results in some training-induced adaptations being reflected in some tests, but not others (Baker et al., 1994a). Consequently it has been proposed that the method of strength testing be similar to the method of training (Baker et al., 1994a). Consequently researchers involved in the

testing of rugby league players have gravitated more towards the traditional free weight tests of maximal strength as were typically used in the American football system (eg. Fry & Kraemer, 1991; Ware et al., 1995; Chapman et al., 1998). Traditionally in the American football system, upper body strength was typically assessed using the bench press exercise (Fry & Kraemer, 1991; Ware et al., 1995; Chapman et al., 1998). Consequently from the early to mid-1990's onwards rugby league researchers have typically used the bench press (BP) to gauge strength levels via a 1 or 3-repetition maximum test (1RM or 3 RM BP) (Meir, 1993; Baker, 1995, O'Connor, 1996). It was presumed the bench press exercise represented the athlete's upper body capabilities in driving an opponent backwards, a fundamental task for players of all positions in both attack and defence in rugby league (Meir, 1993; Baker, 1995; O'Connor, 1996; Gabbett, 2005). Because of the simple nature of the test and almost universal availability of equipment and data for comparative purposes, it appears to have become an accepted measure of general upper body pressing strength used by rugby league players (eg. Meir, 1993 through to Keogh, 2004).

While pressing or pushing an opponent backwards/away is perhaps the most fundamental task in rugby league, there are a number of times that an opponent must be pulled to the ground in defense to halt their forward momentum or to slow down the "play the ball" situations. Consequently testing of upper body pulling strength appears warranted. Again there is a paucity of data concerning the measurement of pulling strength capabilities of rugby league players although this type of test has been used for over a

decade in rugby union players (eg. Baker, 1998a-d). Generally some simple test of pulling such as a pull-up (PU aka chin-up) test is performed with additional resistance added to ensure the test fulfills the criterion of a test of strength (high resistance, very few repetitions such as 1-5 RM, Kraemer et al., 2002) as opposed to the athlete performing multiple repetitions with their own body mass, which may be deemed more a test of strength-endurance. Keogh (2004) reported the pulling strength for SRL and CRL players from such a pull-up test. The pulling strength in this test was similar to the bench press scores. Baker (2000c) reported the percentage maintenance, but not the raw scores, of pull-up strength by rugby league players of various performance levels during an in-season period. No other data has been found that considers the upper body pulling strength of rugby league players. Therefore further research into the pulling strength of rugby league players, especially NRL players, appears warranted.

Power

Testing of upper body power did not appear for rugby league players until the late 1990's when power measurement technologies became more readily available for the testing and training of rugby league players. Baker and Nance (1999a, b), Baker, (2000a-c, 2001a, c, d) and Baker et al. (2001a) first reported the maximum upper body power of rugby league players by the testing of incline or flat bench press throws (BT) in a modified and calibrated Smith machine (Plyometric Power System). The bench press throw (or simply bench throw) in a Smith machine is used because this

exercise involves acceleration through the full range of movement, resulting in higher power outputs as compared to a traditionally performed bench press exercise (Newton et al., 1996). The testing procedures entailed the athletes performing three repetitions in the BT with a battery of absolute resistances (eg. 40, 50, 60, 70 and 80 kg). These resistances were chosen because they encompassed the resistance range of 30-60 % 1RM, which Newton et al. (1997) had shown maximized power output during BT's. Only the highest average concentric power output was recorded for each absolute resistance, with the highest power output overall designated as the Pmax. This testing also allowed for a load-power profile to be developed (see Figure 1 below), based upon the earlier work of Newton et al. (1997), which itself was influenced by the lower body jump squat load-power profiling research conducted by Hakkinen et al. (1985a,b). Based upon the research of these earlier investigators that reported distinct adaptations between strength-oriented and power-oriented training (Hakkinen et al. 1985a,b), it was recommended that the BT load-power profile could be used to aid training prescription (Baker, 2001c). For example, rugby league players with high strength levels but lower relative power levels could be prescribed more Pmax rather than strength training and vice versa (Baker, 2001c; Baker et al., 2001a, b).

Further research in the area of BT or incline BT power testing reported that these tests that were apparently sensitive to high volume training by rugby league players. Baker (2000c) reported a trend (p=0.08) towards decreased power (5.6%) during an extremely fatiguing portion of the in-

season. This trend was reversed with the resumption of normal playing and training loads. A follow up study (Baker, 2001d) also reported that the relationship between 1RM BP and BT Pmax was lower (r = 0.52 - 0.56) when a higher volume of upper body aerobic conditioning (swimming, arm grinding, wrestling etc) was concurrently being performed, however the relationship appeared also to revert back to "normal levels" (r= 0.75 – 0.77) with the cessation of this high volume training. The "normal levels" regarding the extent of the relationship between 1RM BP and BT Pmax were based upon the earlier relationships of that magnitude that were reported by Baker and Nance (1999b) and Baker et al. (2001a, c) with a large number of the same subjects. Various other researchers have also reported a strong cross-sectional relationship between maximum strength and power (Funato et al., 1996; Moss et al., 1997).

Upper body BT power testing has become more accepted in the testing of athletes and it appears to be a test that is sensitive to training and playing load interventions (eg. Drinkwater et al., 2005; Lawton et al., 2006). Consequently future research may focus more on how training and playing load interventions impact on the load-power profile and Pmax or even just 1-2 designated training resistances which may appear sensitive to such interventions (eg. how BT P40-60, power output during bench throws with 40-60 kg, is impacted, Drinkwater et al., 2005).

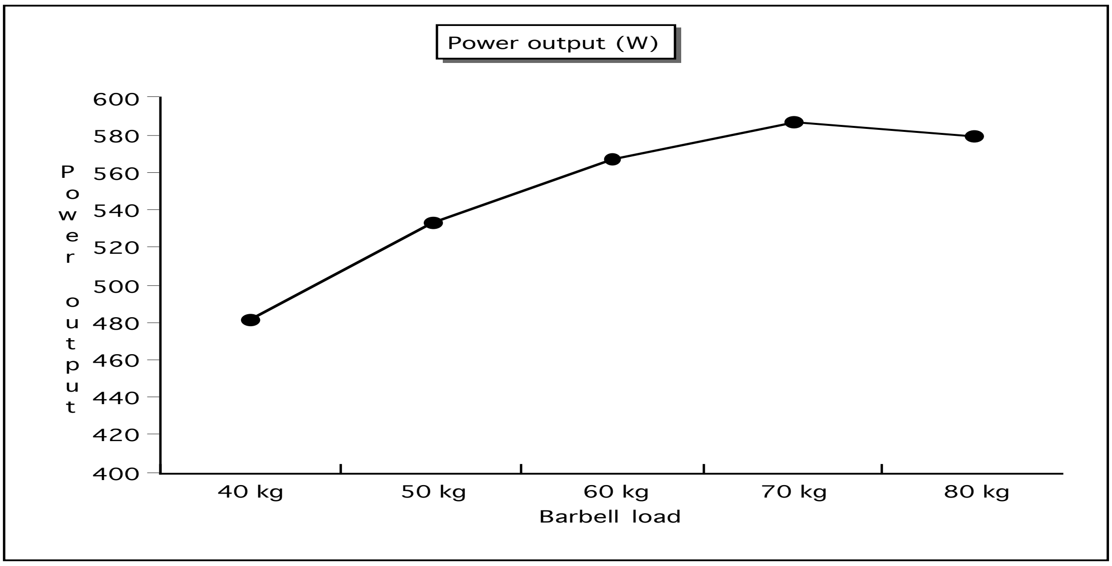

Figure 3. The load-power curve for various barbell resistances (40 to 80 kg) for professional and semi-professional rugby league players (From Baker, 2001c).

Speed

While running speed capabilities seem extensively reported in rugby league players of all different levels (Meir, 1993; Baker, 1999a; Baker and Nance, 1999a; Gabbett, 2000, 2002, 2006; Gabbett & Herzig, 2004), measures of upper body speed have not garnered much interest. As such it is not known if upper body movement speed is a factor of much importance to rugby league players. The first study to look at measuring upper body speed in rugby league players (players from NRL, SRL and CRL levels) utilized an incline BT with an empty 20 kg barbell in the Plyometric Power System (Baker, 2001c). Little difference in this measure was reported between the teams, however this data was collected in 1997 when rugby league players had typically not possessed an extensive background in

specific upper body speed training. Figure 2 (taken from Baker, 2001c) below depicts no difference between NRL and CRL players in the upper body speed test, but an increased percentage difference with increased resistances gravitating towards maximal strength. In an effort to amass more definitive data, a further comparative study was performed three years later in which the subjects were NRL, CRL and "talented" high-school rugby league players (ie. part of a Talent Identification process) who possessed varied resistance training backgrounds (Baker, 2002). The results of this study were more positive insofar as a flat BT test with 20 kg, designating upper body speed capabilities, could distinguish between NRL and lesser players, and therefore may be useful in rugby league talent identification. To date no other studies have investigated upper body speed in rugby league players.

Endurance

Due to the extensive amount of tackling and upper body grappling that occurs in tackles, it has long been thought that training and measuring upper body strength-endurance would be of benefit to rugby league players (Meir, 1993). Specifically the American College of Sports Medicine has recommended that strength-endurance training or testing entails the choice of a resistance in the range of 30-80% 1RM and should allow for the completion of at least 10-25 or more repetitions (Kraemer et al., 2002). The difficulty lies in choosing a test protocol that fulfills these requirements and is appropriate to the demands of the sport.

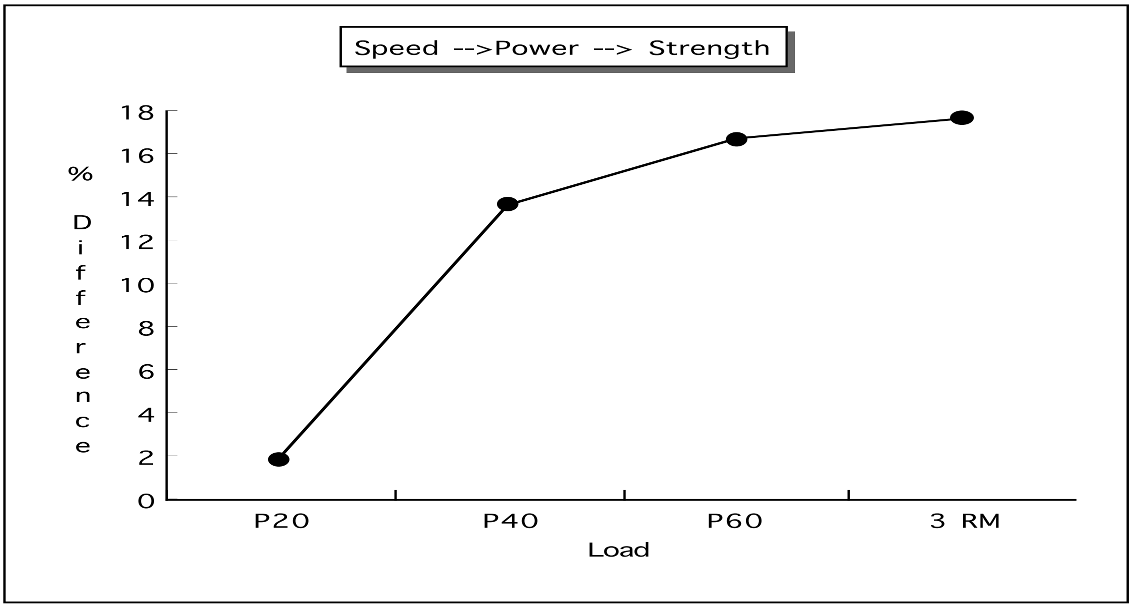

Figure 4. The percentage difference between professional (NRL) and college-aged (CRL) rugby league players in four loads of the speed-power-strength spectrum during upper body exercises. The difference in the Incline BT P20, representing the speed end of the spectrum, was not significantly different whilst differences in the other three loads were. From Baker, 2001c.

Meir (1993) and Meir et al. (2001b) were the first researchers to report an upper body strength-endurance test in rugby league players. They described a pushup test with the repetitions performed in a certain time period (eg. 60-s, Meir 1993) being the indicator of strength-endurance. While pushup tests have been used extensively in many settings such as the military to measure strength-endurance, typically the tests have not been normalized according to each subjects different body mass. Studies have shown that the actual resistance during a pushup is actually about BM x .67 (LaChance and Hortobagyi, 1994; Gouvali and Boudolos, 2005). Therefore

heavier subjects may perform less RTF, indicating less strength-endurance when analysed in this manner, but they may be actually performing more absolute work. The same situation applies when performing RTF pull-up tests with only the athlete's own body mass as resistance. In rugby league, defensive situations are thought to be the portion of the game most requiring strength-endurance (due to the upper body grappling occurring in the tackle) and in these defensive situations the onus is to perform work (work = mass x distance, ie., move the body mass of the opponent backwards or downwards). Therefore an upper body strength-endurance test that standardized the resistance to be overcome and measured the absolute work efforts based upon the RTF performed with that standardized resistance has been sought. A widely accepted and performed test in the American football system is a RTF BP test performed with a resistance of 102.5 kg (NFL 225 test,), which is used at the NFL draft combine (McGee & Burkett, 2003). Typically these athletes have high body mass levels and an extensive history of strength and power training (eg. 2-4 years at both high school and then college) ~ consequently the resistance of 102.5 kg allows for the completion of a high number of repetitions, fulfilling the ACSM (2002) guidelines regarding strength-endurance. However as rugby league players are talent identified and recruited by clubs at a younger age (Baker, 2002), with less resistance training experience, it must be presumed that this test would not fulfill the ACSM guidelines regarding strength-endurance. For example, in the research of Baker (2002), with the exception of the NRL squad, the NFL 225 test would be too heavy for the vast majority of younger

subjects to lift even once and for the remainder of the subjects capable of actually lifting this resistance, their performance of only 1-5 repetitions would invalidate it as a test of strength-endurance. Therefore while the NFL 225 test appears to be a valid test for strength-endurance (and for an extrapolated 1RM, eg. Ware et al., 1995; Chapman et al. 1998) in the American football system, this absolute resistance is too heavy for the vast majority of rugby league players. Consequently a strength-endurance test appropriate to the vast majority of adult rugby league players is sought.

2dii. Does testing identify trends in the team grading (a measure of performance) or positional grouping of rugby league players?

The most fundamental reasons to test the physical qualities of rugby league players are for the purposes of player talent identification and to provide a guide or rationale for adjusting training to improve playing performance levels through the enhancement of physical capabilities. Therefore tests should be able to discern differences in elite and non-elite performers in a sport. As an example, Secher had rowers of international, national and club level perform a number of tests of muscle strength and function in an effort to discern which tests were most capable of discriminating between the athletes at each of these levels (Secher, 1975). Only one test, an isometric pull in the start position of the rowing stroke was capable of identifying between the oarsmen (about 10% difference in force levels between each level of oarsmen). All the other standardized tests of

muscle strength and function were virtually useless for the purposes of identifying which athletes were elite or non-elite performers.

Sechers' study has become a benchmark for researchers looking to distinguish elite or more highly performed athletes from non-elite and lesser-performing athletes and as such this type of comparative study has been utilized in a number of sports ranging from kayaking (Fry & Morton, 1991) to American football (Fry & Kraemer, 1991) and volleyball (Fry et al., 1991). The testing of rugby league players should presumably follow this basis of testing being able to distinguish better performers in the sport from lesser skilled performers. However the first published studies concerning rugby league typically reported results for only one performance level of player (Meir, 1993; O'Connor, 1996). This provides information pertinent only to that one level of performance unlike the study of Secher, where a club level oarsman could see that an isometric pulling force of 1600 N was adequate for that level of competition but levels of 1800N and 2000N would be necessary to attain national and international level, respectively. It could be said that test studies that are aimed at identifying physical differences between elite and non-elite performers should include as many levels and/or ages of athlete as possible. This would allow for the generation of a talent identification/physical performance pathway from the lowest to highest levels (LTAD).

With regards upper body testing, the first study to do so was performed by Baker (2001c), who compared NRL, SRL and CRL upper body strength, power and speed capabilities. The difference in 1RM BP strength

between the three groups was in the order of 11-14% between each level whereas for power the differences were about 10%. There was no difference in the speed test. The basic result of that study was that the heavier the resistance used in a test procedure, the greater the difference between NRL, SRL and CRL players (see Figure 4).

A follow up study performed three years later found more profound differences between the 1RM BP levels of the CRL and NRL groups, which was attributed to greater resistance training experience of the NRL groups (Baker, 2002). The high-school rugby league players in this study were obviously less strong and possessed slower movement speed as compared to the NRL and CRL players (BT P20 test). This result concerning the high-school players was of course expected and that data was in reality collected for the purposes of establishing a talent identification/physical performance pathway ranging from junior to senior high-school, to CRL and finally NRL level. The fact that upper body speed differentiated the CRL group from the NRL, which was different to the previous result (Baker, 2001c) was interesting. It may be attributed to the increasing professionalism of elite NRL players and the growing sophistication of their training whereas the semi-professional CRL training standards and practices have perhaps remained less changed.

As yet no study has been performed that compares the strength-endurance capabilities of elite players to players of a lower performance level. Consequently it is not known if strength-endurance capabilities discriminate between rugby league players of a certain level and whether

testing strength-endurance would be useful in terms of talent identification or performance enhancement. Currently some commentators in the popular media believe that due to changes in, and interpretations of, the rules of the game (eg. concept of "dominant tackle" and "surrender tackle"), strength-endurance for the upper body and high-intensity running endurance for the lower body have become the dominant physical qualities required for success in rugby league. Obviously it is of interest to attempt to determine if upper body strength-endurance had surpassed maximal strength, power or upper body speed in importance, factors that had been shown to differentiate NRL, SRL and CRL, at least to some degree, prior to the "dominant tackle" rule changes.

Player Position

Studies of American football players clearly illustrate differences in strength and power levels not only between players of different performance levels (eg, starters and non-starters) but also according to the playing position of the players (Fry & Kraemer, 1991). As rugby league entails players having certain positional grouping requirements, it is possible that some of the upper body measures could also differ in importance. Therefore, analyzing the upper body capabilities according the positional grouping of the players appears warranted. Earlier studies testing rugby league players tended to use the two basic groupings of forwards and back-lines players (Meir, 1993; Brewer & Davis, 1995). However, this dichotomy oversimplifies the matter, as within these two groups are some player's tasks that overlap or may be quite different. Later researchers such as O'Connor

and Meir et al. (2001a,b) analysed players according to their distinct positional groupings (5-9 groups) and reported some differences between groups in maximal upper body strength (1 and 3RM). Meir et al. (2001b) labeled this more finite grouping as “the players position on the team”. Meir et al. also included the standard, simplified forwards versus backline analyses off upper body strength (forwards 10% > back-line players) and strength-endurance (back-line players performed 33.65 and forwards, 31.28 repetitions in a 30-s speed push-up test). No normalization for differences in body mass were taken into account for the strength-endurance test ~ therefore it is not known if differences truly existed in absolute workload performed as would be readily observable in a test that standardized absolute workload.

However, while Meir et al. (2001b) also analysed players into four sub-groups, which were labeled as forwards (props, second row players known as the “hit-up forwards”), outside backs (centres, wingers and fullbacks), ball distributors (hookers and half-backs) and adjustables (locks and five-eighths), none of the analysed tests were of upper body functioning (only sprint and 5-minute endurance running tests were analysed). This positional sub-grouping was based on current coaching strategies at the time. However, former Australian national team coach Wayne Bennett believes the analyses or training of players should be according to three sub-groupings with the adjustables and ball-players joined as their roles are linked and inter-changeable to a large degree (Wayne Bennett, personal communication, 1995 to present). Furthermore, the “style of play” of some

players in their "position on the team" should determine which sub-group they belong to, not simply "position on the team". For example, a fullback that is used in attack like a second five-eighth should be considered to be in the adjustable/distributors group whereas a fullback who is more of a ball-runner would be considered to be an outside back (Wayne Bennett, personal communication, 1995 to present). The same situation applies to the lock forward "position on the team" ~ their style of play may enable them to be in the adjustable/distributors group or in the hit-up forward group (Wayne Bennett, personal communication, 1995 to present).

In conclusion, irrespective of how players are grouped or sub-grouped there has been no study that has compared upper body maximal strength, power, strength-endurance or speed levels between playing positions or sub-groups from different performance levels. Maximum strength, power and upper body speed have been previously been show to differentiate between different performance levels (Baker, 2000a-c; 2001a, c, d; 2002), while maximum strength has been shown to differentiate to some degree between different "positions on the team" (O'Connor, 1996, Meir et al., 2001b). Strength-endurance has been analyzed in a simple forward versus back-line player comparison with no (Meir, 1993) or only minor differences (Meir et al., 2001b) in the repetitions performed in time constrained push-up tests. Absolute work was not assessed in either strength-endurance test, so this area of analyses remains devoid of definitive data.

Given the NRL salary cap and its strict enforcement, elite rugby league clubs in Australia must now focus on talent identification and physical

performance enhancement (Wayne Bennett, personal communication 2004 to present). As such rugby league clubs seek better talent identification protocols, including establishing norms for various upper body functioning tests for players of different positional sub-groupings at different levels of team performance (eg. NRL, SRL and CRL). Consequently the purposes of some of the studies within this thesis are to establish normative data for a number of upper body tests and to determine if these tests indeed discriminate between players from different performance levels or positional sub-groupings. The upper body tests would involve mainly standard tests used previously in rugby league players such as 1RM bench press and pull-up tests to assess maximum strength; BT power tests with a resistance battery of 40 to 80 kg to assess maximum power; BT P20 test to assess upper body speed; and a new strength-endurance test, the RTF BP60 (repetitions till fatigue bench pressing 60 kg) which is based upon the well accepted NFL 225 test, but modified to utilize a lighter resistance more appropriate to assessing the strength-endurance levels of rugby league players. Study 1 will investigate whether differences exist in upper body strength, power, speed and strength-endurance for players in three different positional groupings (hit-up forwards, outside backs and ball-distributors/adjustables) x team rankings (NRL, SRL and CRL). Study 2 will investigate pulling and pressing strength differences between SRL and NRL players. Study 3 will investigate whether high intensity RTF tests can be used to accurately predict 1RM BP and PU performance in rugby league players.

Summary and Implications of the Literature Review

This review of the literature has defined various qualities of upper body muscular functioning such as strength, power, speed and strength-endurance. The neural and muscle contractile basis for force output have also been reviewed. Theoretically in a high force sport such as rugby league football it could be assumed that testing of strength and power would be extensive and that strength and power may be prominent descriptors of performance level. However there is a paucity of data concerning upper body strength testing in rugby league players and even less data exists concerning power testing. Furthermore, given recent rule changes and current game trends, some debate exists as to whether strength and power are as important as strength-endurance. Therefore the purpose of Study 1 was to determine the relative importance to rugby league playing level of tests of upper body strength, power, speed and strength-endurance. The same movement pattern for each test must be used to limit chances of potential differences being ascribed to individuals' inter-test variance. Also a comparison between upper body pushing and pulling strength was deemed necessary as most strength studies tend to focus upon pushing/pressing strength. Given the large amount of pulling that occurs in defense (pulling an opponent to the ground etc), it was posited that this measure of strength should not be neglected when assessing the strength of rugby league players (Study 2). If pulling strength was different between NRL players and lower level players, then pulling strength must addressed in the training content of these lower level players. As 1RM strength testing can be a difficult and time consuming process when dealing with a large number of athletes, especially those not greatly experienced in resistance training, a simplified version of extrapolating 1RM test scores suitable for lower level athletes was also deemed of interest (Study 3). The

results of these testing investigations should direct the training goals and content of rugby league players.

The review of neural control of force output has potentially identified a theoretical basis for some specific acute power training strategies. As power movements entail rapid muscular contractions, they rely upon finite interplay between various neural control mechanisms. If specific training variable configurations could influence this neural interplay, then conceivably power output could be enhanced. This review identified two methods of acutely favourably influencing power output ~ one through the use of alternating sets of a heavier load in the same movement with sets of the designated power training resistance (Study 4) and the other through alternating sets of an antagonist training movement with sets of the designated power training resistance (Study 5).

Hypertrophy of muscle (and/or changes in the contractile qualities of muscle) was also identified as one of the main avenues that experienced resistance trainers may use to increase maximal strength. However the high volume of training thought to favourably influence hypertrophy was also identified as not being conducive to power development. The possible deleterious effects that an acute hypertrophy-oriented training bout has upon power output needs to be investigated (Study 6).

Most resistance training studies in the literature are short-term studies (< 6 months) using college students as subjects (with little or moderate resistance training experience). How the results of any of these studies can be applied to long-term experienced resistance trainers has been questioned by a number of researchers and strength coaches alike. Furthermore the few long-term studies (up to 2-years) that exist in the literature have shown that the scope and magnitude for increases in strength and power appear to diminish with increased training experience. What the nature and scope of long-term resistance training adaptations in maximal strength and power in

experienced, professional athletes across even longer multi-year periods is a question that need to be addressed (Study 7).

In terms of Long-term Athlete Development (LTAD) ~ Is there any advantage in commencing regimented strength/power training in the latter teenage years as compared to the early twenties with regards the development of strength and power in professional rugby league players (Study 8)? This would appear to be an important question for professional coaches.

As well as the testing, intervention and long-term observation studies outlined above, this review of the literature has identified that there are acute and chronic training strategies that can affect resistance-training outcomes such as strength and power output. Consequently two papers detailing these acute and chronic strategies were published arising from this literature review.

Chapter 3. Copies of Original Papers

The papers in this thesis appear in the manner in which they were accepted for each journal. Accordingly the style of referencing, layout and structure vary due to the preferences of each journal. Due to this fact, the references for each publication must also be included at the end of each publication (and are distinct from the references for Chapter 2 - Review of the Literature). Furthermore, some small differences (eg. grammar) may exist between the versions contained below and how they appear in the journals, due to further minor alterations made by the editorial staff of each journal.

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Paper 5.

"Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. "

by

Daniel Baker and Robert U. Newton

published in the

Journal of Strength and Conditioning Research,

19(1):202-205. 2005.

Abstract

It is known that the efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength. It has also been demonstrated that weak antagonists may limit speed of movement and consequently that strengthening the antagonist muscles leads to an increase in agonist muscle movement speed. However the effect of combining agonist and antagonist muscle exercises into a power training session has been largely unexplored. The purpose of this study was to determine if a training complex consisting of contrasting agonist and antagonist exercises would result in an acute increase in power output in the agonist power exercise. Twenty-four college-aged rugby league players who were experienced in combined strength and power training served as subjects for this study. The subjects were equally assigned to an experimental (Antag) or control (Con) group who were no different in age, height, body mass, strength or maximal power. Power output was assessed during bench press throws with a 40 kg resistance (BT P40) using the Plyopower training device. After warming up, the Con group performed the BT P40 tests three minutes apart to determine if any acute augmentation to power output could occur without intervention. The Antag group also performed the BT P40 tests, however an intervention strategy of a set of bench pulls, which is an antagonistic action to the bench throw, was performed between tests to determine if this would affect acutely power output during the second BT P40 test. While the power output for the Con group remained unaltered between test occasions, the significant 4.7% increase for the Antag group indicates that a strategy of alternating agonist and antagonist exercises may acutely increase power output during complex power training. This result may affect power training and specific warm-up strategies used in ballistic sports activities, with increased emphasis placed upon the antagonist muscle groups.

Key words: reciprocal inhibition, triphasic pattern, acceleration

Introduction

It is known that the efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength or torque (7, 9, 17). This appears to be achieved by a neural strategy of enhanced reciprocal inhibition of the antagonist musculature. However, little research has been conducted examining the role of agonist and antagonist muscle interplay in power movements. The faster lifting speeds involved in power training may make it more difficult (as compared to traditional strength training) to efficiently control unwarranted co-contraction between agonist and antagonist muscle groups, potentially reducing power output (18).

It has also been demonstrated that weak antagonist muscles may limit speed of movement (22) and that strengthening of the antagonist muscles leads to an increase in agonist movement speed (16). It would therefore seem prudent to strengthen the antagonist muscles involved in the power training action or movement. One method of integrating strength and power training into a training session has been labeled as complex or contrast training (1-5, 10, 11, 13, 14, 23). Traditional recommendations for contrast loading have included the alternating of sets of heavy and light resistances in similar agonist exercises or movement patterns (13, 14, 23). This method of alternating contrasting resistances to enhance power output has been substantiated for the lower body on a number of different occasions (1, 3, 4, 14, 23). It has also been shown that heavy resistance exercises increase the concentric rate of force development while lighter, plyometric type exercises enhance eccentric rate of force development (22). This combination of effects conceivably partially explains the success of this combined method of power training. With regards to upper body complex training, only one study to date has documented any significant effects (5) with other studies reporting no augmentation to power output or performance (11, 15).

While the traditional methodology of complex power training has entailed contrasting resistances in similar agonist exercises (eg. alternating heavy and light resistances in squats and jump squats), no research exists concerning complexes of contrasting muscle actions. If some augmentation to force output occurs due to a neural strategy of enhanced reciprocal inhibition of the antagonist musculature, then contrasting strategies involving the antagonist musculature may also prove fruitful for enhancing power output. In support of this, Burke et al. (8) recently reported that a high speed antagonist contraction immediately preceding an agonist contraction resulted in increased torque during the agonist contraction (isokinetic seated bench press/pull movements). As yet it has not been determined if the effect reported by Burke et al would transfer between alternating sets of agonist and antagonist exercises in typical isoninertial resistance training.

The purpose of this study was to examine the acute effect upon power output of alternating agonist and antagonist exercises during typical isoninertial complex power training.

Methods

Experimental approach to the problem

To determine if power output generated during an exercise could be acutely affected by the subsequent performance of an antagonist exercise, an intervention study was implemented. This entailed two groups of athletes performing a Pre test of power output during bench press throws with a standard resistance. The control group would then repeat this test three minutes later to provide data pertinent to whether power output could be acutely affected without some form of active intervention. The experimental group would perform the same tests, however an intervention strategy of performing a set of an antagonist exercise of bench pulls between power tests would be implemented to determine whether power output could be acutely

affected.

Subjects

Twenty-four college-aged rugby league players who possessed at least 1 year of resistance training experience and specifically at least 6 months of contrast/complex power training served as subjects for this study. They were informed of the nature of the study and voluntarily elected to participate in the testing and intervention sessions and were divided equally into an experimental (Antag) and control group (Con). A description of the subjects is contained in Table 1.

Table 1. Description of subjects. Mean (standard deviation).

	Age (yrs)	Height (cm)	Mass (kg)	1RM BP (kg)	BT Pmax (w)
Antag (n =12)	18.7 (.65)	184.5 (6.0)	87.6 (6.8)	111.2 (6.9)	522 (43)
Control (n =12)	19.0 (1.0)	184.1 (5.3)	93.0 (9.3)	115.8 (15.1)	554 (84)

Testing procedures

Power output was tested during explosive bench press style throws with an absolute resistance of 40 kg (BT P40) using the Plyometric Power System (PPS, Norsearch, Lismore, Australia), which has been described extensively elsewhere by various authors (4-6, 18-22). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a "Smith" weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide about two

hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power output in watts (w) of the concentric phase of the bench press throws based upon the displacement of the barbell, time of displacement and mass of barbell (* gravity) data (M * G * D / T=Power output in watts, where G = gravity). Test reliability of r = 0.92 was previously established with a group of 12 subjects.

Prior to pre-testing, subjects warmed up by performing five repetitions of both the bench press (60 kg) and bench throw exercise (20 kg). After three minutes rest, the subjects performed the pre-test, which consisted of five consecutive repetitions with the investigated resistance (Pre-BT P40). Only the repetition with the highest concentric average power output was chosen and recorded for analysis. The Con subjects were Post-tested after three minutes rest. This provided data pertinent as to whether any augmentation to power output may occur without active intervention.

The experimental Antag group performed the intervention strategy of a set of a moderately heavy resistance antagonist muscle action exercise. In this case the prone bench pull with a free weight barbell was used. For this exercise, the subjects lie prone upon a special high bench with the barbell placed upon the floor directly under their chest. The subjects were instructed to pull the barbell as forcefully as possible towards their chest-abdomen region for eight repetitions. The construction of the bench prevented any impact of the barbell with the subject’s body. The subjects were allowed to virtually drop the bar to the floor to lessen any potential effect of fatigue that may have arisen from the slow or careful eccentric lowering of the barbell. This meant about a 1-2 second rest existed between consecutive repetitions as the subjects re-gripped the bar. These strategies were implemented to

ensure the athletes performed the bench pulls in manner similar to the bench throws (ie. explosively and with loss of hand contact with the bar). The resistance of the barbell for the bench pull was set at 50% of each subjects 1RM BP. This meant the subjects were bench throwing a mass of 40 kg and prone bench pulling a mean barbell mass of 56.2 kg (+ 3.8 kg). The Antag group was then retested for BT P40 three minutes after completing the intervention strategy of bench pulls.

Statistical Analyses

To determine the effect of the intervention on test occasion, a repeated measures analysis of variance (ANOVA) was used. Significance was accepted at an alpha level of $p < 0.05$ for all testing.

Results

The results are detailed in Table 2. The 4.7 % increase in the Post-test BT P40 as a result of the intervention strategy of heavy antagonist bench pulls for the Antag group was statistically significant. The power output for the BT P40 remained unchanged in the Control group between test occasions.

Discussion

The experimental Antag group increased power output as a result of the intervention of a set of antagonist bench pulls between sets of the power exercise while the power output for the control group remained unaltered. The acute increase in power output as a result of the contrasting contraction strategy gives support to the effect reported by Burke et al (8). If this augmentation to power output was due to a neural strategy of enhanced reciprocal inhibition of the antagonist musculature, then the nature of these strategies might need to be discussed to provoke further research in this area.

Table 2. The acute effect upon power output of imposing a set of antagonist prone bench pulls between sets of bench press throws with 40 kg. Mean (standard deviation).

	BT P40 power output (w)	
	Pre	Post
Antag	468 (31)	490 (38)*
Control	508 (54)	505 (59)

* denotes significantly different from Pre test occasion, $p < 0.05$

During some rapid, ballistic movements of the limbs a particular neural pattern of motor unit firing known as the triphasic or “ABC” pattern becomes evident (16). This pattern is characterized by a large “Action” burst of activity by the agonist musculature followed by a shorter “Braking” burst of activity by the antagonist musculature of the limb and finally a short “Clamping” burst again by the agonists to complete the movement. As the net force produced during a movement is a trade-off between the force of the agonists and the counteracting force of the antagonists (7, 9), then the interaction between these bursts of myoelectrical activity warrant interest. Strength training reduces the interfering effect of co-contraction between agonists and antagonists in rapid movements (16). Therefore a more efficient control of the ABC pattern may benefit the power athlete.

For example, the “maximal resistance” theory of myoelectrical augmentation (10, 11, 13, 14, 23) in agonist complex training (eg. alternating very heavy squats and light jump squats) would rely on an increase in the

“Action” burst of activity in the agonists muscles (caused by enhanced neural stimulation resulting from the very heavy squats) to facilitate the increase in power during the ensuing exercise. This would be the “post-tetanic potentiation” advocated by Gulich & Schmidtbleicher (14). However, in this study a contrasting antagonist contraction was alternated with the power exercise and hence it is not readily conceivable how this strategy could directly affect the amount of activity of the Action burst of the agonists. It is conceivable that the heavy bench pull set effected the timing of the “Braking” burst of the antagonists during the agonist power exercise. A shorter, more succinct “Braking” phase would mean that the agonist Action burst could be continued for longer into the total contraction time (16). Given that the total concentric contraction time during bench throws with this sort of resistance is only around 500-650 msec (19), then any significant increase in action time and reduction in braking time could be beneficial. Indeed Jaric et al. (16) demonstrated that increased strength of the antagonists as a result of training resulted in increased speed during ballistic elbow flexion movements. They demonstrated that the increased strength allowed for a shorter “braking” period, a greater relative acceleration period and favourable alterations in the ABC myoelectrical patterns. Some evidence also suggests that increased power output could result without increased agonist or antagonist strength if a more synchronous firing of motor units within a muscle occurred within the first 60-100 ms of the contraction (18). Conceivably, complexes of agonist and antagonist exercises may aid in these situations.

While this study illustrated the acute effect upon power output of alternating agonist and antagonist exercises during complex training, it is unknown if this effect would transfer to greater increases in power output over long term periods. Longitudinal studies of many months duration need to be performed that compare the development of power through various intervention strategies used in complex training to the more traditional straight

sets method of power training. Conceivably this agonist/antagonist strategy could also be used as a specific warm-up strategy to acutely increase power output for sports activities. For example, baseball pitchers and tennis players could alternate antagonist shoulder external rotation exercises (eg. with rubber tubing) with their agonist pitching and serving drills.

When selecting antagonist power training exercises it may be even more appropriate to choose exercises that allow acceleration for the entire range of movement. For rapid upper limb movements this could mean throwing movements alternated with rapid pulling movements, such as the top pulls and power cleans from hang/boxes. The alternating of agonist and antagonist power exercises may be area for future exploration for strength coaches.

Practical applications

While traditional contrasting resistance/complex training recommendations have focused upon the alternating of heavier and lighter resistances in exercises of similar agonist movement patterns, the alternating of agonist and antagonist movement patterns may be useful in ballistic power training. The effect of directly stimulating the antagonist musculature in a power-training complex may be to reduce the time necessary for the braking phase that occurs about halfway through the ballistic limb movement in the ensuing agonist movement. In turn, this may increase resultant force, speed and power. Practical combinations of agonist and antagonist exercises for the upper body would be bench press throws and bench pulls, bench press throws and power clean from hang or various forms of explosive medicine ball throwing alternated with explosive pulling, shoulder external rotation and elbow flexion exercises (with resistance provided by dumbells, rubber tubing, medicine balls or sports implements in some cases).

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Paper 6.

“Acute negative effect of a hypertrophy-oriented training bout on subsequent upper-body power output.”

by

Daniel Baker

published in the

Journal of Strength and Conditioning Research,

17(3):527-530. 2003

Abstract

Athletes regularly combine maximal strength, power and hypertrophy-oriented training within the same workout. Traditionally it has suggested that power-oriented exercises precede strength and hypertrophy-oriented training within a workout to avoid the possible negative effects that the latter types of training may have upon power output. However, with regards to upper body training, little study has been performed to verify this commonly held belief. The purpose of this study was to determine the extent, if any, of a high repetition, short rest period, hypertrophy-oriented training dose upon upper body power output. Twenty-seven college-aged rugby league players were tested for average power output during bench press throws with a resistance of 40 kg (BT P40). The experimental group (Hyp, n = 15) then performed a typical hypertrophy-oriented work bout (3 x 10 at 65% one repetition-maximum bench press,1RM BP) before being retested for power output with the same resistance. In comparison to the control group (Con, n = 12), whose power output remained unchanged between the Pre- and Post-test periods, the Hyp group experienced a large, significant decrease in BT P40 power output. Even after further passive rest of seven minutes, power output remained suppressed from the Pre-test values. Furthermore, the strongest five subjects experienced significantly larger percentage declines in power output than did the five less strong subjects. This study shows that a high repetition, short rest period training can acutely decrease power out. Coaches should plan the order of exercises carefully when combining power and hypertrophy training.

Key words: bench press, bench throw, fatigue, strength

Introduction

Typical recommendations have suggested that power training should precede strength or hypertrophy-oriented training within a workout or training cycle (3, 21). It is thought that these other forms of resistance training may induce some acute fatigue that could compromise power output (21). However, those who advocate complex training embrace the alternating of strength and power exercises or sets within a workout (2, 3, 4, 11, 12, 14 15). The strength work recommended within contrast/complex training is typically of very low volume (3, 11, 14), which may not have a deleterious effect upon power output and indeed has been shown to increase power output (4, 6). However, hypertrophy-oriented training is usually distinguished from strength-oriented training by a much higher training volume (21). Theoretically this higher volume of training may acutely impair power output (21). In some support of this hypothesis is the recent work of Leveritt and Abernethy (18) who reported a decrease in squat strength and isokinetic knee extension torque following a bout of mixed aerobic and anaerobic exercise.

To date few studies exist that have examined the acute effect of higher volume hypertrophy-oriented training on upper body power output within a workout, despite the seemingly commonality of the “power before hypertrophy” edict. The purpose of this study is to report the acute effects of a dose of high volume, hypertrophy-oriented training on power output during upper body training.

Methods

Subjects

Twenty seven college-aged rugby league players, who were experienced in power training, served as subjects for this study. They were informed of the nature of the study and voluntarily elected to participate in the testing and intervention sessions. Fifteen were assigned to the experimental

group (Hyp), who were to perform the hypertrophy-oriented intervention strategy, while twelve served as controls (Con). There was no difference between the groups in any of the performance tests such as One-repetition maximum bench press (1RM BP) or bench press throw maximal power output (BT Pmax) that were conducted 72 hours prior to testing. Nor was there any difference in anthropometric data. The mean ($\pm$ standard deviation) height, body mass, age, 1RM BP and BT Pmax were 182.7 $\pm$ 5.5 cm, 88.1 $\pm$ 6.0 kg, 19.1 $\pm$ 1.2 yrs, 112.8 $\pm$ 8.2 kg and 523 $\pm$ 43 W for the Hyp group and 1823.2 $\pm$ 4.5 cm, 92.4 $\pm$ 9.7 kg, 18.8 $\pm$ 1.1 yrs, 116.0 $\pm$ 15.0 kg and 560 $\pm$ 88 W, for the Con group.

Testing

Power output was tested during explosive bench press style throws with an absolute resistance of 40 kg (BT P40) using the Plyometric Power System (PPS, Norsearch, Lismore, Australia), which has been described extensively elsewhere (2-10, 19, 20, 22, 23). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a “Smith” weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide about two hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power output in watts (w) of the concentric phase of the bench press throws based upon the displacement of the barbell, time of displacement and mass of barbell (* gravity) data (M * G * D / T=Power output in watts). Test reliability (r = .92) was conducted using the Con group, who were retested after four days. Prior to pre-testing, subjects warmed up by performing five repetitions of both the bench press (60 kg) and bench throw exercise (20 kg). After three minutes rest, the subjects

performed the pre-test, which consisted of five consecutive repetitions with the investigated resistance (Pre-BT P40). Only the repetition with the highest concentric average power output was chosen and recorded for analysis.

The Con subjects were Post-tested after three minutes rest. This provided data pertinent as to whether any augmentation to power output may occur without active intervention.

The Hyp subjects performed three sets of ten repetitions of the free weight bench press exercise with a resistance of 65% of their 1RM BP, separated by a 1.5 minute rest between sets. This intervention strategy was chosen as a typical example of a hypertrophy-oriented workout. The Post-testing consisted of the athletes repeating the BT P40 test two more times (Post #1 BT P40 and Post #2 BT P40). A 1.5 minute rest period existed between the conclusion of the intervention segment (3 x 10 @ 65%1RM BP) and Post #1 BT P40 to determine the immediate effects upon power output of such a hypertrophy-oriented bout of resistance training. After five more minutes rest the subjects performed another test (Post #2 BT P40) to gauge the extent of recovery. Statistics

To determine if any difference existed between the Hyp or Con groups at any testing occasion a two-way analysis of variance (ANOVA) with repeated measures was used. To discern if absolute workload had a more deleterious effect upon power output in stronger subjects, two largely disparate sub-groups were identified. A factorial ANOVA based on each subjects absolute 1RM BP was used to identify two significantly different groups of five subjects (Strong and Less Strong). The percentage decline results for these two sub-groups were also compared using factorial ANOVA. Significance was accepted at an alpha level of $p \leq 0.05$ for all testing.

Results

The results are outlined in Table 1. All post-test scores for the Hyp

group were significantly different from each other ($p \leq 0.05$) and from those of the Con group, who remained unchanged. The intervention strategy of high repetition, short rest period, hypertrophy-oriented training had caused an acute 18% decrease in power output to be manifested 1.5 minutes after the cessation of the last intervention set. After a further five minute rest period (about seven minutes after the last intervention set), power output was still depressed by an average of 6.6%.

Table 1. Acute effect of performing high repetition, short rest period, hypertrophy-oriented training upon power output (w). Mean ± standard deviation.

	Pre-BT P40	Post-#1 BT P40	Post-#2 BT P40
Hyp group	479 ± 29	393 ± 41*	447 ± 32*
Con group	508 ± 54	505 ± 59	-

* denotes test scores significantly different to each other at all occasions

Discussion

The results detailing the deleterious effect of just three sets of hypertrophy-oriented training on power output support the common edict that power exercises should be performed before or separate from high repetition or hypertrophy-oriented training. The fatiguing effects of high repetition, short rest period training was quite pronounced and actually had a more pronounced effect than a much longer, more voluminous conditioning bout had upon muscle strength in previous research (1, 18).

Leveritt and Abernethy (18), who studied the acute effects of prior combined aerobic and anaerobic conditioning training upon squat and

isokinetic knee extension strength and Kramer et al (17), who reported large reductions in work capacity resulting from high volume, short rest period protocols, stated the source of such impairment in performance may be due to a combination muscle acidosis (high muscle lactates) or changes in the electrical/tissue properties of the muscle. Neither of these factors by themselves would appear to capable of the 18% decline in power in the current study and as such this study tends to support a multi-faceted fatigue approach. For example, as isokinetic strength can be impaired even four hours after an acute dose of such conditioning, by which time muscle acid levels should have returned to normal, then this may not be the only fatigue mechanism (1). In this study the prescribed intervention workload should not have depleted glycogen to such a level that it could account for the 18% decline in power output and the fact that power levels increased significantly after a further five minutes rest tends to support this. In light of Hakkinen's (16) research demonstrating acute “neural fatigue” within a training session consisting of multiple sets of maximal effort squats, this avenue of fatigue must also be considered. With increased rest (7 mins) there was a gravitation back towards pre-test power levels, indicating that simple rest offers some respite from the mechanisms inducing performance decrement. Simple rest may provide time for lactate clearance and neural “relaxation”, helping to restore power levels.

Another possible neural source for decreased power output may be, in part, due to the “Speed-control Theory” as enunciated by Enoka (13). The slower speed of the hypertrophy-oriented training may tune the neural system into performing the power test at a less than the normal speed, resulting in lower post-test power outputs.

An interesting observation of the results was the effect of absolute workload upon fatigue. While every subject lifted the same relative workload as the intervention strategy (3 x 10 @ 65% 1RM BP), stronger (in absolute

mass lifted) subjects performed a much higher absolute workload. To discern if this absolute workload had a more deleterious effect upon power output, two largely disparate groups of five subjects were identified, based upon absolute 1RM BP (a Strong and Less Strong group). This strategy of discerning disparate sub-groups of only 5 or 6 of the strongest or less strong subjects within a population has been performed before and yielded interesting results upon the adaptations to resistance training (6, 23). A significant difference ($p \leq 0.05$) in the degree of decline in power output from the Pre-BT P40 to the Post #1 BT P40 was observed between the Strong (24.4%) and Less Strong groups (13.1%). Thus the stronger subjects, performing higher absolute workloads for the intervention strategy (8000 kg v 6750 kg), fatigued to a significantly greater degree than their less strong counterparts. Previously it has also been shown that high-volume training accompanied by very short rest periods severely compromises work capacity in very strong athletes (17). This result would indicate that for stronger athletes, even greater care must be taken to ensure the negative effects of high repetition, short rest period training does not impact upon power training.

Practical applications

High repetition, short rest period hypertrophy-oriented training has a significant severe acute impact upon power output. This negative impact upon power output is still significant seven minutes after a mild dose (3 x 10) of such training. It could be posited that if a number of exercises were performed in such a hypertrophy-oriented training session, than the cumulative effects upon power output would be even more severe. As such it must be recommended that high repetition, short rest period training not be alternated with or performed before power training sets or exercises.

A significantly higher decline in power output was noted in the five strongest athletes, as compared to the five less strong athletes. Given that

stronger athletes perform higher absolute workloads than less strong athletes, strength coaches should be aware of the possible interfering effects that the compounding (eg. 5-10 exercises x 3 sets x 10 repetitions) of hypertrophy-oriented training may have upon power output within a session or training week. Consequently, strength coaches may need to curtail or carefully manage the hypertrophy-oriented training of their strongest athletes when in training cycles aimed at maximizing power output.

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Paper 7.

"Adaptations in upper body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes."

by

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published in the

Journal of Strength and Conditioning Research, 20(3):541-546, 2006.

Abstract

The purpose of this investigation was to observe changes in maximal upper body strength and power and shifts in the load-power curve across a multi-year period in experienced resistance trainers. Twelve professional rugby league players who regularly performed combined maximal strength and power training were observed across a four year period with test data reported every two years (years 1998, 2000, 2002). Upper body strength was assessed by the one repetition maximum bench press (1RM BP) and maximum power during bench press throws (BT Pmax) with various barbell resistances of 40 to 80 kg (BT P40-80). During the initial testing, players were also identified as Elite (n=6) or Sub-elite (n=6) depending upon whether they participated in the elite first division national league (NRL) or second division league. This sub-grouping allowed for a comparison of the scope of changes dependent upon initial strength and training experience. The Sub-elite group was significantly younger, less strong or powerful than the Elite group but no other difference existed in height or body mass in 1998. Across the four-year period significant increases in strength occurred for the group as a whole and larger increases were observed for the Sub-elite as compared to the Elite group, verifying the limited scope that exists for strength gain in more experienced, elite resistance trainers. A similar trend occurred for changes in BT Pmax. The changes in BT Pmax were highly correlated with changes in 1RM BP (r=0.75). This long-term observation confirms that the rate of progress in strength and power development diminishes with increased strength levels and resistance training experience. Furthermore, it also indicates that strength and power can still be increased despite a high volume of concurrent resistance and endurance training.

Key words: Bench press, bench throw, rugby league,

Introduction

It has been theorized that considerable gaps exist in our understanding of the long-term adaptations to resistance training due to the short term nature of most university based training studies (17, 39). Typically these training studies last 6-12 weeks and consist mainly of college students or athletes with limited resistance training experience serving as subjects (eg. 15). It has been demonstrated that the effectiveness of one program over another program may take at least 8-weeks to manifest itself (17, 28), limiting the extrapolative value of a number of studies. Furthermore, how the adaptations stemming from these shorter training studies reflect the adaptations that athletes training for many years may experience has been questioned by both experienced strength coaches and researchers alike (37, 39).

In light of these limitations Finnish researchers have garnered considerable data examining the adaptations resulting from participation in resistance training for periods longer than typically occur in American college-based studies. These studies have detailed the effects of training and detraining in periods of up to 6-months in athletes and various other population groups (19-26).

However, knowledge of long-term resistance training adaptations in elite athletes is scarce and tends to rely on cross-sectional data analysis (eg. 23). Very little longitudinal tracking data exists concerning the extent and nature of muscular adaptations resulting form prolonged resistance training over a multi-year period in elite athletes. To date only a few studies exist that track changes in maximal strength, force, power or various other muscular functioning tests across multi-year periods (16, 24, 25, 27). These studies reported that changes in muscular functioning reflect the nature of training, but also that the relative ease with which strength may be increased in novices

and those with a more limited training history is in stark contrast to the great difficulty that exists in trying to increase strength in experienced, elite strength athletes (17, 18).

Almost all of the multi-year data garnered from the above research has concerned lower body strength and power adaptations and little data exists concerning long-term upper body strength and power adaptations. The purpose of this study is to report upon the changes in upper body maximum strength and power levels as well as shifts in the load-power curve for a group of twelve highly resistance-trained professional rugby league players who performed combined maximal strength and power training for a four year period. Furthermore, the differential effects resulting from the initial resistance training experience of the athletes will also be examined.

Methods

Experimental approach to the problem

Three strength and power testing sessions conducted two years apart over four years in highly trained strength-power athletes (1998, 2000 and 2002). The subjects were professional athletes who performed combined upper body strength and power training on a regular basis. This repeated measures comparative analysis provide information pertinent to the long-term changes in strength and power output as a result of intense resistance training across a multi-year period. Differences in the extent of adaptations, based upon initial playing status and resistance training experience, would also be observed and compared.

Subjects

Twelve professional rugby league players who were experienced in strength and power training served as subjects in this investigation. All subjects were members of the same World Champion club team and underwent similar training (relevant to their playing position and individual

strength and power levels) during the four-year period. All subjects were aware of the methods and nature of the testing and voluntarily participated in the testing sessions, which were a regular part of their testing and conditioning regime. Of the twelve subjects, two disparate groups of six subjects each could be identified based upon resistance training experience and playing status at the commencement of the study. Researchers have been able to distinguish differences in the scope, magnitude or direction of adaptations to the same resistance training stimuli experienced by athletes with different starting levels of adaptation/strength (eg. 7, 8, 17, 38). These two groups were identified as an Elite group who were currently participating in the elite, first-division national league (NRL) in 1998 and had a resistance training experience entailing combined maximal strength and power training for a period of greater than three years and a Sub-elite group participating in the second division competition. The Sub-elite group was also training to become potential participants in the NRL. The Sub-elite group was younger than the Elite group and possessed a combined resistance training background of less than three years. Fortuitously, the disparate groups were matched exactly for playing position with three hit-up forwards, two outside backs and one hooker in each group. Descriptions of the group as a whole and of the two sub-groups are contained in Table 1.

Procedures

Training

Throughout the four-year period, training for the upper body was conducted on average, twice per week except in “end of season” periods where no training occurred (usually 4-6 weeks per year). The training program was periodized throughout the year with general preparation (usually 4-8 weeks per year), specific preparation (usually 6-10 weeks per year) and in-season competition (usually 24-32 weeks per year) periods. The

preparation period usually consisted of two linear periodization phases separated by a two-week transition period during the Christmas-New Year period. The general preparation phase contained only exercises that developed hypertrophy, basic strength and agonist/antagonist muscle balance. The specific preparation phase contained explosive power development exercises as well as strengthening exercises.

Table 1. Description of subjects as a whole Group (n=12) and as identified as Elite (n=6) or Sub-elite (n=6), based upon initial resistance training and playing experience in 1998. Mean (standard deviation).

	Body mass (kg)	Height (cm)	Age (years)
Group	97.8 (8.7)	186.7 (4.6)	20.2 (1.6)
Elite	95.5 (10.4)	186.3 (4.7)	21.3 (1.4)*
Sub-elite	100.7 (6.7)	187.2 (4.9)	19.0 (0.6)

* denotes significantly different between groups

In-season resistance training followed a wave-like periodization progression. The wave-like progression has been described previously (4), but briefly it entails repeating two cycles of three weeks with an additional introductory week emphasizing hypertrophy and a concluding week emphasizing peak strength and power (eight weeks in total). The first four-week block was geared slightly more towards developing basic strength and hypertrophy with a concomitant decreased volume of power exercises while the second four-week block was geared slightly more towards peaking maximum strength and power with an increased number of power exercises, increased training intensity and decreased training volume.

Within each training week, the first training day was oriented slightly more towards the development of maximal strength and the factors that affect strength (eg. hypertrophy, agonist/antagonist muscle balance) while the second training day was oriented slightly more towards the development of maximal power and other factors that affect power (eg. acceleration, rapid force development, ballistic speed). This alternating of strength- and power-oriented training days also caused an undulatory pattern (a higher load and lower load day) in the weekly periodization scheme throughout the year.

Typically upper body workouts lasted about 50 minutes in the preparation period and 30 minutes in the in-season competition period. Various other lower body (eg. full squats, jump squats, lunges, step-ups) and whole body exercises (eg. power clean, push press, jerks, 1-arm dumbbell snatches, Dominator whole body rotations) appropriate to rugby league (4) were also performed throughout the year following the same periodization scheme. Examples of how sets and repetitions were manipulated in different periods and phases are contained in Table 2.

As rugby league players cover distances of up to 10 km in each 80-minute game (30, 31), then endurance training is also of importance to the total preparation of the player. In the general preparation period, five conditioning sessions are performed each week (3 running, 1 wrestling, 1 mixed ergometry) with differing volumes, intensities and methods (continuous, fartlek, long interval, short interval). This is reduced to 2-3 endurance workouts in the specific preparation period with a concomitant increase in speed and agility training. Team tactical training sessions also entail running volumes of 2-5 km.

Table 2. Typical example of the sets and repetitions periodisation for upper body exercises for the maximal strength bench press (BP) and various assistant strength exercises (AS) and maximal power bench throw (BT) and various assistant power exercises (AP).

	General preparation		**Transition**	**Specific preparation**		
			Weeks			
	1-2	3-4	5-6	7-10	11-12	13
BP	4 x10	4 x 8	3 x 10-12	4 x 5	3 x2-3	Test
AS	3 x 10	3 x 8	2 x 10-12	3 x 8-10	3 x 5-6	
BT	N/A	N/A	N/A	4 x 5	4 x 2-4	Test
AP	N/A	N/A	N/A	3 x 5-8	3 x 3-6	

					In-season competition				
	1	2	3	4	5	6	7	8	9
BP	3 x 8	8-6-5	6-5-3	5-3-2	8-6-5	6-5-3	5-3-2	2-1-1	Test & repeat
AS	2x10	2x8	2x6	2x5	2x8	2x6	2x5	2x5	
BT	3 x 5	3 x 5	5-4-3	4-3-2	3 x 5	5-4-3	4-3-2	3-2-2	Test & repeat
AP	3x6	3x6	3 x5	3 x4	3x6	3x5	3x4	3x4	

Testing

Testing consisted of maximum upper body strength as assessed by the 1 repetition maximum bench press (1RM BP) according to the methods previously outlined (6, 7, 12). Testing of upper body maximum power (Pmax) was assessed during bench press throws (BT) using the Plyometric Power System (PPS, Plyopower Technologies, Lismore, Australia) and the methods

previously described (6-8, 13). Bench press throws in a Smith machine weight training device such as the PPS result in much higher power outputs than traditionally performed bench presses making this exercise more suitable for power testing (35, 36). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a "Smith" weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide up and down two hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average power output of the concentric phase of each bench press throw based upon the displacement, time and mass data. Specifically, each subject performed three repetitions during bench press throws with 40, 50, 60, 70 and 80 kg (BT P40, BT P50, BT P60, BT P70 and BT P80), with only the highest power output at each resistance recorded. This battery of resistances allowed for generation of a load-power profile or curve (6, 8, 13, 35), similar to what has been done before for the lower body using jump squats with various resistances (19-21). The highest power output for any individual, irrespective of the resistance, was deemed the BT Pmax.

Statistical procedures

At the initial testing occasion, two disparate groups of six subjects could be identified based upon whether they were participating in the NRL team or the second-division team. These Elite and Sub-elite groups were compared using a factorial one-way analysis of variance (ANOVA) for performance and anthropometric data to discern if any differences existed between them (See Table 1).

The results for the whole Group 1RM BP, BT Pmax and BT P40-80 were compared using a repeated measures one-way analysis of variance

(ANOVA) to determine if any of the test scores in 2000 and 2002 differed from the base-line scores of 1998. Also the test scores for the Elite versus Sub-elite group were compared for the same variables. If a significant effect of test occasion was found, Fisher Least Squares Difference (PLSD) post hoc comparisons were performed to determine which test occasions produced significantly different results. Pearson's product moment correlations were used to determine the strength of relationships between variables. Statistical significance was accepted at an alpha level of $p \leq 0.05$. Due to the low subject numbers and difficulty of performing such research on elite professional athletes no adjustment of the alpha level was made for comparison of multiple variables.

Results

The results for changes in 1RM BP for the group as a whole and according to sub-grouping are contained in Table 3. The results for changes in BT Pmax for the group as a whole and according to sub-grouping are contained in Table 4. The changes in power output with various resistances ranging from 40 to 80 kg are displayed graphically in Figure 1 for the group as a whole and Figure 2 when compared according to sub-grouping. There was a significant increase in body mass up to 100.2 +/- 9.4 and 101.7 +/- 9.0 kg for year 2000 and 2002 respectively for the group as a whole. The Elite group increased body mass significantly by about 5% from 1998 to 2000 from where it remained statistically unaltered. The Sub-elite group's increase of 3% in body mass was only significant from 1998 to 2002. There was no significant difference between the sub-groups in body mass at any period.

Table 3. Results for 1RM BP for the group as a whole and according to sub-grouping as Elite or Sub-elite presented as mean (standard deviation).

	1RM BP (kg)		
	Group	Elite	Sub-elite
1998	129.6 (15.3)*	139.2 (11.6)+	120.0 (12.7)
2000	141.0 (15.6)*	144.6 (12.7)	137.5 (18.6)
2002	148.1 (16.5)*	147.5 (13.0)	148.7 (20.1)

* denotes that Group 1RM BP were significantly different at each test occasion,
+ denotes Elite group significantly different to Sub-elite in 1998 only.

Discussion

This study details the changes in strength and power across a 4-year period by a number of athletes who were members of a World champion team and who experienced in combined strength and power training.

Changes in subjects. Over the four years all Sub-elite players progressed to become "elite" players (by participating in the NRL competition), with the team winning two Championships. Seven of the twelve also earned selection into the national team, who were the World national team champions. Essentially by 2000, there were no differences between the sub-groups in performance data. These results merely reflect the high caliber of athlete involved in this observation.

Initial strength and power levels. The initial data from 1998 detailing the differences in strength and power between the Elite and Sub-elite group are to be expected and have been reported previously not just for upper body strength and power (6-9) but also lower body power (9) and abdominal strength (5) when comparing participants in the elite professional NRL to

participants in second and third division leagues (SRL and CRL). However the upper body strength levels of both groups appears to far exceed the average that had been previously reported for large groups of professional rugby league players (32), perhaps indicating the intensive resistance training history of the twelve subjects compared to other professional rugby league players. This is to be expected when it is considered that subjects in 1998 were World Champion club team members and could be expected to be stronger than less successful counterparts.

Table 4. Results for BT Pmax for the group as a whole and according to sub-grouping as Elite or Sub-elite. Mean (standard deviation).

		BT Pmax (w)	
	Group	Elite	Sub-elite
1998	611 (80)*	666 (61)*+	555 (55)*
2000	715 (81)	727 (55)	703 (105)
2002	696 (86)	699 (82)	693 (97)

* denotes BT Pmax in 1998 significantly different to year 2000 and 2002,
+ denotes Elite significantly different to Sub-elite in 1998 only

Changes in maximal strength. While the training group as a whole exhibited a 14.3% increase in 1RM BP across four years, the Elite group only exhibited a 6.0% increase compared to the 23.9% for the younger Sub-elite group. The results of this long-term observation suggest that maximum upper body strength can still be increased in experienced strength-power athletes, however there appears to be a diminishing degree of positive adaptation with increased training experience. Training experience and existing strength levels reduce the scope for strength improvement, even if both groups follow the same program (17). This becomes even more apparent by further

examining the progress over the last two years of the observation, from 2000 to 2002. During this two year period the Elite group exhibited only a 2.0% increase in 1RM BP, similar to the amount reported by Hakkinen et al (25) for the Finnish national Olympic weightlifting squad across a two-year period. The Sub-elite group exhibited an 8.1% increase in 1RM BP during this time period, further supporting the concept of diminishing progress with increasing training experience. In reality, the Sub-elite group are two years behind the Elite group in age and training experience in 1998 and hence the scope of adaptations experienced by the Sub-elite group for the final two year period from 2000 to 2002 are similar to the first two years of the Elite group. Thus it could be posited that the progress that the Sub-elite group make in the next two year period may also only quite small.

Changes in maximal power and the load-power curve. The results for changes in maximal power (BT Pmax) largely reflected the changes in 1RM BP, with diminished progress with increased training experience. For example, over the four year period the group as a whole significantly increased BT Pmax by 14%, with the Elite group improving only 5% compared to 25% for the Sub-elite group.

Power output with all investigated resistances (40 to 80 kg) also increased significantly from 1998 to 2000 and then remained unchanged. The emphasis on combined maximal strength and power training is reflected in greater increases in the heavier portion of the load-power curve. From Figures 1 and 2 it can clearly be seen that power output with heavy resistances such as 70 and 80 kg increases far more (13.7%) than power output with resistances of 40 kg (8.7%). This was one of the objectives of the training over the 4-year period as previous research has established that BT P70 and BT P80 significantly and strongly discriminate between rugby league players who participate in the NRL versus second and third division leagues (8).

Of interest is the fact that neither group's BT Pmax or load-power curve improved over the last two years of the observation. It is not clear why this occurred, but most simply it may again reflect the limited scope for improvement in power output with experienced athletes (17, 24-26).

Relationship between changes in strength and power. It has been well established that on a cross-sectional basis, maximum strength and maximum power are highly related (6-14). The relationship may reduce slightly with increased training experience or with the direction that training takes (eg. endurance training, strength-, hypertrophy- or power-oriented training may affect the relation, 7, 8). The results of this study tend to confirm this with a slightly diminishing correlation between 1RM BP and BT Pmax ranging from $r = .85$ to $r = .81$ to $r = .78$ at the three successive testing occasions for the group as a whole.

It is interesting to note is that changes in 1RM BP significantly correlated with changes in BT Pmax across the four-year period ($r = .75$, $p = .005$), which is in almost complete agreeance with the relationship ($r = .73$) that was reported across a 19-week in-season period in college-aged rugby league players (7). This suggests that increasing maximum strength is of extreme importance to athletes who need to increase maximum power. However, given the diminishing scope for strength improvements with increased training experience and the multi-faceted nature of power (34), other avenues of increasing Pmax, such as improving movement speed, must also be considered (8). When strength begins to plateau, such as for the Elite group after year 2000, then increases in maximum strength do not necessarily equate to increases in maximum power. Other methods of training may need to be embraced to enhance power output (3, 34).

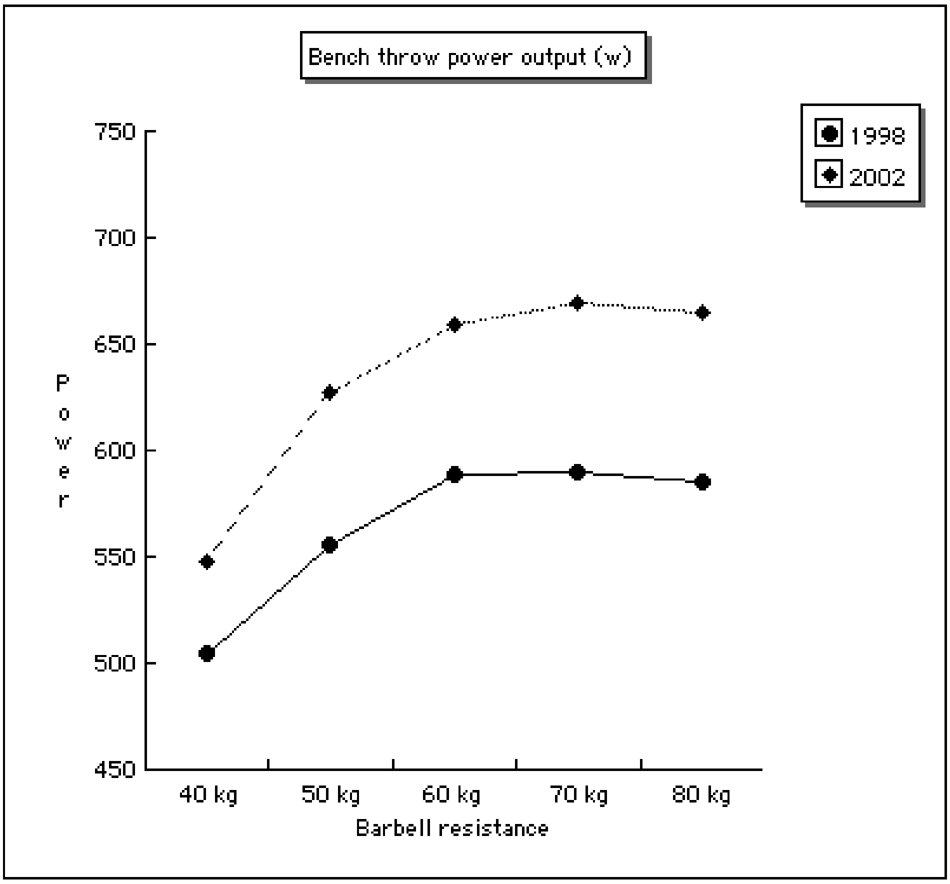

Figure 1. Shifts in bench throw load-power curve for the combined group (n=12) of rugby league players across a four-year period. All changes were significant. Because 2000 and 2002 were not different to each other, 2000 results have been omitted for clarity. SD bars omitted for clarity.

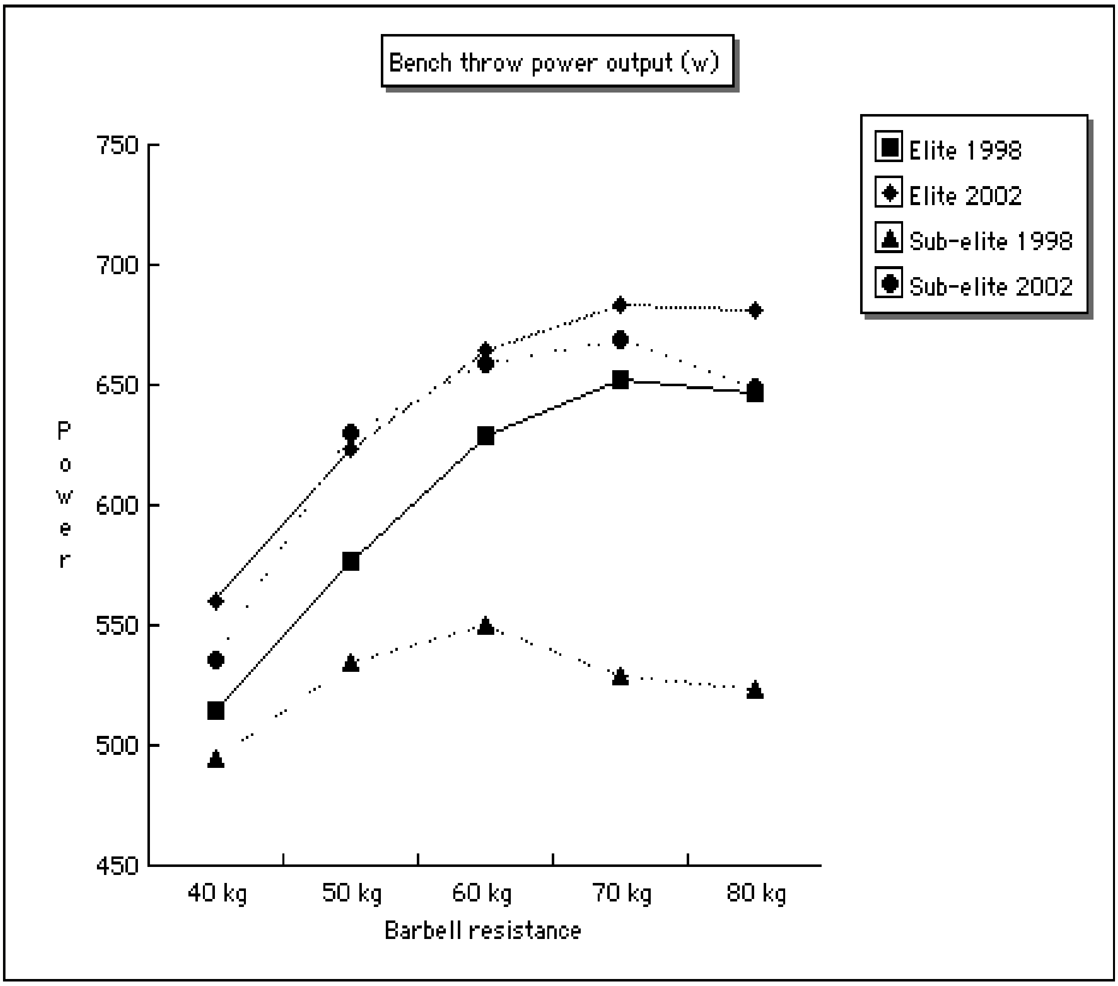

Figure 2. Shifts in bench throw load-power curve for the Elite and Sub-elite groups (n = 6 each) of rugby league players across a four-year period. All changes were significant. Because 2000 and 2002 were not different to each other, 2000 results have been omitted for clarity. SD bars omitted for clarity.

Relationship between changes in body mass and changes in strength and power. While it has been shown that changes in body mass or lean body mass largely account for increases in maximal strength in males accustomed to resistance training, especially in regards to upper body strength (12), that finding was not confirmed in this research (ns). Clearly with the experienced athletes in this study mechanisms such as neural, fiber or other morphological adaptations must have largely accounted for the changes in 1RM BP and BT Pmax rather than simple increases in body mass. The extent and nature of these adaptations is beyond the scope of discussion for this paper (see ref. 17, 18).

Concurrent strength and endurance training. This current observation has shown that the group as a whole increased strength and power by around 14% across four years, despite the large total concurrent resistance and conditioning workloads. Despite some current beliefs that strength and power cannot be improved or are severely limited when a large amount of conditioning and heavy resistance training are performed concurrently (1, 54) the results of this and other long-term observations (7, 29) emphatically illustrate otherwise.

It has been suggested previously that better conditioned athletes and more efficient periodization and sequencing of training may allow athletes to perform concurrent strength and endurance training without significant negative results (1, 7).

Practical applications

This long-term observation of changes in upper body strength and power output in experienced resistance trainers has supported the earlier findings concerning the limited scope for improvements in lower body strength and power with increased training experience.

Maximum upper body strength and power can still be increased in advanced strength-power athletes, however the degree of improvement diminishes with increased strength/power levels and training experience. The time frames over which increases in strength/power may be observed may become quite lengthy in more advanced athletes.

For advanced strength/power athletes it would appear that when both types of exercises are performed concurrently in the training regime, then statistically at least, increases in maximum strength go hand-in-hand with increases in maximum power. Based upon this result, it is recommended that coaches prescribe both strength and power exercises in a periodized fashion to maximise the muscular adaptations in multi-year resistance training.

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Paper 8

"The effects of systematic strength and power training during the formative training years: A comparison between younger and older professional rugby league players."

by

Daniel Baker

published in

Strength and Conditioning Coach.

Vol. 11, No. 2, pp.9–11. 2005.

Introduction

Maximum levels of strength and power distinguish between rugby league players of different levels (1, 2). Professional players competing in the national rugby league competition (NRL) are stronger and more powerful than those in the State leagues (SRL), who in turn are stronger and more powerful than players in city based leagues (CRL) (1, 2). This can be predominantly attributed to greater strength and power training experiences and probably some degree of natural selection.

However, of interest is a comparison between younger and older players at the NRL level. Systematic strength and power training did not gain much popularity in some NRL clubs until the early till mid-1990's. This meant that some of the current older (>28 years) NRL players may not have performed much, if any, systematic strength and power training in their formative training years (circa 16-17 up to 21-22 years). In comparison, younger NRL players (<24 years) have generally been performing such training during their formative training years.

Therefore while both older and younger groups of NRL players may possess a strength training age of greater than five years, a difference between them could be described as when this training was undertaken (eg. 17-23 years v 23-29 years of age). Thus it would be of interest to compare the strength and power results for players, matched for playing position, who could be described as having undertaken systematic strength training at a younger or older age.

Methods.

A total squad of 20 NRL players was investigated. Twelve subjects could be identified and matched into a Younger (N=6) or Older (n=6) group. These groups each consisted of three forwards and three halves/hookers players. No difference existed in body mass or height between the groups,

however the Older group were significantly older (29.5 $\pm$ 2.4 v 23.2 $\pm$ .8 yrs) and had played more NRL games (199.3 $\pm$ 42.4 v 59.8 $\pm$ 27.4).

Testing of maximum strength consisted of a 1RM bench press (1RM BP) and 1RM full squat (1RM SQ) using the methods previously described (1, 2, 3, 4, 5, 6, 7). Testing of upper body maximum power (Pmax) included a bench press throw test (BT Pmax) with various barbell loads using the methods previously described (1, 2, 6). Testing of lower body power output consisted of a jump squat (JS Pmax) test with various barbell loads using the methods previously described (3, 4,7).

The results for each group were compared using a one-way analysis of variance (ANOVA) to determine if differences existed between the groups in 1RM BP, 1RM SQ, BT Pmax or JS Pmax. In the event of a significant F-ratio, Fisher PLSD post hoc comparisons were used to determine where these differences existed. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The results for all tests are contained in Table 1. The Younger group was significantly stronger and more powerful than the Older group in all of the four tests. For lower body tests the magnitude of the difference was 19% for both tests, while for the upper body the percentage differences were 13% (1RM BP) and 28% (BT Pmax).

Discussion

This study compared two groups of players who were matched for playing position and had basically performed the same training for four to five years previously, but were differentiated by only two factors (apart from age). These factors were (1) total NRL games and (2) the age that they had commenced and/or consistently performed systematic strength and power training. The basic finding was that the group that commenced systematic

strength training during their formative training years (circa 17-23 yrs) were significantly stronger and more powerful in both the upper and lower body, despite no significant difference in body mass or height, than the group who had commenced such training at a later age (>23 yrs). Why these large difference existed in strength or power must then be ascribed as due to some aspects related to either of these two factors listed above.

Table 1. Strength and power testing results for the Older and Younger NRL players. Mean ± standard deviation.

	1RM BP	1RM SQ	BT Pmax	JS Pmax
Younger	143.3 ± 15.4	182.5 ± 23.6	670 ± 78	1881 ± 254
Older	126.7 ± 7.5*	153.3 ± 12.1*	548 ± 48*	1579 ± 197*

* denotes statistically difference between groups.

Whilst the total number of professional NRL games would be expected to impact upon the integrity of the neuromuscular system (through the accumulation of playing and training injuries etc), which in turn may negatively affect strength and power, it is arguable that this alone could not explain the magnitude of the differences between the groups. What effect (either negative or positive) an extra 130 games (5-6 seasons) would have upon strength and power is impossible to determine. Furthermore, recovery methods used after games and during the training week are now far more professional than six or more years ago. Therefore this discussion will focus more upon the impact that commencing strength and power training at an earlier age may have had upon the results.

This analyses is unique in that a situation may not exist again whereby players from the same football club can be compared based upon what age

they commenced systematic strength and power training. It is inconceivable that a situation will ever exist again whereby players may play a number of seasons of NRL level without performing systematic strength and power training, as was the case in the early 1990's, making a another comparison like this unlikely. This is due to increased player professionalism and the greater role played by strength and conditioning coaches in the physical preparation of players.

Basically both groups had performed the same training for four to five years prior to this analyses, but were differentiated by at what age this training commenced. With the advent of the "super" professionalism (i.e. the Super League wars and the ensuing explosion in player payments in the mid-1990's), coaches demanded greater training commitments from players. Previously players generally trained 2-3 times per week with strength training not being compulsory and rarely performed in-season. Thus the Older group of players in this study participated in this type of regime during their formative training years prior to the mid 1990's.

In opposition to this, the Younger group of players in this study was in their formative training years (17-23 yrs) from the mid-1990's till now. This period has entailed four strength and power sessions per week during the pre-season and two per week during the in-season for all players in this study. So despite similar recent training dosages since late 1995, the Younger group displayed greater strength and power.

From international powerlifting records (IPF, 2000), it can be shown that the world records for athletes older than 23 yrs are greater than those for athletes younger than 23 yrs. Generally strength levels do not peak or at least begin to decrease till about 30-35 years of age (10). Therefore the gross affect of simply being older by about five years could not explain the differences reported in this study.

Thus it appears that performing systematic strength and power training from about ages 17-18 onwards will be of greater benefit than commencing this training at a later training age. This may be due to the effect that such training has upon the still maturing neuromuscular system of athletes of this age. Performing strength and power training at such an age may lead to more lasting positive adaptations within the neuromuscular system. This “value adding” effect of training at age 17-18 onwards may gradually dissipate as the athlete ages (into their early to mid-20’s). It is not known exactly what this “value adding” of the neuromuscular system may be, but it is worthy of future longitudinal study.

Conclusions and practical applications

Commencing systematic strength and power training during the formative training years appears to be advantageous as compared to commencing training at a later stage. This may be due to a “value added” effect that such training may have upon the still maturing neuromuscular system. It is recommended that rugby league players commence strength and power training whilst still in their teenage years, although at this stage it is not known if starting at an even earlier age (circa 14-15 years) would be even more advantageous than commencing this type of training at 17-19 years of age.

Balyi (8) has outlined different stages of the long-term development of the athlete and has commented upon the importance of physical preparation in the “training to train” or formative training age. This analyses tends to support that view.

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Paper 9.

"Methods to increase the effectiveness of maximal power training for the upper body"

by

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published in the

Strength and Conditioning Journal

27(6):24-32. 2005.

Introduction

A cursory glance at many resistance training programs or recommendations aimed at increasing muscular power would typically reveal a high proportion of Olympic weightlifting (eg. power cleans, pulls) or plyometric exercises (eg. jumping, bounding) (3, 19, 21). While these methods of training often produce tremendous increases in lower body power, methods for developing upper body power appear less explored. Maximal upper body pressing/pushing power is of importance to both American and rugby football players and as well as boxers and martial artists to enhance the ability to push away/strike opponents. The purpose of this article is to outline some practical methods that have been implemented in our program to develop maximal upper body pressing power in rugby league players. Astute coaches will be able to determine the relevance and application of these concepts and methods to the broader area of athlete preparation for other sports.

Maximal power (Pmax) for the purpose of this paper is defined as the maximal power output for the entire concentric range of movement/contraction (peak power refers to the highest instantaneous power output for a 1-msec period within a movement) (5-10). Upper body pressing Pmax is usually determined by measuring power output during lifting of a number of different barbell resistances in a designated exercise (eg. bench press, BP or bench throws, BT, in a Smith machine) using the Plyometric Power System software (PPS, see 5-10, 25, 26) or other software or testing modalities. The load-power curve or profile (see Figures 1 and 2) that is generated for each individual from this testing can aid in prescribing training (5-10). For example, an individual whose load-power curve was characterized by high power outputs with light resistances but also exhibited pronounced reductions in power output with heavier resistances would be prescribed more maximal power-oriented and heavy resistance strength training. Maximal strength has

been shown to be highly correlated to Pmax in both the upper- (5-10) and lower-body (11) for both elite and less experienced athletes. As the relationship between an individuals change in Pmax and change in maximal strength as a result of training is much higher in less experienced athletes than it is in elite athletes (6).

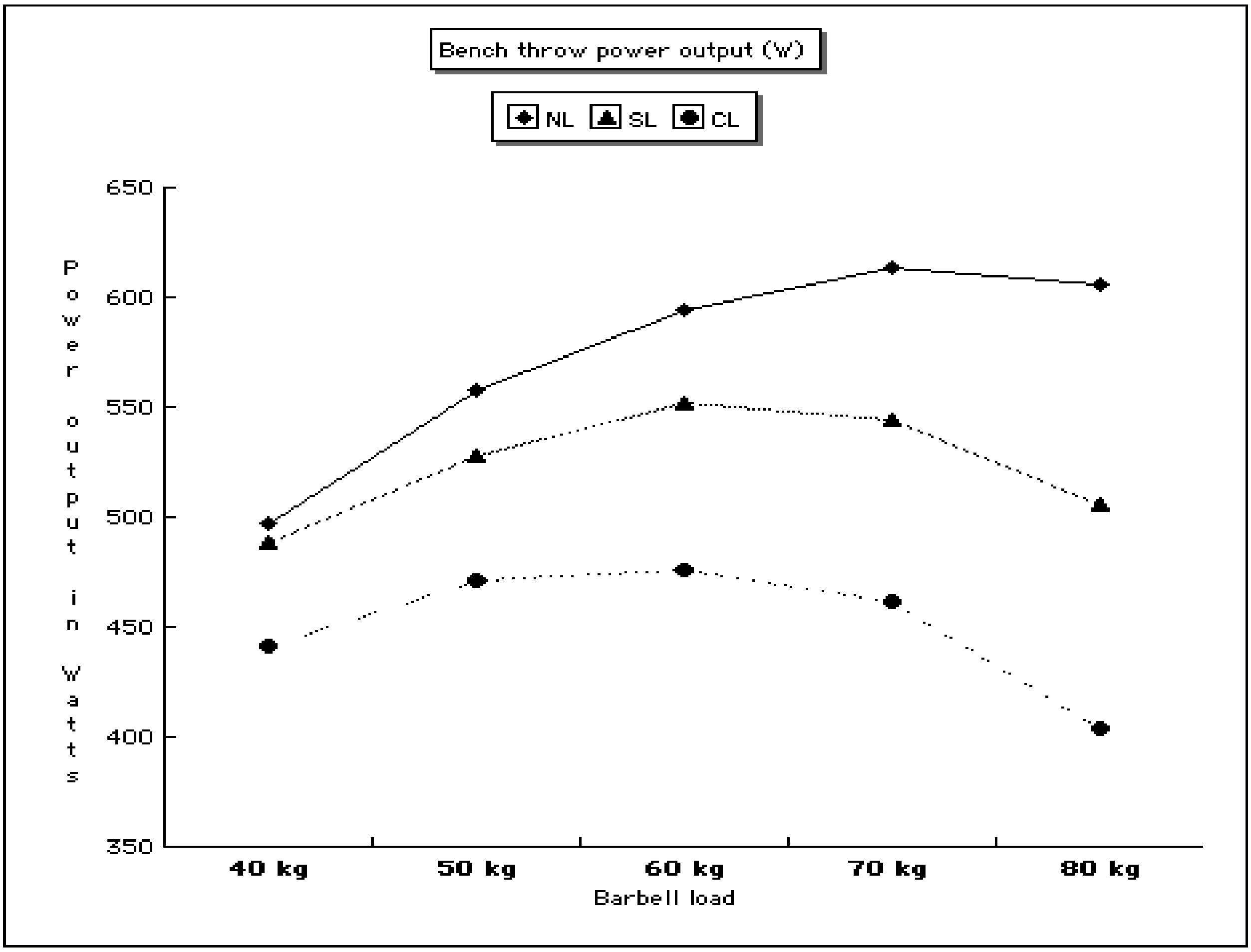

Figure 1. Load-power curves (average concentric power) for rugby league players participating in the professional National Rugby League (NL), or college-aged state leagues (SL) or city based leagues (CL). From reference 7.

However, as maximum strength is the physical quality that most appears to underpin Pmax, it is advisable that athletes who wish to attain high Pmax levels develop and/or maintain very high levels of strength in muscle groups important in the sport in both agonist and antagonist muscle groups. The strength of the antagonists should not be neglected for athletes who require rapid limb movements as research has shown that strengthening of agonists increases both limb speed and accuracy of movement due to favourable alterations in the neural firing pattern (22). It has been shown that some power training practices described below are only effective for stronger, more experienced athletes (14, 28). Once a good strength and muscle conditioning base has been established the following practices will be most useful.

1. Include full acceleration exercises as power exercises

It is important to differentiate exercises as being used primarily for the development of strength (or hypertrophy, depending on sets, reps, rest periods etc) or power. What differentiates between these two classifications of strength or power exercises is whether the performance of the exercise entails acceleration throughout the range of movement, resulting in faster movement speeds and hence higher power outputs (23, 25-27). Power exercises are those exercises that entail acceleration for the full range of movement with resultant high lifting velocities and power outputs. Strength exercises are those exercises that entail heavy resistances and high force outputs but also pronounced periods of deceleration resulting in lower lifting velocities and reduced power outputs (26). Performing an exercise where acceleration can occur throughout the entire range of movement (such as a bench throw in a Smith machine, see Figure 3, medicine ball throws, power pushups etc) allows for higher lifting speeds and power outputs (23, 25, 26). If athletes attempt to lift light resistances explosively in traditional exercises

such as bench press and squats, large deceleration phases occur in the second half of the movement, resulting in lower power outputs as compared to power versions of bench throw and jump squats (26, 27). Thus a heavy resistance bench press is considered a strength exercise whereas the bench throw is considered a power exercise.

Training to maximise upper body pressing/pushing power should entail both heavy resistance, slower speed exercises for strength development and exercises that entail higher velocities and acceleration for the entire range of movement for power development (eg. bench throws, medicine ball chest passes, plyometric pushups and other throwing exercises, ballistic pressing/pushing exercises) (3, 7). This approach should result in the musculature being to contract both forcefully and rapidly.

2. Alter the kinetics of some strength exercises to more favorably affect rapid-force or power output

Because heavy resistance strength exercises such as bench press typically entail slow movement speeds and low power outputs (23, 26), they alone are not specifically suited to developing Pmax (23). This phenomenon has been the subject of considerable research attention. There are power specific adaptations in terms of the neural activation, muscle fiber/contractile protein characteristics and muscle architecture (12) that must be considered. As discussed above, attempting to lift light resistance bench presses explosively also results in large deceleration periods (26). However, there are a number of strategies that the strength coach can implement to alter the force profile or lifting speeds of strength exercises to make them more suitable to rapid-force development.

For example, the performance of the bench press can be modified by adding chains to the end of the barbell to alter the kinetics of the exercise so that the acceleration phase can be extended further into the range of

movement. When the barbell is lowered to the chest, the chains are furled on the floor and only provide minimal resistance (see Figure 4). As the barbell is lifted, the chains unfurl and steadily increase resistance throughout the range of motion (see Figure 5). This method means that a lighter resistance (eg. 50-75% 1RM) can be lifted explosively off the chest but as the additional resistance (+10-15% 1RM in chains) is added by the constant unfurling of the chain links off the floor, the athlete can continue attempting to accelerate the bar but it will slow due to the increasing mass, rather than the athlete consciously reducing the push against the barbell. This alters the kinetic profile of the strength exercise to become more like a power exercise (acceleration lasts longer into the range of motion). A similar strategy is to use rubber tubing resistance (power bands) on the ends of the barbell to increase resistance throughout the range of motion. In this case the athlete pushes upward in the bench press and stretches the large rubber bands attached to each end of the barbell. The higher into the range, the more stretch and so the greater the elastic resistance. Similar to the chains example, this allows the athlete to explode upwards and continue to apply high force much later into the movement.

Another strategy is the use of Functional Isometric (FI) training (23). A FI exercise can be performed for the top half of a movement in a power rack or Smith machine, altering the force characteristics considerably (23). Other methods of altering the kinetic profile include partial repetitions in the top half or maximal force zone of the lift (24). Weighted adjustable hooks (periscope type design) that are constructed to fall off the barbell when the base of the apparatus contacts the floor during the lowest portion of the bench press can also alter barbell kinetics within a repetition. Their use allows for heavier eccentric and lighter concentric phases, conceivably resulting in enhanced concentric lifting velocities. The use of chains, power bands, FI, partials, hooks and other devices to alter the resistance/force production (and

acceleration) throughout the barbell trajectory and particularly the end of the range of movement (so that it more closely mimics power exercises) can be basically applied to any free weight barbell exercise used in upper body training.

3. Use complexes of contrasting resistances or exercises

A method of training where sets of a heavy resistance strength exercise are alternated with sets of lighter resistance power exercises is known as a complex (14-18, 28) or contrast training (1, 7, 14). This type of training has been shown to acutely increase explosive force production or jumping ability when implemented for lower body power training (4, 14, 18, 28), presumably through stimulating the neuro- or musculo-mechanical system(s) (14, 18, 28). Recent research also illustrates it is effective for acutely increasing upper body power output (1). This research found that bench presses with 65% 1RM alternated with bench throws (30-45% 1RM) resulted in an acute increase in power output (1). An agonist-antagonist complex may also warrant consideration from the coach as speed of agonist movement may be improved in these situations (13, 22). Thus a strength coach has a choice of implementing agonist strength and power exercises or antagonist and agonist strength and power exercises in a complex to increase power output.

It is recommended that if upper body resistance training is performed twice per week, then one day of the training week could emphasize strength development with heavy resistance training and another training day emphasize power development with training complexes alternating contrasting sets of light resistances (30-45% 1RM) and medium-heavy resistances (60-75% 1RM) (1, 7).

4. Periodize the presentation of power exercises and resistances

Many authors have suggested the periodization of resistance training exercises to enhance power output (7, 19). While prescribing resistances in a periodized manner is not a novel idea in relation to training for power as has traditionally been used with Olympic weightlifting style exercises, it has not been fully utilized for simpler, upper body power exercises such as the bench throw. Baker has previously suggested that the resistances used for the upper body (or lower body jumping) power exercises be periodized (7) to effectively stress the multi-faceted nature of muscle power (19). Four power training zones and their analogous strength training zones are outlined in Table 1. Across a training cycle the power training resistances can progress from lighter resistances where technique and ballistic speed are emphasized to the heavier resistances that maximize power output (about 50% 1RM = 100% Pmax). Table 2 details the last four weeks of an elite athletes bench press and bench throw training cycle aimed at simultaneously maximizing strength and power output. The progression in power training resistances (from 40 to 80 kg in bench throws) and concomitant increase in power output from 573 to 755 W can be seen.

If coaches don't have access to technologies that can measure the actual Pmax and the resistance at which it occurred, it is recommended assuming 50-55% 1RM BP for most athletes, 45%1RM BP for very strong athletes (eg. 1RM BP = >150 kg) and greater than 55 % 1RM BP for less experienced or strong athletes (7). This means that a resistance of 50% 1RM BP equals 100% Pmax (and hence this resistance is the Pmax resistance).

It is important to note that, for example, training with a 50% Pmax resistance does not mean the athlete will attain only 50% of their maximal power output. For example, from Table 2 it can be seen that the athletes Pmax resistance is 80 kg for bench throws, but that 40 kg, representing 50% Pmax resistance, actually allows for the athlete to attain a power output of 76-78% of the maximum. During week 2, training with a resistance of 50 kg

(representing 63% of his Pmax resistance of 80 kg) allowed the athlete to attain power outputs of around 600 w or 80% of maximum. Therefore an athlete can attain very high power outputs at lower percentages of the Pmax resistance. Because of the plateauing of power output around the Pmax (see Figure 1), it can be seen that the use of resistances of around 85% or more of the resistance used to attain Pmax will usually result in the athlete training at or very close to Pmax (eg. 70 kg in Table 2 = 84 % Pmax resistance but results in power outputs of up to 96% Pmax).

Table 1. Zones of intensity for strength and power training, modified from reference 7.

	Type and / or goal of training of each intensity zone	
	Strength	**Power**
Zone 1: < 50% *	General muscle & technical	General neural & technical (< 25 % 1RM)
Zone 2: 50-75%	Hypertrophy training	Ballistic speed training (25 - 37.5 % 1RM)
Zone 3: 75-90%	Basic strength training	Basic power training (37.5 - 45 % 1RM)
Zone 4: 90-100%	Maximal strength training	Maximal power training (45 - 55 % 1RM)

* For strength, percentage of maximum refers to 1RM (100%). For power, 100% = Pmax resistance (circa 45-55% 1RM if exact Pmax resistance not known). Equivalent percentage ranges based upon 1RM are included in brackets for cases where exact Pmax resistance is not known.

5. Use low repetitions when maximizing power output

Low repetitions are necessary to maximise power output. High repetition, high workload, hypertrophy-oriented training acutely decreases power output (2) and should not precede or be combined with maximal power

training. It would appear important to avoid fatigue when attempting to maximise power output and a simple method for achieving this is by using low repetitions for power exercises (and obviously ensuring the appropriate rest period is utilized).

Anecdotal evidence from training hundreds of athletes with the PPS shows that power output markedly decreases after three repetitions when using resistances that maximize power output (around 45-50% 1RM BP) during the BT exercise. Based on this evidence, for power exercises it is usually recommended that only 2-3 repetitions be performed when training in the maximal power zone, 3-5 in the general power and ballistic power zone and higher repetitions (eg. 8-10) are only performed when using lighter resistances in the technical/neural zone (learning technique or warming up).

6. Use "clusters", "rest-pause" or "breakdown" techniques for some strength or power exercises

To increase force output, velocity and reduce fatigue within a set, some specific methods have evolved over the years (23). Recent research indicates that, compared to the traditional manner of performing repetitions, force or velocity can be increased when repetitions are presented in clusters (20) or by using the "rest-pause" or "breakdown" methods (23). Clusters are a method whereby a set of higher repetitions is broken down into smaller "clusters" of repetitions that allow a brief pause between performances of these clusters. For example, eight repetitions can be performed as four clusters of two repetitions with a 10-second rest between clusters. The rest-pause system is essentially similar but typically entails the breakdown of a lower repetition set (for example, 5RM) into single repetitions with a short pause (for example, 2-15 secs) between repetitions. A "breakdown" (aka "stripping") set consists of small amounts of resistance being taken from the barbell during short pauses between repetitions. This reduction in resistance

to accommodate the cumulative effects of fatigue results in a decreased degree of deterioration in power output across the set as well as increased force in the initial repetitions as compared to the traditional manner of lifting a heavy resistance (23).

7. Use an ascending order of resistances when maximizing power output

Whether the resistances are presented in an ascending (working up in resistance) or descending (working down in resistance) order during power training has been cause of some debate (7). A recent study examining the effects of ascending or descending order on power output during bench throws reported that an ascending order resulted in the highest power output during BT (7). It was also recommended that an ascending order of resistances with the inclusion of a lighter "down set" may be an effective method of presenting power training resistances.

Rest periods

The rest period between sets or even repetitions will depend upon the objective of that set, the number of repetitions being performed, the intensity of the resistance, the type of exercise, the training state of the athlete and the periodization phase. When the objective of the set is maximise the power output that can be generated with the selected resistance, the rest period between sets of a power exercise should be one to two-minutes or as is long enough to ensure that the objective is met. When performing a complex of a strength and power exercise, anecdotal evidence suggests a four-minute turn-around period (eg. set of bench press then 90 s rest, set of bench throw then 120 s rest before repeating complex) has been shown to be adequate as evidenced by the power outputs measured by the PPS. Shorter rest periods (eg. < 1-minute between sets of a power exercise or < 3-minutes for a

complex) result in reduced power outputs, diminishing the effectiveness of the entire power-training process.

Long term progress

Maximal upper body pressing power can still be quite readily increased over the long term even in advanced trainers. Changes in the load-power curve for a group of twelve elite rugby league players as well as the individual progression of one young rugby league player (player X) across a four year period is depicted in Figure 2 (9). It is clear that even for advanced trainers such as this group that progression can still be quite pronounced, especially in power output against heavier resistances. The load-power curve for the group as a whole as well as for player X has shifted upwards and slightly towards the left. From the graph it is visible that while power output generated while lifting a resistance of 40 kg (BT P40) changes only slightly, power outputs with heavier resistances of 60-80 kg increased markedly, a favourable situation considering the strong relation between high power outputs generated while lifting 70 and 80 kg in the bench throw exercise and progress into the elite professional rugby league ranks (7). As power output with lighter resistances improved relatively less than power output with heavier resistances, it is obvious that increases in strength rather than speed accounted for the majority of change. Statistically Pmax is more related to maximal strength rather than speed in these athletes (7).

During this time player X progressed from playing in the city-based leagues into the ranks of the full-time professional national rugby league. His BT Pmax increased 39%, from 603 w to 836 w while his 1RM BP increased from 135 to 180 kg (33%) at a relatively constant body mass of 110 kg. For the group of twelve subjects as a whole, the BT Pmax increased from 611 w to 696 w. This 14% increase appears to be underpinned by a similar change of 14.3 % in 1RM BP (from 129.6 to 148.1 kg) (9). From this evidence it would

appear that the concept of combining maximum strength and power training, using the methods outlined above, can result in enhanced upper body power output over long-term training periods.

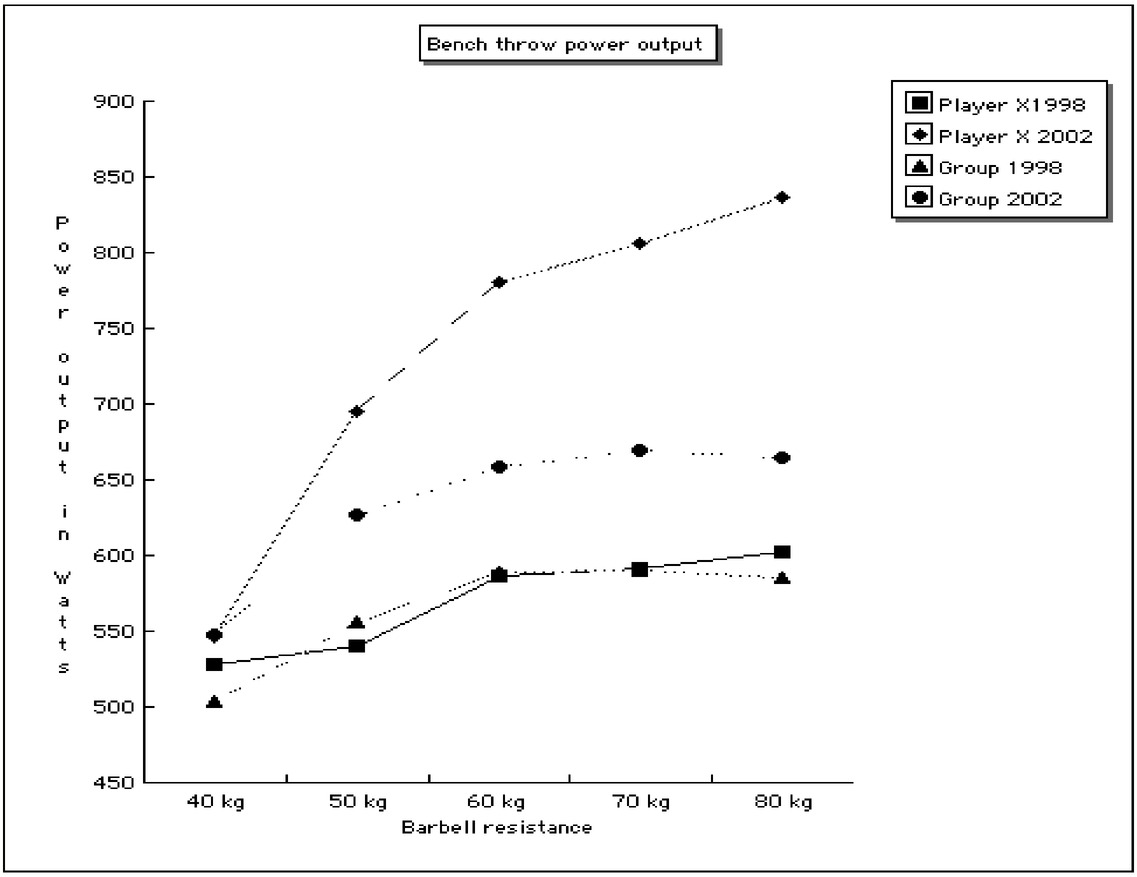

Figure 2. Change in the upper body bench throw load-power curve (average concentric power) across a four-year period in a group of twelve professional rugby league players as well as for one individual who made considerable progress (player X). The change in 1RM BP appears to underpin the change in BT Pmax during this time. From reference 9.

Practical applications

A number of practical methods used for increasing the effectiveness of upper body power training have been presented. It is not necessary to use all of these methods at one time to effectively develop maximal upper body pressing power. However, it is not difficult to implement a number of these methods simultaneously either. For example, a bench press and bench throw workout to maximize pressing power that entails six methods: full acceleration exercise; kinetically altered strength exercise; contrasting resistance complex; low repetitions; ascending order of resistances for the power exercise; and clustered repetitions is detailed in Table 3. Variation and periodization should influence if, when and how, any of these strategies are implemented.

This paper has addressed mainly the training for maximal power production and especially may be of value for athletes who must overcome large external resistances such as the body mass of opponents (eg. football, rugby league and union, wrestling, judo, mixed martial arts). Athletes who require a greater speed contribution rather than pure strength contribution in their power production (eg. boxing and related martial arts, tennis, javelin) may need to modify their training accordingly and their load-power curves would reflect this by perhaps showing increased power output with lighter resistances of 10-40 kg. However, many of the methods described above would be applicable to many sporting situations and it is the job of the astute coach to modify and implement them accordingly.

Table 2. Actual sample training content for bench press and bench throws across the last 4-weeks of a pre-season strength-power training cycle for an elite professional rugby league player. Testing occurred in week 5.

		Weeks				
		1	**2**	**3**	**4**	Test Pmax
Bench throws						
D1	Power	573 w	599 w	696 w	683 w	755 w
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 70 kg	@ 80k
%BT Pmax		76	79	92	91	100 %
D2	Power	588 w	605 w	722 w	746 w	
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 80 kg	
%BT Pmax		78	80	96	99	
Bench press						1RM BP
D1	Wt	130 kg	135 kg	140 kg	150 kg	=170
	SxR	3x5	3x5	3x5	3 x 3	
% 1RM		76.5	79.4	82.4	88.2	100%
D2	Wt	105 kg	110 kg	125 kg*	125 kg*	
	SxR	3x5	3x5	5 x 3	5 x 3	
% 1RM		61.8	64.7	73.5	73.5	

W = power output in watts, Wt = resistance in kilograms, SxR = Sets x Repetitions, D1 = Heavier, strength-oriented training day with BP performed before BT. D2 = Medium-heavy, power-oriented training day consisting of contrasting resistance complexes (alternating sets of BP & BT, same sets and repetitions). Denotes 110 kg barbell load plus 15 kg in chains attached to the sleeves of barbell. See text for a description of this bench press + chains exercise. Grip width was altered to a narrower grip for all D2 BP workouts.

Table 3. Sample workout for combined bench press and bench throws on a power-oriented training day during the peaking maximum strength/power phase for an athlete possessing a 1RM BP of 130 kg.

		1	2	3	4
	Sets	1	2	3	4
	Wt (kg)	40	50	60	70
1a. Bench throws (Smith machine)	Reps	5	4	3	3
	Wt (kg)	60	100*	100*	100*
1b. Bench press + chains*	Reps	5	1,1,1	1,1,1	1,1,1

1a, 1b. = Alternate exercises as a contrast resistance complex.
* = 85 kg barbell resistance + 15 kg in chains attached = 100 kg resistance at lockout.
1, 1, 1= 3-rep cluster sets, rest 15 secs between each clustered repetition.

Paper 1.

" Analyses of tests of upper body strength, power, speed and strength-endurance to describe and compare playing rank in professional rugby league players."

by

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was published in the

International Journal of Sports Physiology and Performance

1(4):347-360, December 2006

Purpose: The purpose of this study was to examine the upper body strength, speed, power and strength-endurance capabilities of rugby league players of different playing rank. This data would provide information pertinent to the importance of upper body strength, power, speed and strength-endurance for different grades of rugby league and for positional groups within those different grades in professional rugby league players.

Methods: Sixty rugby league players, comprised of 20 participants each in the elite, national first-division league (NRL), state-based second division league (SRL) and intra-city third division league (CRL), served as subjects in this investigation. Maximal upper body strength, power, speed and muscle endurance were assessed using the bench press exercise.

Results: The NRL players were significantly stronger (141.4±15.4 kg) than SRL (126.6±13.1, ES=1.033) and CRL players (108.1±11.6, ES=2.458) and more powerful (NRL=680±99 W, SRL=591±72, CRL=521±71, ES=1.037 and 1.867, respectively) than other players. The differences in speed (NRL=345±31 W, SRL=319±29 and CRL=303 ±29 (ES=0.884 and 1.409 respectively) and strength-endurance (NRL=36±7 reps, SRL=32 ±7 and CRL=24±5, ES=0.521, ns 1.984, respectively) were generally not as pronounced.

Conclusions: The results of this investigation illustrate that of the tests undertaken, maximal strength best describes those players who attain NRL ranking. Maximum power and strength-endurance were also strong descriptors of attainment of NRL level. Upper body speed appears less likely to strongly discriminate between those players who attain NRL and those who

do not. These results tended to hold true across the different positional groupings within the team.

Key Words: speed, power, strength, endurance, football

Introduction

Rugby league is a collision-sport played world-wide and in particular is popular in Australia, New Zealand and Great Britain. A rugby league team each consists of 13 players participating on the field (six forward-line and seven back-line) as well as up to four interchange players (of mixed positional groupings). At the professional level, the game is typically played over two 40-minute halves separated by a 10-minute rest interval. Success in rugby league football appears heavily reliant upon the players possessing an adequate degree of various physical fitness qualities such as strength, power, speed and endurance as well as the individual skill and team tactical abilities[1-3]. In particular, upper body strength, power, speed and endurance would appear to be of importance due to the large amount of tackling and grappling that occurs both in attack and defense during an 80-minute game. It has previously been established that maximum strength and power levels could distinguish between players participating in the elite national first division league and players participating in second- and third-division leagues[4-9]. Furthermore, a test of upper body speed distinguished between players participating in these professional leagues from younger high-school players[7]. Other previous work also illustrated differences in strength between high school and college-aged (17-21 yrs) rugby union and rugby league players[6, 9].

There is scant research investigating upper body endurance in rugby league players. The studies listed above illustrated the importance of maximum strength and power but did not investigate strength-endurance as an outcome measure. Recent changes in referee interpretations, coaching

strategies and game play have conceivably increased the importance of upper-body strength-endurance. For example, previously only 1-2 defending players would generally commit to a tackle and then, as stipulated by the rules, quickly move away from the tackled player. This meant a high level of maximum strength and power would be required by those 1-2 defending players to quickly halt the forward momentum of the attacking player. Since circa 2001 the concept of a “dominant tackle” has been promoted by some coaches and commentators and is now interpreted by referees throughout the game. This has had the effect of increasing “gang tackles” and “grapple tackles” whereby 4-5 defenders attempt to take extra time to halt the forward momentum of the attacker and “wrap up” the ball to stop the attacker unloading the ball to further promote the attack. This has had the effect of increasing the number of tackles each player may be involved in during a game, but these tackles may require less strength and power effort per tackle than prior to 2001. This situation has led many commentators in the popular media and coaches to ascribe to the theory that high levels of upper-body strength-endurance and lower body running endurance (elite rugby league players can cover distances of up to 10 km in an 80-minute game, [1]) are now the main physical requirements needed by rugby league players who aspire to reach the highest levels of competition.

The purpose of this study was to compare the upper body strength, speed, power and strength-endurance capabilities of selected rugby league players participating in the elite, national first-division (NRL), state-based second division (SRL) and intra-city third division (CRL) rugby league

competitions. In addition, a further analysis by positional grouping was also performed, similar to that of Meir et al [2]. This data and analyses would provide information pertinent to the importance of upper body strength, power, speed and strength-endurance for different grades of rugby league and for positional groups within those different grades in professional rugby league players. In particular whether upper-body strength-endurance, as measured in this investigation, had become the dominant upper body physical quality (rather than maximum strength or power) that separated NRL players from SRL and CRL players was of interest.

Methods

Subjects

Sixty rugby league players, comprising twenty full-time professionals participating in the elite first-division National Rugby League competition (NRL), as well as twenty semi-professionals each participating in a second division State League (SRL) and third-division intra-city league (CRL) served as participants in this investigation. All were members of the same football club and performed the same resistance training relative to their different playing positions, and individual strength levels under the same resistance training coach to ensure homogeneous exercise technique development occurred across the different squads. Irrespective of which team a player was in, his entire resistance training program was prescribed according to his positional grouping, which was the same throughout all three squads. The bench press portion of the training was exactly the same for each individual in

terms of training volumes (sets x repetitions) and relative intensities (%1 repetition maximum, RM) for at least 8-weeks prior to testing. Therefore the players in each positional grouping were resistance trained in a homogeneous manner and each player performed exactly the same bench press training for the eight weeks prior to testing, irrespective of his position or squad. Although the full-time professional NRL players performed additional training sessions (fitness, skill, tactics), no additional resistance training was performed by these players. All subjects were aware of the methods and nature of the testing and voluntarily participated in the testing sessions, which were a regular part of their testing and conditioning regime. This study conformed to the policy statement of the Declaration of Helsinki regarding research involving human subjects. All of the athletes had performed a pre-season resistance training cycle immediately prior to testing. Descriptive data for the various player groupings is contained in Table 1.

Experimental Design

Tests of strength, power, speed and high-intensity strength-endurance during upper body pressing movements were measured in rugby league players participating in three different playing grades. Scores in these tests were analyzed to determine if there were differences in these tests between the different grades. A further analysis by positional grouping was also performed to determine if upper body strength, power, speed or strength-endurance are more important for players in different positions in rugby league.

Table 1. Description of subjects as participants in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. Mean (standard deviation).

	Body mass (kg)	Height (cm)	Age (yrs)
NRL	96.8 (10.4)	183.6 (5.4)	25.3 (3.1)
SRL	94.2 (8.1)	184.6 (4.9)	20.7 (2.5)
CRL	88.7 (7.7)[b]	182.0 (5.4)	18.6 (.9)[a]

[a] denotes all groups different, $p \leq 0.05$, [b] Denotes CRL different to NRL, $p \leq 0.05$

Methodology

Four tests were chosen to measure the strength, power, speed and strength-endurance of the upper body musculature. All tests entailed the exact same movement pattern whereby the weights were lowered to the chest and then forcefully and rapidly pressed away from the body (bench press movement). Individuals can exhibit differences in performances in strength and power between different test movements for the same muscles [10]. By using the same test movement to assess all four physical qualities it was presumed that if differences occur then these differences could be ascribed to the level of performance in the four physical qualities rather than inter-test differences. The bench press is a very common exercise in the training regimen of many athletes and is commonly used to assess strength and other

upper-body physical qualities in rugby league players [5-9, 11-13] as it replicates pushing away an opponent, a fundamental task in both attack and defense. Each player, irrespective of position or squad, performed the same bench press training routine for 8-weeks prior to testing. The tests of maximum strength and strength-endurance were performed on day one, with the maximum strength test performed first. Both of these tests were performed using the free weight bench press exercise.

The tests of upper body maximum power and speed were performed four days later, with the speed test performed first. Both of these tests entailed the use of the Plyometric Power System (PPS), which has been described previously [5, 6, 11-13]. Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a “Smith” weight-training machine. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power output of the concentric phase of bench press throws based upon the displacement, time and mass data.

Strength testing - Maximum upper body strength was assessed by the 1 Repetition Maximum bench press (1RM BP) using free weights and according to methods previously outlined [5-7, 11].

Strength endurance - This test was devised based upon the results of pilot work and entailed the athlete attempting to bench press a free-weight

resistance of 60 kg for as many repetitions as possible till fatigue (RTF BP60). This absolute resistance was chosen as it complied with the American College of Sports Medicine (ACSM) Position Stand for Progression Models in Resistance Training for Healthy Adults concerning strength-endurance[14]. Specifically this absolute resistance was between 30-80% for all subjects and allowed for the completion of at least 10-25 repetitions or more as recommended by the ACSM guidelines. Recent research has illustrated that absolute resistances, for example 40 kg during bench throws, are reliable indicators of training-based changes [6, 15]. Thus players who could perform more repetitions with this absolute mass are performing more absolute work, a factor rugby league coaches believe is more important than measures relative to body mass or 1RM. A resistance of 60 kg was also only marginally different between groups in terms of relative percentage of body mass and represented 62%, 63.7% and 67.6% of the NRL, SRL and CRL groups' body mass. Test–retest reliability was r = 0.94 (n =19).

Speed testing - Upper body speed testing was conducted using the PPS and a resistance of 20 kg (the empty barbell representing the lightest resistance that could be used in the PPS) using methods described previously [7]. After warming up, the athlete performed five repetitions of the bench press throw exercise with the highest power output generated during the concentric phase recorded as the speed capability of the upper body (BT P20).

Power testing - Maximum power output (BT Pmax) was assessed for the upper body during the concentric phase of bench press throws with resistances ranging from 40 to 80 kg using methods described previously[5-6, 11-

[13]. Briefly this entailed the subjects performing three repetitions of bench throws with resistances of 40, 50, 60, 70 and 80 kg, with the highest power output at any of the resistances deemed the Pmax.

Player groupings

Players were analyzed according to a method modified from Meir et al. [2] where the front-row and back-rowers were defined as the hit-up forwards while the centers and wingers were defined as outside-backs. The hookers, halves, fullbacks and utility players were defined as the ball-players as their primary role in a game is the setting up of plays, distribution of the ball and general organization of attack. These were the groupings determined by their club coaches based upon contemporary trends and practices and the players training was organized in such groupings to a large degree.

Statistical Analyses

Means and standard deviations for each measured variable were calculated for both playing level and team position groupings. The Levene test was used to assess homogeneity of variance and age and body mass were the only variables that did not pass this test. Multivariate ANOVA was used to determine if differences existed between the groups or positional sub-groups in age, body mass, height, 1RM BP, BT Pmax, BT P20 or RTF BP60. In the event of a significant F-ratio, Bonferroni post hoc comparisons were used to determine where these differences existed, except for age and body mass where Dunnett T3 was used to account for lack of homogeneity of variance for these two variables. Spearman rank correlations were calculated between individual test scores and progression from CRL to NRL level. Pearson's

product moment correlations were calculated to examine the inter-relationships between performances in the different tests. Significance was accepted at a criterion alpha level of $p \leq 0.05$.

Results

Summary data for age, height and body mass are contained in Table 1. Age was significantly different between all groups (p<0.001, df=2, ES=0.598) but height was not (p=0.308, df=2, ES=0.040). Body mass was not different between NRL and SRL players (p=1.000, df=38, ES=0.283), or SRL and CRL (p=0.163, df=38, ES=0.693) however NRL players were significantly heavier than CRL players (9.1%, p=0.016, df=38, ES=0.896). Results for the strength, power, speed and strength-endurance tests are contained in Table 2. Maximum strength and power were significantly different between all groups. NRL players were stronger than SRL (11.6%, p=0.003, df=38, ES=1.033) and CRL players (30.8%, p<0.001, df=38, ES=2.458) and SRL players were stronger than CRL (17.1%, p<0.001, df=38, ES=1.497). In terms of upper body power output, BT Pmax was higher for the NRL players compared to the SRL players (15.0%, p=0.003, df=38, ES=1.037) and CRL players (30.6%, p<0.001, df=38, ES=1.867). Also SRL players produced more power compared to CRL players (13.6%, p=0.025, df=38, ES=0.987). Strength-endurance was not different between the NRL and SRL groups (p=0.250, df=38, ES=0.521), however both groups were significantly different to the CRL group (49.3%, p<0.001, df=38, ES=1.984 and 34.6%, p<0.001, df=38, ES=1.356 respectively). The NRL group was significantly different to both

groups in upper-body speed. That is, BT P20 was higher for the NRL players compared to the SRL players (8.4%, $p=0.019$, df=38, ES=0.884) and CRL players (13.9%, $p<0.001$, df=38, ES=1.409) however there was no difference between SRL players and CRL players ($p=0.310$, df=38, ES=0.536). The relation of the four physical factors to progression to NRL level was $r = 0.75$, 0.63, 0.63 and 0.55 for strength, power, strength-endurance and speed, respectively. Body weight alone exhibited a much lower relation to progression to NRL rank ($r = 0.34$). This analysis indicated that maximum strength displays the highest correlation to playing level. Differences in the performance data according to three broad positional groupings for the players of different ranking are depicted in Tables 3 to 5. In the main these results reflected those of the team group data

Discussion

The aim of this study was to assess and compare upper body strength, speed, power and endurance in rugby league players across three competition levels and by playing position. Prior to testing, all players performed exactly the same bench press routine. Therefore the differences exhibited are not due to the NRL players training more often or relatively harder prior to testing, but must reflect long-term adaptations garnered from multiyear training as well as some possible genetic influences which are beyond the scope of this manuscript. The results illustrate that all the measured variables tend to discriminate between rugby league players of different grades or achievement levels to some degree. This is

understandable given the intense physical nature of rugby league football and the need to forcefully push away opponents.

Table 2. Comparison of strength, power, strength-endurance and speed scores between rugby league players participating in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. Mean (standard deviation).

	1 RM BP (kg)	BT Pmax (w)	BT P20 (w)	RTFBP60(reps)
NRL	141.4 (15.4)	680 (99)	345 (31)[b]	35.6 (6.6)
SRL	126.6 (13.1)	591 (72)	319 (29)	32.1 (6.9)
CRL	108.1 (11.6)[a]	521 (71)[a]	303 (29)	23.8 (5.3)[c]

[a] denotes all groups different to each other, $p \leq 0.05$
[b] denotes NRL different to both other groups, $p \leq 0.05$
[c] denotes CRL different to both other groups, $p \leq 0.05$
1RM BP = 1 Repetition Maximum bench press, BT Pmax = Maximum power generated during bench throws with 40-80 kg, BT P20 = Power generated during bench throws with empty 20 kg barbell, RTF BP60 = Maximum number of repetitions performed till fatigue while bench pressing 60 kg.

First, overall maximum strength appears the most potent descriptor for the three different grades of rugby league players, as has been reported previously [5-7, 11]. Upper body pressing strength, as assessed by the 1RM BP, was different by about 15% between each grade. Thus the NRL squad was 30% stronger than the CRL and about 15% stronger than the SRL squad.

The magnitude of the relationship between strength and progression to NRL (r = 0.75) ranking can be defined as very large according to Hopkins' scaling and interpretation of correlations and effect sizes (r > 0.7 = very large) [16]. Although the ES differences between the NRL and SRL squads could be deemed to be moderate according to Hopkins' analysis [16], the differences between NRL and CRL and SRL and CRL can described as either large (ES = 1.2 - 2) or very large (ES = >2). Thus the relationship between strength and NRL ranking and the magnitude of ES differences between the squads mean that of the variables in this investigation, strength is the most distinguishing between rugby league players of different ranking.

This difference cannot be explained solely by differences in body mass as there was no significant difference in body mass between the SRL and NRL groups (but differences with the CRL group). If results for 1RM BP are scaled relative to body mass then the scores of 1.46, 1.34 and 1.22 kg/kg-BM for the NRL, SRL and CRL groups respectively are still significantly different to each other. Even if an allometric method of scaling such as the "two-thirds" formula is used (1RM BP / (BM * .67) [17], then the scores of 2.18, 2.00 and 1.82 for the NRL, SRL and CRL groups respectively are still significantly different to each other. Therefore issues other than simple measures of total BM or even fat-free mass must explain these differences in strength. Consequently, various neural, tissue/morphological or maturation (the NRL group were older) adaptations must explain this result. It has been shown that increased neural activity occurs in muscles, perhaps due to increased rate coding and signal intensity, in the first 8-12 weeks of strength training [18-19].

It has been postulated that other neural adaptations that occur with long-term periodized strength and power training would be more efficient neural patterning of the skill of the strength exercises, diminished levels of unwarranted antagonist co-contraction, synchronous firing of motor units (especially during the initial concentric phases of ballistic power exercises) and reduced inhibitory feedback from force receptors/regulators such as the Golgi tendon organ and Renshaw cells [18]. To what extent these adaptations occur and the time frame for their occurrence is yet to be fully determined. Qualitative muscle tissue adaptations such as changes to the fiber type or myosin heavy chain expression could also presumably be occurring with increased training experience. Further discussion of the type, extent and nature of these adaptations is beyond the nature of this manuscript, but have been reviewed extensively elsewhere [18-20].

Maximum upper body pressing power, as assessed by the BT Pmax, also clearly differentiated between the three groups. The NRL and SRL groups were 30 and 15% more powerful than the CRL group. The extent of the relation of power to NRL ranking was large according to the Hopkins interpretation [16]. Effect size differences were quite large between NRL and CRL players and moderate between NRL and SRL players and SRL and CRL players. The outcome mirrors almost exactly the result for maximum strength, which is understandable given the very strong correlation between maximum strength and power [12, 21]. Thus, maximum power would appear to be a potent descriptor of which athletes progress from CRL to SRL to NRL level, a finding verifying previous research [5, 11].

Movement speed, as assessed by the BT P20, illustrated a difference between the NRL group and the other two groups but not a difference between the lower two groups. Overall the percentage differences between the groups, magnitude of the relation of speed to NRL progression and ES were about half compared to strength and power. There was no significant difference in upper body speed between the CRL and SRL groups, however the apparent 5% difference in scores may have a practical significance for elite athletes. A previous report on this type of testing also demonstrated that the movement speed test was not as strong a discriminator of rugby league playing level as a test of maximum strength [11]. This finding may indicate that upper body movement speed, as assessed while lifting a light resistance, is less important to rugby league success than absolute strength and maximum power.

Strength-endurance, as assessed by the RTF BP60 test, has not been assessed in this manner before in rugby league players and this paper is the first to report on its suitability or otherwise for this athlete population. Our preliminary pilot work attempted to analyze the ability of a common test of high-intensity strength-endurance used in the American football system to describe and compare rugby league players of different grades. However it was felt the resistance used in the test (RTF while bench pressing 102.5 kg, a test known as the NFL 225-lb test [22]) was inappropriately heavy for a large number of subjects who could either not lift this resistance at all or for only a few repetitions. As a result the test became a feat of maximum strength, rather than strength-endurance, for a large proportion of the subjects. It was

concluded that a lighter absolute resistance of 60 kg be used during bench press RTF testing to determine the relative importance of strength-endurance for success in rugby league. The repetitions to fatigue performed while bench-pressing 60 kg in the current study ranged from 16 to 50, clearly indicating that this was a valid test of strength-endurance in terms of repetitions completed and the relative %1RM used, according to the ACSM guidelines [14]. This test of strength-endurance differentiated between CRL players and the other higher ranking groups with the relation to NRL ranking and ES indicating a large difference. However between the NRL and SRL groups the differences were not significant and the ES could be deemed to be small. So while there was clearly a significant difference between the lower ranked CRL group and the higher ranked groups in the performance of this test, it would be appear not to be as potent a descriptor of rugby league playing ability as the upper body test of maximum strength and power between athletes already at state-league level. Given that the NRL players are substantially stronger than SRL players and that there is a strong relationship between 1RM strength and the number of repetitions performed with sub-maximal resistances [22-24], it is not fully understood how the strength-endurance test failed to be different between these two groups. Further research is required in the area of high intensity strength-endurance to determine its relevance to rugby league.

The relative importance of these tests to whether a player attained NRL, SRL and CRL ranking and interpretation to Hopkins' scale [16] is interesting. By assigning numbers 3, 2, and 1 respectively to the players in the NRL, SRL and CRL squads and then rank correlating these numbers to

the different test scores for an individual, the relationship of these absolute test scores to the players ranking can be determined. For example, body mass was significantly related to attainment of NRL level (r = 0.34), but the very moderate extent of this relationship suggests that it is not as strongly related as the performance factors of strength (very large), power, speed or strength-endurance (large). Thus merely being a rugby league player with a large body mass is far less important than being a strong rugby league player, irrespective of body mass.

As rugby league football entails players with different positional tasks, it could be expected that the different upper body muscular qualities may be more or less desirable in these different positions [2]. To discern if this was true, further analyses were implemented along the positional groupings that were determined by their club coaches according to contemporary practices and trends. Conceivably the upper body strength, power, speed and strength-endurance needs for these three different positional groups could differ substantially.

Tables 3 to 5 describe the differences in these four qualities of upper body muscular performance for each of the three positional groupings. As is the case for the squad data, maximum strength and power again tend to be the best descriptors of rugby league playing ability. For the hit-up forwards, maximum strength and power clearly distinguish the NRL players from the SRL players (11-13%, ES = 1.855 to 2.267) and the CRL players (33-38%, ES = 2.6). Upper body speed results are less markedly different and muscular endurance only separated the NRL and SRL hit-up forwards from their CRL

counterparts (ES >= 1.5), not from each other. For the more robust physical tasks confronting the larger hit-up forwards during a game of rugby league, maximum strength, power and body mass (ES = 1.75 - 3.39, = large to very large differences) appear more highly desirable and better able to describe those who progress to NRL level from those who do not.

Table 3. Comparison of upper body strength, power, speed and strength-endurance between rugby league hit-up forwards participating in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. Mean (standard deviation).

	1 RM BP (kg)	BT Pmax (w)	BT P20 (w)	RTF BP60 (# reps)	Body mass (kg)
NRL (n = 8)	150.0 (19.3)	740 (86)[b]	362 (29)[b]	36.6 (8.5)	107.6 (2.9)
SRL (n = 9)	126.9 (5.6)	596 (41)	322 (26)	32.3 (4.5)	99.4 (5.2)
CRL (n = 6)	112.5 (10.0)[a]	536 (70)	305 (32)	25.3 (4.4)[c]	93.7 (5.2)[a]

[a] Denotes all groups different to each other, $p \leq 0.05$, [b] denotes NRL different to both other groups, $p \leq 0.05$, [c] denotes CRL different to both other groups, $p \leq 0.05$

1RM BP = 1 Repetition Maximum bench press, BT Pmax = Maximum power generated during bench throws with 40-80 kg, BT P20 = Power generated during bench throws with empty 20 kg barbell, RTF BP60 = Maximum number of repetitions performed till fatigue while bench pressing 60 kg.

The results for the outside backs are similar to those for the hit-up forwards, with the NRL outside backs being 13-14% stronger (ES = 1.86, large and 3.44, very large differences) and 29-30% (ES = 1.2-1.98, large differences) more powerful than their SRL and CRL counterparts, respectively despite no significant difference in body mass. While strength was significantly different between all three team levels, power and speed were similar between the SRL and CRL players. Strength endurance was different between the CRL and both the NRL (ES = 2.854) and SRL groups, who were statistically similar. Based upon the magnitude of the % differences and the ES, clearly the outside backs at NRL level are much stronger and more powerful than lower ranked counterparts. Most importantly they do not rely upon differences in body mass to provide those advantages.

The magnitude of differences in the muscular performance tests for the ball-players was less pronounced. Differences in strength, strength-endurance and power existed between CRL players and the SRL and NRL players (ES = 1.46 – 2.909, designating large to very large differences), but not between these latter two groups. As the ball-players are deemed to be the most skillful players, it is probable that the factors separating the SRL and NRL players in this positional grouping are not upper body strength or power but may be more related to other attributes such as ball skills, organizational ability and game-related decision making.

While the positional grouping x team ranking analyses is hampered by lower numbers of subjects, we feel that this is unavoidable when dealing with elite and sub-elite athletes. In this case study approach we desired subjects

with a recent homogeneous training background but whom their coaches ranked differently. This then allowed us to investigate whether their performance in strength, power, speed and endurance in one simple test motion (bench press) could largely distinguish their different team rankings.

Table 4. Comparison of upper body strength, power, speed and strength-endurance between rugby league outside backs participating in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. Mean (standard deviation).

	1 RM BP (kg)	BT Pmax (w)	BT P20 (w)	RTFBP60 (# reps)	Body Mass (kg)
NRL (n = 5)	141.0 (4.2)	698 (41)[b]	351 (11)[b]	37.4 (4.0)	94.9 (6.2)
SRL (n = 7)	125.0 (13.0)	604 (105)	325 (29)	31.0 (6.7)	93.4 (7.3)
CRL (n = 7)	109.3 (14.2)[a]	535 (93)	308 (31)	22.7 (5.6)[c]	87.3 (7.1)

[a] Denotes all groups different to each other, $p \leq 0.05$, [b] denotes NRL different to both other groups, $p \leq 0.05$, [c] denotes CRL different to both other groups, $p \leq 0.05$.
1RM BP = 1 Repetition Maximum bench press, BT Pmax = Maximum power generated during bench throws with 40-80 kg, BT P20 = Power generated during bench throws with empty 20 kg barbell, RTF BP60 = Maximum number of repetitions performed till fatigue while bench pressing 60 kg.

Table 5. Comparison of upper body strength, power, speed and strength-endurance between rugby league ball-players participating in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. Mean (standard deviation).

	1 RM BP (kg)	BT Pmax (w)	BT P20 (w)	RTF BP60 (# reps)	Body mass (kg)
NRL (n = 7)	131.8 (10.2)	597 (91)[d]	321 (30)	33.1 (5.5)[d]	86.0 (8.9)
SRL (n = 4)	128.8 (25.6)	558 (62)	299 (35)	33.5 (12.3)	84.0 (4.2)
CRL (n = 7)	103.0 (9.6)[c]	493 (46)	296 (26)	23.7 (6.2)	86.0 (3.5)

[c] denotes CRL different to both other groups, $p \leq 0.05$, [d] denotes NRL different to CRL only, $p \leq 0.05$
1RM BP = 1 Repetition Maximum bench press, BT Pmax = Maximum power generated during bench throws with 40-80 kg, BT P20 = Power generated during bench throws with empty 20 kg barbell, RTF BP60 = Maximum number of repetitions performed till fatigue while bench pressing 60 kg.

Thus this was a performance oriented approach to determining the relative importance of upper body strength, power, speed and strength-endurance in a real world setting with elite and sub-elite athletes, rather than a controlled mechanistic study of the underlying factors affecting strength, power, speed and strength-endurance. Thus we rated performance as team ranking, as determined by the professional coaches and attempted to ascertain how the upper body factors affected this measure of “performance”. Using the descriptors linked to the correlation coefficients and effect sizes

proposed by Hopkins[16], the overall team analyses show that strength "very largely" and the other factors, "largely", do distinguish team ranking. This is especially so for both the hit-up forwards and the outside backs and to a lesser degree for the ball-players.

The inter-relations between various muscular performance factors are also of interest and are detailed in Table 6. First, body mass exhibits only moderate relationships between maximum strength, power, speed and strength-endurance (r [95% confidence interval] = 0.48 [0.22 to 0.74], 0.58 [0.32 to 0.84], 0.51 [0.25 to 0.77] and 0.40 [0.14 to 0.66], respectively).. Maximum power, strength and speed were very highly inter-related, a finding that has been reported numerous times before in rugby league players [5,6,11,12] as well as other athletes [21].

Practical Applications

A pathway in upper body strength, power, speed and strength-endurance for professional rugby league players in different positions and team rankings has been illustrated in this paper. Strength and conditioning specialists and players must devote considerable training time to increasing these aspects if they are to maximize their playing level. The preparation of the elite rugby league athlete will include a long training history of hypertrophy-oriented training (to increase body mass to the levels of SRL and NRL players), heavy resistance training to maximize strength development and exercises to develop upper body power output. Strength-endurance training also appears to be of importance to NRL attainment and should be

stressed in the resistance-training regime of rugby league players. Players should initiate resistance training during adolescence and gradually increase in volume and intensity as they mature and rise in playing level if they are to be successful in elite competition.

Table 6. Inter-correlations between tests of upper body strength, power, speed and strength-endurance between rugby league players participating in the national (NRL), intra-state (SRL) or intra-city (CRL) based rugby league competitions. All relationships are $p \geq 0.0001$.

	BT Pmax	BT P20	RTF BP60
1RM BP	.84	.71	.83
BT P20	.84	-	.55

Conclusions

Despite recent rule changes, referee interpretations, coaching strategies and ploys that have conceivably increased the upper body strength-endurance demands upon the players, strength-endurance, as assessed in this investigation, was not found to be the most dominant upper-body descriptor of NRL playing rank. Of the four upper body tests assessed in this paper, maximum strength appears the most highly related to success in rugby league and displays the highest percentage differences between different teams. Maximum power and strength-endurance, which were both strongly related to maximum strength, were also strongly and similarly indicative of successful attainment of NRL level. Upper body movement speed, while still

significant, tends to describe team ranking less readily than the other measures of upper body muscular function. When analyzed according to positional groupings, the results are similar. Based upon these results younger rugby league players who desire to attain higher playing levels should strive to increase upper body maximum strength, which appears to underpin performance in other key muscular performance factors such as maximum power and strength-endurance.

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Paper 2.

"An analysis of the ratio and relationship between upper body pressing and pulling strength."

by

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published in the

Journal of Strength and Conditioning Research,

18(3):594-598. 2004.

Abstract

It has been posited that certain balances in strength should exist for opposing muscle groups (eg. hamstrings and quadriceps) or actions (eg. internal and external rotation of the shoulder) to improve sports performance or limit the likelihood of injury. Typically, expensive laboratory equipment such as isokinetic devices have been used to determine strength balances. The purpose of this paper was to determine if two popular field tests of strength could be used to determine a concise strength balance in roughly opposing muscle actions for the shoulder girdle. The two opposing movement actions of pressing away from the shoulder girdle and pulling in towards the shoulder girdle were assessed via the one repetition maximum bench press (1RM BP) and one repetition maximum pull-up (1RM PU), respectively. Forty-two rugby league players, comprising 21 national league (NRL) and 21 state league (SRL) players who regularly performed both exercises in their training served as subjects in this investigation. The equivalence of the strength ratio (BP/PU*100) and correlation between tests were also examined. The pooled data exhibited a strength ratio of 97.7% (9.0%) and correlation of r = 0.81 between the 1RM BP of 130.1 $\pm$ 20.2 and 1RM PU of 133.1 $\pm$ 17.1. The small standard deviation exhibited tends to indicate that athletes should exhibit a concise ratio of around 100% if pressing and pulling strength have been addressed fairly equally in training. However, some athletes may have body types, preexisting injuries or training histories that predispose them to excelling or conversely performing poorly during strength activities for either upper body pressing or pulling actions with differences in strength of up to

15% existing in some individuals. These factors need to be taken into account when prescribing training based upon the strength ratio between pressing and pulling strength.

Key words: bench press, pull-up, strength ratio, rugby league, muscle balance

Introduction

It has been posited that certain balances in strength should exist for opposing muscle groups (eg. hamstrings and quadriceps) or actions (eg. internal and external rotation of the shoulder) to improve physical or sports performance or limit the likelihood of injury (5-7, 11-15, 17, 19, 23). If one muscle or movement action is markedly stronger than its opposing muscle or movement action, it is thought performance could be compromised or that muscles strains may occur in the weaker muscles (5, 7, 11, 12, 15, 17).

For example, increased strength of antagonist muscles has been shown to increase the movement speed, via a decrease in the "braking" time, and accuracy of the limbs in rapid ballistic movements (14, 22). Therefore it may be seen that opposing movement actions need a certain strength balance so that the antagonist muscles can "brake" the agonists succinctly in rapid limb movements. If the forces produced in one movement action largely dominates over its antagonist muscle or opposite action, then conceivably limb speed and accuracy are impaired (14). This would then lend itself to an impairment in sports performance.

Furthermore Burkett reported increased incidence of hamstring strain in football players who possessed markedly stronger quadriceps (5). This may be due to the antagonist hamstring muscles not possessing enough strength to adequately "brake" the lower limb during a rapid knee extension movement such as sprinting. It is also thought that throwing and racquet sport athletes are at increased likelihood of rotator cuff strain if their training or sport activities have created strength imbalances in the shoulder, favouring the

larger internal rotator muscles of the shoulder (11, 12, 15, 17). Again it is believed that the smaller, weaker external rotator cuff muscles do not possess enough strength to adequately “brake” or counteract the tremendous forces produced by the internal rotators during the rapid throwing or serving movements (12, 17). With regards to resistance training for the upper body, it is theorized that a preponderance of pressing movements in the resistance training regime and/or imbalances in strength may predispose the shoulder complex to injuries such rotator cuff muscle strain and impingement (11, 15). Therefore the concept of opposing muscle or movement strength balance appears well founded. The level of balance between muscle groups in opposing actions is often termed the strength ratio.

A number of sports require athletes to be able to use their shoulder girdle musculature to both forcefully press away an opponent’s body or limbs and/or conversely pull an opponents body or limbs towards them or to the ground. Athletes such as wrestlers, judoists, mixed martial artists and rugby football players are required to both press away and/or pull in large external resistances such as their opponents. Athletes such as male gymnasts also require tremendous levels of upper body pressing and pulling strength to move their own body mass during the performance of their routines on the various apparatus such as rings, high bar and parallel bars.

Therefore both upper body pressing and pulling strength is vital for success in these sports. Large discrepancies in strength in either movement action may limit the success of the athlete in these sports or increase the

likelihood of shoulder injuries such as muscle strains or tendon impingement (eg. bicep or rotator cuff).

Typically, laboratory equipment such as isokinetic devices have been used to determine strength ratios in opposing muscle or movement actions (6, 12, 13, 17, 18). Some limitations of such equipment are its expense and hence availability to the broader sporting population. Also these isokinetic tests are generally isolated muscle tests, which may be less practical or sports-specific than more integrated functional tests of strength or muscle function (18). Strength coaches typically prefer integrated field or gymnasium tests of strength that they can easily implement themselves at little or no extra cost. Data collected from these tests could then be analysed to determine the strength balances in certain movements or muscles and training altered accordingly if needed.

The purpose of this paper was to determine if two popular field tests of strength could be used to determine the existence of a concise strength ratio in the roughly opposing muscle actions of pressing away from~ and pulling in~ towards the shoulder girdle. The relationship between pressing and pulling strength will also be investigated and analysed according to the training status of the athletes.

Methods

Experimental approach to the problem

This study was designed to investigate the strength ratio of two common movement actions ~ pressing away and pulling in ~ about the

shoulder girdle. This was to be assessed by measuring and comparing one repetition maximum (1RM) strength in two common resistance-training exercises that entail these movement actions. The null hypotheses was that there would be no significant relation between the bench press and pull-up 1RM and that a largely disparate strength ratio would exist indicating no concise balance in strength exists in these roughly opposing actions. A concise ratio would be defined by the existence of similarities and a very small standard deviation in the strength ratio. Two groups of athletes with differences in the length and level of resistance training adaptation were also studied to determine if these factors impact upon the extent of the strength ratio or relation.

Strength testing.

The exercises chosen for 1RM testing and analysis were the bench press (BP) and pull-up (PU). The tests were carried out on separate days, with the 1RM BP being performed on the first day and the 1RM PU being performed 72 hours later. The 1RM BP was chosen as it is a universally accepted test of upper body pressing strength that entails lowering a barbell resistance towards the chest and then pressing the barbell away to arms length. The methodology of testing has been described extensively elsewhere (1-4), but briefly it entailed the athletes warming up with lighter resistances and then performing single repetitions with progressively heavier resistances till a 1RM was achieved. Standard free-weight equipment such as a standard power lifting bench, olympic barbells and plates were used.

The PU was chosen to test strength because it is a fairly universally popular exercise often used to test strength-endurance via the maximum number of repetitions that can be completed lifting one's own body mass (21). Therefore athletes and coaches are reasonably familiar with it in both the testing and training environment. The PU 1RM test was rather unique in implementation and requires further description. The 1RM was determined by adding the athletes body mass to the attached additional mass to garner the total mass that was successfully lifted during the 1RM PU test. Additional mass was attached to the athletes lifting belt via a rope or light chain. This allowed for the incrementation and calibration of lifting mass during the 1RM PU test. For example a 90 kg athlete who could perform a PU with an additional 40 kg attached to the waist and a 70 kg athlete who could perform a PU with an additional 60 kg attached to the waist would both score 130 kg as their 1RM PU.

The PU test was performed with a supinated grip and the testing repetition was preceded by an eccentric phase, as is the case for the BP. For the preceding eccentric phase to occur, the athlete and attached additional mass had to be held by three spotters in the starting position of arms flexed and chin in line with the pull-up bar. On the testers command, the athlete's support was removed and he proceeded into the eccentric phase to arms length, whereupon he immediately pulled himself back to the flexed arm starting position. Any attempt that did not entail an eccentric portion to full arms length and return to the start position was disallowed.

After generalized warm-up of callisthenic and dynamic stretching exercises, the athletes commenced the testing procedure by performing three repetitions in the PU with their own body mass. After this the athletes performed only single repetitions with additional mass attached to their waists, starting at an extra 20 kg for the NRL and 10 kg for the less strong SRL group. Mass was increased by 2.5-10 kg at each further attempt till both the athlete and tester were satisfied that the 1RM PU had been attained. The test-retest reliability of r= 0.90 was established upon a subset of sixteen of the subjects.

Thus the tests incorporated roughly opposing muscle actions in fairly simple and universally popular resistance training exercises. For example, the BP entailed grasping a barbell with a pronated grip and lowering it to the body, which is stabilized upon a bench, and then pressing this resistance to the starting position of arms extended. The PU entailed gripping a bar, which remains stable, and then lowering the resistance to arms length whereupon it is immediately pulled back to the start position of arms flexed.

Subjects

Forty-two rugby league players from the same rugby league football club served as subjects in this investigation and consented to be tested as part of the conditioning requirements of their sport. All were in current resistance training and performed both upper body pressing and pulling resistance-training exercises equally and regularly in their training. All the subjects were tested at the end of their pre-season training cycle when their strength and power levels were expected to be at peak levels. Almost all subjects attained or bettered their personal bests in both testing exercises.

These subjects were investigated as a whole group (Pooled) and according to their status as full-time professional athletes participating in the in the elite national rugby league competition (NRL, n =21) or as the semi-professional college-aged subjects participating in an intrastate league competition, equivalent to a second division competition (SRL, n=21). A description of the subjects is contained in Table 1. The NRL group was older and more experienced in resistance training, typically with a resistance training history of greater than six years. The SRL group was younger and typically possessed a resistance training history of one to three years. This grouping would provide data pertinent to training history affecting either the levels of maximum strength in the 1RM BP or 1RM PU, the equivalence of the strength ratio and the relationship between the pressing and pulling tests. Recent studies have indicated that the strength levels and training status of athletes can affect the extent of adaptation to various resistance training stimuli (eg. 2, 24).

Table 1. Description of subjects. Mean (standard deviation)

	Age (yrs)	Height (cm)	Weight (kg)
Pooled (n = 42)	22.0 (3.8)	184.2 (6.2)	94.4 (10.2)
SRL (n = 21)	19.8 (2.0) *	184.6 (6.7)	92.2 (9.5)
NRL (n = 21)	24.2 (4.0)	183.8 (5.9)	96.6 (9.5)

* denotes significantly different to NRL group, $p \leq 0.05$

Statistics.

Factorial ANOVAs were used to determine if differences existed between the groups in 1RM BP, 1RM PU and strength ratio. In the event of a significant F-ratio, Fisher PLSD post hoc comparisons were used to determine where these differences existed. The strength ratio was calculated by dividing the 1RM BP by the 1RM PU and expressing as a percentage (BP/PU*100). Pearsons moment correlations were also calculated between 1RM BP and 1RM PU. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The results for the strength scores are contained in Table 2. The NRL and SRL groups were significantly different to each other for 1RM BP, 1RM PU and strength ratio. The results for the relations between 1RM BP and 1RM PU are contained in Table 3. Overall the pooled data indicates a strong and significant relation between upper body pressing and pulling strength in athletes who simultaneously train for maximum strength in both actions. The relation between BP and PU was much lower in the stronger and more experienced NRL group than in the SRL group. The relation between body mass and 1RM BP and 1RM PU were $r = 0.60$ and $r = 0.61$, respectively ($p \leq 0.05$).

Table 2. Group mean (standard deviation) results for upper body pressing and pulling strength and comparative strength ratio.

	1RM BP (kg)	1RM PU (kg)	% BP/PU
Pooled	130.1 (20.2)	133.1 (17.1)	97.7 (9.0)
SRL	117.4 (16.3)*	123.8 (13.5)*	94.6 (5.6)*
NRL	142.7 (15.2)	142.4 (15.3)	100.7 (10.7)

* denotes significantly different to NRL group, $p \leq 0.05$

Discussion

The 1RM BP results for the NRL and SRL groups are similar to those published before for these groups of athletes (1-4) and require little further discussion. The 1RM PU was a novel test and no data could be found that directly compares strength levels in this pulling test with the results of similar athletes. While data for upper body pressing strength in exercises such as the bench press (BP) is quite extensively reported upon (1-4), a paucity of data exists for upper body maximum pulling strength of athletes. It was expected that the NRL group would be significantly stronger in the 1RM PU than the SRL group given the results for 1RM BP in the studies listed above and the fact that pulling and pressing strength were equally emphasized in the training program.

Typically data for upper body pulling strength is reported as the maximum number of repetitions that can be performed in the pull-up (PU) or chin-up exercise (21). As elite athletes may perform a considerable number of repetitions in the PU, then these types of tests in reality become tests of

strength-endurance not maximum strength. More recently, elite wrestlers have used a speed rope-climb test, which while being more dynamic and strength-oriented than the maximum pull-up repetitions test, is still more a test of speed-strength rather than pure maximum strength (8). Thus a simple test of upper body maximum pulling strength that is as readily accepted and easy to implement as the upper body pressing test of 1RM BP is required. While conceptually a seated row test is more truly antagonist to the BP than a PU, practical experience has shown it difficult to perform very strictly with heavy resistances. Athletes will tend to cheat by invoking small amounts of almost indiscernible back, hip and knee extension, which are summed to the upper body pulling strength, distorting the strength score. This could easily lead to erroneous conclusions being made upon an athlete's upper body pulling strength. The PU is a simple exercise widely used in training in gymnasiums, wrestling halls, judo dojos and the military. Its familiarity, basic equipment and simple performance with strict criteria lends itself to 1RM or maximum repetition testing. That is why it was used in this investigation as opposed to a seated row type of movement.

For the pooled data, the 1RM BP and 1RM PU were very similar in the mass lifted and expressed as a strength ratio indicating a general equivalence of strength in the opposing actions of pressing and pulling in these athletes. Because the standard deviation for the strength ratio was quite small (9%), it can be seen that a definite concise ratio exists. If the standard deviation for the strength ratio was quite large, it would indicate that tremendous disparities exist in the strength ratio for individuals, reducing the validity of the concept.

Some previous testing of shoulder internal and external rotation strength ratios in tennis players reported standard deviations of 12-28% (12). In comparison, the younger SRL subjects who were a similar age to the tennis players in that study, the standard deviation was less than 6%.

While there was a strong correlation between test scores, there was also enough variance to suggest that good pressing strength will not ensure good pulling strength. This data would indicate that athletes in sports that require high levels of both upper body pressing and pulling strength should generally possess similar levels of 1RM BP and PU strength, which is probably attained by giving equal attention to both actions during training.

However, an analysis of the test results for the 1RM BP and 1RM PU indicate some interesting results. While the strength ratio of the mean test scores was close to 100% for the elite professional NRL group, there was a much lower relation between the 1RM BP and 1RM PU as compared to the less strong SRL group. The SRL group was actually significantly different to the NRL in the strength ratio, indicating that they were proportionately stronger in the PU than in the BP, although by only a small amount. These athletes were significantly younger than the NRL group and possessed a shorter resistance training experience. This shorter training or playing experience may have affected the development of pressing strength, as opposed to pulling strength, to a greater degree.

Why the NRL group would exhibit a markedly lower relation between 1RM BP and PU was of interest. At first glance it was assumed that some of the NRL group may have possessed an unbalanced training history where

perhaps pressing movements were over-emphasized earlier in their resistance training histories at the expense of pulling movements and that this may have had impacted upon the relation between pressing and pulling strength. However, an analysis of the results in fact reveals the exact opposite. To allow for a direct comparison of subjects' strength scores across a large body mass spectrum, the classical or "two-thirds" normalizing formula was applied to the strength test scores (16). The "two-thirds" normalizing formula was chosen because currently there are a number of different formulas for different lifts available to normalize the strength scores of athletes with largely disparate body masses, however none has been developed specially for the PU exercise. Thus a decision was made to use the very generic "two-thirds" formula for this investigation so as not to use a formula that may favour the bench press, upon which a considerable amount of investigation in this area has been reported (eg. 9, 10). By normalizing the strength scores with a body mass correction formula (1RM / {BM * .67}), a direct comparison of strength scores between subjects of different body masses was possible. From this procedure, three subjects were identified that were more than one standard deviation below the group mean in 1RM BP strength. For these three subjects the strength ratio was only 84.6%, indicating average pulling strength (149.7 kg), but below average pressing strength (126.6 kg) at a mean body mass of 103.3 kg. Three other subjects were identified as being more than one standard deviation above the group mean in 1RM PU strength. For these three subjects, the strength ratio was 89.0%, indicating average pressing strength (139.2 kg) and exceptional

pulling strength (156.0 kg) at a mean body mass of 91.0 kg. There were no subjects who were more than one standard deviation above the group mean in 1RM BP strength and the only statistical outlier that existed in the SRL group possessed a strength ratio of 97.5%. If the six statistical outliers are eliminated from the NRL data, then the relation between 1RM BP and 1RM PU increase markedly from r = 0.52 to 0.78. The reasons why these six individuals exhibited large differences in their strength ratios may be more likely due to reasons other than merely previous training history. Factors such as muscle and limb lengths and/or muscle attachments or preexisting training / game related injuries may affect joint / muscle integrity or the effectiveness of training. These factors may eventually predispose those individuals to enhanced pulling strength or diminished pressing strength. Due to the intense physical front on upper body contact and the use of no (or at best minimal) shoulder padding in rugby league, contact injuries and constant micro-trauma may affect the anterior musculature responsible for pressing strength, leading to a suppression of pressing strength. Because the pulling musculature is mainly on the posterior side of the body and not liable to brutal front on contact as much, it may suffer less and hence pulling strength is less affected. The fact that the six outliers were all better pullers than pressers and all existed in the elite professional NRL group may lend credence to this. The SRL may merely have not had as many opportunities to have damaging contacts to their anterior musculature or the contacts that they experience in their second division competition may not be as damaging as those experienced in the elite professional league. There may also be a cumulative

effect of this type of front on contact, leading to a suppression of pressing strength over the years in some players the elite professional group.

On the basis of this research it can be posited that upper body pressing and pulling strength should be fairly equivalent in athletes who train these actions fairly equally in training. However, some individuals may have preexisting injuries or specific anatomical considerations that may predispose them to score lower in the pressing movements or conversely higher in the pulling movement. Also athletes in sports such as rugby union and rugby league, wrestling, judo, and various other mixed martial arts while requiring tremendous levels of both upper body pressing and pulling strength, also must deal with the physical contact that can damage the integrity of the joints and musculature. The intense and prolonged brutal physical contact may lead to an accumulation of injuries that may suppress pressing strength, giving rise to a strength ratio favouring pulling strength. Coaches may need to take this into account when diagnosing and prescribing training based upon the results of these two tests.

It must also be considered that athletes who may over-emphasize pressing movements at the expense of pulling movements may exhibit strength ratios in favour of the 1RM BP, although none of the subjects in this study would have appeared to have done this. However, it could also be expected that athletes from sports where upper body pressing movements dominate (eg. shot-put, American football lineman, boxing) may possess strength ratios in favour of BP strength. Strength and conditioning coaches may need to develop an appropriate ratio for these athletes, different from the

concise 95-100% ratio that existed for the majority of athletes in this study who had possessed a resistance training history entailing pressing and pulling fairly equally. Conversely, athletes who participate in sports where upper body pulling movements predominate over pressing (eg. swimming, kayaking, rowing) would also need to develop their own strength ratios, which would most likely favour pulling strength in these types of athletes. Nonetheless enough evidence exists to suggest that resistance training should be fairly well balanced between agonist and antagonist muscles or movement actions. This would then lead to an equivalence in the strength ratio between upper body pressing and pulling movements and theoretically develop a more balanced and stable shoulder complex. At all times coaches need to consider that weak antagonist muscles may limit limb speed and accuracy during rapid movements (14, 22) or possibly lead to muscle strains or tendon impingements.

Table 3. Correlation and co-efficient of determination (r-squared expressed as a percentage) between upper body pressing (1RM BP) and pulling (1RM PU) strength.

	Pooled	SRL	NRL
Correlation (r =)	0.81	0.93	0.52
C o D	65%	86%	27%

Practical considerations

A 1RM test can be easily implemented to determine upper body pulling strength in the simple and universally popular pull-up exercise. This test was a roughly antagonistic version of the popular upper body pressing movement of BP. A comparison of the test scores should indicate a strength ratio equivalence of around 100%, indicating the same amount of mass can be lifted in the respective pressing and pulling movements. Strength coaches of sports such as rugby types of football, wrestling, judo and various other forms of martial arts that must both forcefully press away or pull in opponents should monitor the development of strength in both actions. However, they should also be aware that some individuals are predisposed to better performances in one test as compared to the other and that this may confound correlation results to some degree. Also younger athletes tend to perform slightly better in the PU test as compared to the BP test. It could also be expected that athletes from sports where upper body pressing movements dominate may possess strength ratios in favour of BP strength whereas athletes from sports where upper body pulling predominates may possess strength ratios in favour of PU strength.

Prolonged exposure or perhaps one acute bout of intense physical contact, which typically involves the anterior musculature, may affect pressing strength. Cumulative trauma may also be a factor that needs to be taken into account when diagnosing strength ratios and prescribing training for athletes in contact sports.

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Paper 3.

"Predicting 1RM or sub-maximal strength levels from simple "reps to fatigue" (RTF) tests."

by

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published in

Strength and Conditioning Coach , Vol. 12 (4) pp.19-24. 2004.

Abstract

The validity of estimating one-repetition maximum (1RM) or estimating repetition performance at levels between 60-100% 1RM from a table of correction factors was investigated in two studies. In study one, thirty-four (34) male professional rugby league players were tested for 1RM bench press (BP) and repetitions to fatigue (RTF) while lifting an absolute resistance of 102.5 kg. In study two, twenty-three (23) male professional rugby league players were tested for 1RM pull-up (PU) and RTF with body mass. The actual repetitions performed by each individual in the RTF tests were correlated to the number of repetitions that were predicted to be performed according to each individual's 1RM and the data from the table. High correlations of $r = 0.93$ and $r = 0.83$ were found between the actual repetitions and predicted repetitions performed in the RTF test for the BP and PU, respectively. This result indicates that RTF tests appear to be reliable predictors of strength performance in these two exercises. Consequently RTF tests can be recommended for estimating 1RM performance or repetition performance at sub-maximal resistances. This may be especially useful when dealing with large numbers of athletes, especially inexperienced athletes.

Key words: strength, 1RM, bench press, pull-up, prediction

Introduction

When commencing the strength coaching of a new athlete it is often good to have some idea of their capabilities. As a coach, you can interview them regarding their capabilities, implement lengthy One-repetition Maximum (1RM) test procedure(s) or perhaps implement quicker, more simple test(s) that estimate 1RM levels through the performance of a “reps to fatigue” (RTF) test with a given sub-maximal resistance. This last procedure relies on understanding the relationship between maximum and sub-maximum capabilities to estimate 1RM levels.

The relationship between human power output or performance and time to exhaustion is not a linear relationship, but a hyperbolic relationship (18). Many equations that have been developed to estimate maximum capabilities from sub-maximum performance do not take this into account and tend to over-estimate 1RM capabilities by inferring a more linear relationship (16, 17, 20). Also some equations are not gym friendly, requiring a spreadsheet to determine the complicated equations. Simple three-digit correction factors are believed more appealing as they can be used with a simple pocket calculator in the gym to calculate training weights or estimates of 1RM (12). Instead of developing another semi-useful equation, I developed a table that allows a coach to extrapolate a 1RM from a RTF effort and conversely, by back-extrapolation, determine how many repetitions could be performed at other sub-maximal resistances in that exercise. Table 1 provides a guide as to the relationship between repetitions performed and %1RM between 1 and 20 reps with a reconversion factor to estimate 1RM

from a RTF effort or test. This table is based upon my primarily upon my own research (2) and training observations upon the hundreds of athletes that I have trained, but is also influenced by other research (1, 6-9, 12-17, 20-22) as well as the tables of renowned strength coaches Boyd Epley (10), Charles Poliquin (19), Nate Foster (11) and the American National Football League (NFL) table (9). The table of correction factors that I developed has been validated before, when between three and six repetitions have been performed (2, 12), but further validation is needed for the higher repetition ranges. Generally correction factors become less accurate further away from 80% 1RM, when higher repetitions are performed (16, 17, 22). Also very little data has been published concerning 1RM pull-up strength, RTF and predictive correction factors.

The purpose of this paper is to validate the predictive qualities of the table by comparing RTF results predicted from 1RM test results to actual RTF performance in the bench press (BP) and pull-up (PU) exercise (aka chin-up).

Methods

Two experiments were carried out with professional rugby league players as subjects. All were experienced in resistance training and were tested at the completion of a strength development cycle. In Study One, thirty-four players were tested for 1RM bench press (1RM BP) and RTF with an absolute resistance of 102.5 kg.

Table 1. Guide for determining 1RM from varying repetitions performed to maximum effort. An estimate of 1RM is made when the weight lifted is multiplied by the reconversion factor according to the number of repetitions that were performed with that weight.

Guide for 1-10 reps			Guide for 10-20 reps		
Reps	%1RM	Reconvert*	Reps	%1RM	Reconvert*
1	100	n/a	11	73	1.36
2	95	1.05	12	71	1.40
3	92	1.08	13	69.5	1.43
4	89	1.12	14	68	1.47
5	86	1.16	15	66.5	1.5
6	83	1.20	16	65	1.53
7	81	1.23	17	64	1.56
8	79	1.26	18	63	1.58
9	77	1.29	19	62	1.61
10	75	1.33	20	61	1.63

For example, if someone can lift 100 kg for ten repetitions, then the estimated 1RM would be 133 kg (100 kg x 1.33). To estimate what resistance that they could perform 5 repetitions with multiply the estimated 1RM (133 kg) by the %1RM for 5 reps (86%) = 114 kg (round up to 115). To determine a 20-rep resistance, it would be 133 kg X .61 = 81.1 kg (round down to 80 kg) and so on.

In Study two, twenty-three players were tested for 1RM pull-up strength and RTF with an absolute resistance of body mass. In both instances, the amount of repetitions that were predicted to be performed with the designated resistances, based upon an individual's 1RM and the relevant calculations

from Table 1, were compared to the actual repetitions that were performed during the RTF tests.

Study One. The average age, body mass and height of the subjects was 22.6 ± 3.9 yrs, 95.5 ± 10.1 kg and 183.3 ± 5.8 cm. Procedures for 1RM BP testing entailed warming up with sub-maximal resistances and then lifting progressively heavier resistances until 1RM was achieved (2, 3, 4, 5). Three days later a RTF test was performed with an absolute resistance of 102.5 kg (this being the NFL 225-lb BP test). In this test, after warming up, the players performed as many repetitions as possible with this resistance till fatigue (9). The actual repetitions performed were compared to what was predicted to be performed based upon the calculations from Table 1 (eg. 102.5 kg / 137.5 (1RM BP) = 75% which corresponds to 10 repetitions).

Study two. The average age, body mass and height of the subjects was 18.8 ± 1.3 yrs, 89.0 ± 9.6 kg and 182.5 ± 5.1 cm. The PU 1RM test was rather unique in implementation and requires further description. The 1RM was determined by adding the athletes body mass to the attached additional mass to garner the total mass that was successfully lifted during the 1RM PU test. Additional mass was attached to the athletes lifting belt via a rope or light chain. This allowed for the incrementation and calibration of lifting mass during the 1RM PU test (4). For example a 90 kg athlete who could perform a PU with an additional 40 kg attached to the waist would score 130 kg in the 1RM PU test.

The PU test was performed with a supinated grip and the testing repetition was preceded by an eccentric phase, as is the case for the BP. For

the preceding eccentric phase to occur, the athlete and attached additional mass had to be held by three partners in the starting position of arms flexed and chin in line with the pull-up bar. On the testers command, the athlete's support was removed and he proceeded into the eccentric phase to arms length, whereupon he immediately pulled himself back to the flexed arm starting position. Any attempt that did not entail an eccentric portion to full arms length and return to the start position was disallowed.

After generalized warm-up of callisthenic and dynamic stretching exercises, the athletes commenced the testing procedure by performing three repetitions in the PU with their own body mass. After this the athletes performed only single repetitions with additional mass attached to their waists till 1RM was achieved.

The RTF test was performed upon the dame day, about seven minutes after the completion of the 1RM PU was completed, with only the player's body mass representing the absolute resistance. The actual repetitions performed with body mass were compared to what was predicted to be performed, based upon the 1RM PU and the relevant calculations from Table 1 (eg. 95 (= BM) / 135 (1RM PU) = 70.5 % which corresponds to 12 repetitions).

Results

The results outlined in Tables 2 and 3 indicate a very high, statistically significant correlation between the predicted repetitions and the actual repetitions performed in both exercises. Also, of the twenty-three athletes

who performed both tests the correlation between 1RM BP and 1RM PU was also high (r= 0.82), a finding which is line with other research (4).

Table 2. 1RM strength levels, actual and predicted repetitions performed while lifting the standard 102.5 kg mass during the bench press and correlation between actual and predicted reps (n =34). Mean ± SD.

1RM bench press (kg)	102.5 kg as % 1RM	Actual reps	Predicted reps	Correlation co-efficient
135.6 ± 16.3	76.6 ± 8.8	10.1± 4.8	9.8 ± 5.1	r = 0.93

Discussion

The very high correlations for predicting repetitions from extrapolating from Table 1 and an athlete's 1RM would indicate that the calculations could be fairly accurate for predicting 1RM. Also this table would allow coaches to estimate an athletes lifting capabilities across a broad range of repetitions from one simple RTF test.

The reason why the PU exercise exhibited a slightly lower correlation to the BP may be due the fact that both tests (1RM and RTF) were performed upon the same day. Fatigue resulting from the 1RM PU test may have affected some individuals in the exhausting RTF test, slightly reducing the correlation as compared to the BP. Nonetheless predicting 1RM from RTF or conversely predicting RTF from 1RM tests would appear fairly accurate with the figures contained in Table 1.

Table 3. 1RM strength levels, actual and predicted repetitions performed while lifting body mass during the pull-up and correlation between actual and predicted reps (n =23). Mean $\pm$ SD.

1RM pull-up (kg)	BM as % 1RM	Actual reps	Predicted reps	Correlation co-efficient
120.8 $\pm$ 12.0	74.0 $\pm$7.1	11.5 $\pm$ 4.3	11.1 $\pm$ 4.3	r = 0.83

Therefore RTF testing to estimate 1RM could be used by coaches who deal with large numbers of athletes. For less strong athletes, the RTF resistance with the bench press could be much lower, such as 60 kg for high-school athletes and maybe 80 kg for slightly stronger athletes. The absolute resistance need not matter to much, as long as between 2 and 20 repetitions can be performed. For the PU test, a resistance of body mass is a simple and universal resistance for RTF tests.

When implementing programs based upon estimations of 1RM from RTF tests, the following factors must be considered. Firstly, there are obvious individual differences that exist such that some individuals vary greatly from the averages of the table. The table is simply a starting point and over time a coach may develop further information such that they know each individuals variation and in fact develop modified tables for individuals (11). Also it appears that these prediction equations or tables can sometimes be less accurate with untrained people (although this is not unequivocal), less

accurate the further away from 80% 1RM you go (6, 16, 17, 20) and the fact some exercises such as leg press or leg curls do not follow this guide (13). For example, research has shown that about 20 repetitions can be performed at 80% 1RM in the leg press, but only 11 repetitions at 60% in the leg curl (13). But generally, for trained athletes performing multiple-joint free-weight strength training exercises (or pulley exercises such as lat pulldowns), this table appears a useful guide for extrapolating an individual's 1RM. Also back-extrapolating how just how many repetitions can be performed at any designated sub-maximum resistance in this range is also possible.

Conclusion

The data in Table 1 allows a coach to extrapolate what an individuals 1RM would be based upon RTF tests with sub-maximal resistances and also for predicting how many repetitions can be performed at any designated sub-maximum resistance in this range. This could save time when dealing with large numbers of athletes and when coupled with a spreadsheet application, could also allow for very accurate individualized training weight prescriptions.

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Paper 4.

“Acute effect of alternating heavy and light resistances on power output during upper-body complex power training.”

by

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published in the

Journal of Strength and Conditioning Research,

17(3):493 -497. 2003.

Abstract

This study investigated the effect on upper body power output of manipulating resistances during "contrast" or "complex" power training. This power training strategy typically entails the athlete alternating sets of a heavy resistance in a strength-oriented exercise with sets of lighter resistances in a power-oriented exercise. Sixteen rugby league players, who were experienced in power training and who performed complex training on a regular basis, served as subjects for this study and were divided equally into a control (Con) or experimental (Exp) group. Both groups were pre- and post-tested for power output while performing explosive bench press throws in a smith machine with a resistance of 50 kg (BT P50). The Exp group performed an intervention strategy of a six repetition set of bench press with a resistance of 65% of one repetition maximum (65% 1RM) between tests. At the pre-test occasion, no differences was observed between the groups in power output, however at the post-testing, a significant difference in power output was observed between the groups in the BT P50. The 4.5% increase in the power output recorded during the post-testing BT P50 for the Exp group was determined to be significantly different from all other scores ($p \leq 0.05$). This data indicates that the performance of a set of heavy resistance strength training exercise between power training sets will acutely enhance power output in the second power training set. This effect has been previously theorized as possibly due to some combination of acute neural or mechanical adaptations.

Key words: contrast loading, strength, neural, bench press, bench throw.

Introduction

Recently the training method whereby sets of heavier and lighter resistances are alternated in order to elicit an increase in power output has received some attention (2, 5, 10, 11, 13, 14, 15, 20, 26). This method, often called "complex training" (11, 13) or "contrast loading" (2) has previously received scant scientific regard despite training recommendations and prescriptions dating back over fifteen years (13).

Fleck and Kontor (13), who originally reported upon the Russian "complex method" of training, described the alternating of sets of a very heavy resistance (>85% 1RM) in a strength-oriented exercise such as squats or bench press with sets of a lighter resistance (30-45% 1RM) in a power-oriented exercise such as jump squats or medicine ball throws (3, 23, 25, 26). A power-oriented exercise is an exercise where acceleration occurs through the full range of movement, resulting in higher movement speeds and accordingly power outputs (18, 19, 23). The rationale for this contrasting resistance method was that the heavy resistance strength-oriented set provided some sort of enhanced neural drive to the agonist musculature (13, 15). Theoretically this increased neural activity would carry over to the lifting of the light resistance power-oriented exercise, resulting in a higher power output with this lighter resistance than would occur without the prior heavy resistance set (11, 13, 14, 15).

Recently, a number of studies have illustrated the significant acute effect that this training method has on jumping performance (14, 21, 26). These studies have typically involved heavy resistance squats or leg presses alternated with vertical jumps or lighter resistance jump squats. More recent studies have also reported significant enhancement of power output after alternating heavier and lighter resistance sets of merely a power-oriented exercise, in these cases jump squats (3, 5). However, despite the success of the studies listed above and recent training recommendations (3, 10), very

little data exists validating the effects of contrasting loading upon upper body power output. Two recent studies that examined contrast load training during upper body power training could not determine any performance benefit or muscular or mechanical source of augmentation (11). Ebben et. al. (11) reported no performance augmentation in the power exercise (medicine ball throwing) or possible mechanism of augmentation after heavy bench pressing with a resistance of about 90% 1RM. More recently, Hrysomallis and Kidgell (15) also reported no augmentation in performance of the power exercise (explosive pushups) following the performance of a heavy resistance 5RM bench press set. These authors were unclear why non-significant results may occur with complex training for the upper body considering the amount of supporting data existing for the lower body.

The purpose of this study was to report the acute effects upon power output of performing a heavy resistance bench press set between bench throw power sets in athletes experienced in contrast/complex upper body power training.

Methods

The approach to the problem used in this study entailed an intervention strategy whereby all subjects were pre-tested and post-tested for power output during the bench throw power training exercise, however the experimental subjects performed the intervention strategy of heavy bench pressing between power tests. This testing strategy was devised to garner data concerning the effect, if any, that the heavy bench pressing may have upon consequent power output during the post-testing occasion.

Subjects

Sixteen rugby league players participating in the national or state league and who possessed at least one years experience in contrast/complex power training served as subjects for this study. They were informed of the

nature of the study and voluntarily elected to participate in the testing and intervention sessions and were divided equally into an experimental (Exp) and control (Con) group. A description of the subjects is contained in Table 1.

Table 1. Description of subjects. Mean (standard deviation)

	1RM BP	BT Pmax	Height	Mass	Age
Exp	143.7 (20.0)	694 (80)	188.1 (4.2)	107.4 (6.9)*	23.3 (3.1)
Con	137.2 (15.1)	612 (73)	182.4 (7.0)	91.5 (7.4)	22.4 (1.9)

* denotes difference between groups, $P \leq 0.05$.

Testing

Power output was tested during explosive bench press style throws with an absolute resistance of 50 kg (BT P50) using the Plyometric Power System (Norsearch, Lismore, Australia), which has been described extensively elsewhere (3-9, 18, 19, 21, 22). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a “Smith” weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide about two hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power (in watts, w) output of the concentric phase of the bench press throws based upon the displacement of the barbell, time of displacement and mass of barbell data ($M * G * D / T =$ power output in watts). A test-retest reliability of $r = .92$ was previously

established with a group of twelve subjects.

Prior to pre-testing, subjects warmed up by performing five repetitions of both the bench press and bench throw exercise with resistances of 60 kg and 40 kg, respectively (5). After three minutes rest, the subjects performed the pre-test, which consisted of five consecutive repetitions with the 50 kg resistance (Pre BT P50). Subjects were instructed to propel the barbell as explosively as possible and were given verbal encouragement throughout. Only the repetition with the highest average concentric power output was chosen and recorded for analysis. After three more minutes rest the Con group repeated the test (Post BT P50).

The intervention strategy performed by the Exp group consisted of the subjects performing six repetitions of the free weight bench press exercise with a resistance of 65% of their 1RM BP. After three minutes rest the Exp group performed the Post BT P50 test. Thus, after warm-up, both groups had performed a Pre and Post BT P50 power output test, with the Exp subjects also performing an intervention strategy of heavy resistance bench pressing between tests. This experimental design was implemented in order to observe if there had been any augmentation to power output through the intervention of the heavy resistance set in the Exp group.

Statistics

To determine if any difference in power output existed between the groups at either testing occasion, a two-way analysis of variance (ANOVA) with repeated measures was used. Significance was accepted at an alpha level of $p \leq 0.05$ for all testing.

Results

The results are outlined in Table 2. At the pre-test occasion, no differences was observed between the groups in power output, however at the post-testing, a significant difference was observed between the groups in the

BT P50. The 4.5% increase in the power output recorded during the post-testing BT P50 for the Exp group was determined to be significantly different from all other scores ($p \leq 0.05$).

Table 2. Power outputs (w) during bench press throws with a barbell resistance of 50 kg (BT P50) for the control and experimental groups. Mean (standard deviation)

	Pre BT P50	Post BT P50
Exp	595 (57)	621 (66) *
Con	575 (59)	574 (67)

* denotes difference between groups, $P \leq 0.05$.

Discussion

Similar to previous results for the lower body (1, 3, 5, 14, 20, 26) but dissimilar to previous upper body studies (11, 15), the method of alternating heavy and light resistances had a small but significant acute effect upon power output. This discussion will now focus upon mechanisms via which augmentation to power output may occur as a result of the intervention of a heavy resistance set during complex training and the reasons why the current study reported significant results in contrast to the previous upper body studies.

The reason why power output is increased by the intervention of a contrasting heavy resistance set may be due to short term neural or mechanical adaptations or combinations of both. In the studies listed above, the various authors have postulated upon why the alternating of heavy and light resistances may increase power output. These authors have surmised

that this acute augmentation in power output may be the result of neural adaptations such as increased descending activity from the higher motor centres, direct myoelectrical potentiation, increased synchronization of motor unit firing, reduced peripheral inhibition from the Golgi tendon organ (GTO), reduced central inhibition from the Renshaw cell and enhanced reciprocal inhibition of the antagonist musculature (5, 10, 11, 13, 14, 26). None of these possible mechanisms need be exclusive and a number of the above mechanisms could function together simultaneously.

Gulich and Schmidtbleicher (14) and Young et al. (26) rationalized that the intervention strategy must be a very heavy resistance of maximal or near-maximal intensity to increase motor unit activation (≥ 85-90% 1RM). The fact that Young et al. (26) found greatest augmentation to jumping height in the strongest athletes using the heaviest 5RM loads, would tend to support the fact that some tension sensitive mechanisms were at least partly responsible. However, the present study entailed a much lower resistance of 65% 1RM as the contrast set. As five repetitions performed at a resistance of 65% 1RM is insufficient to cause a full tetany to occur, the “post tetanic augmentation” as theorized by Gulich & Schmidtbleicher (14) could not fully account for the augmentation to power output in the current study. Previous lower body studies have also reported significant results with much lighter contrasting resistances (5). This would suggest that other neural strategies associated with lifting heavier, though not maximal, resistances can be used for contrast/complex training.

If the intervention mechanism is related to resistance, but not necessarily the heaviest resistance, then some tension sensitive mechanism of the neuromuscular system that are affected by resistance/force must be at least partly responsible (14). Tension sensitive receptors such as the Golgi tendon organ and Renshaw cell could possibly account for this consequent change in power output by reducing their negative inhibitory feedback (2, 16).

An effective relaxation of the antagonist muscles to prevent excessive co-contraction must also be considered an option available to the neuromuscular system (17). Thus it is feasible that the heavier contrasting resistance set may enable athletes to be better able to process and over-ride inhibitory signals that occur in ensuing sets. However, the only previous study that assessed neural output levels during upper body contrast/complex training found no change in electromyographic activity during the performance of the power exercise, but this may not be unexpected as no performance augmentation was reported either (11). Therefore it is still unclear via which, if any, neural mechanism may be responsible when augmentation to power output occurs during complex training.

Another possible avenue of augmentation is the stiffness of the musculo-tendinous unit and specifically the series elastic component (SEC) (16, 22-25). Depending upon the resistance to be overcome, some increased SEC stiffness may be useful in regulating force output during stretch-shorten cycle movements (16, 23, 25). A heavier resistance set of 65% 1RM may temporarily result in a favourable increase in SEC stiffness, proving favourable for power production in ensuing power training sets. However, a very heavy resistance (85-90% 1RM) set may temporarily result in a SEC that is stiffer than would be optimal considering the lighter resistance to be overcome in the power movement (23, 25).

Therefore at this stage it is not known exactly via which avenues an increase in power output may occur, but conceivably some acute neural adaptations and stiffness regulation of the SEC probably account for the effect. How long this effect may last is not yet known, but this would have implications for athletes who use contrast loading complexes in sport warm-ups. For example, how long could any possible augmentation to power performance last from using a weighted bat donut for baseball batters? Conceivably if the augmentation is primarily accounted for by neural or

stiffness regulation, then the effects may dissipate after a matter of minutes (perhaps less than 10 minutes). Further research into the length of time power remains elevated is warranted.

The reason why a significant result was obtained in this investigation but not in previous upper body studies may be due to a number of reasons. Primarily, the level of the intervention resistance was not as high in this study as compared to the previous upper body studies. In the two studies that investigated the upper body during complex training, subjects performed 4-5 repetitions at a resistances of about 85-90% 1RM in the bench press alternated with medicine ball drop throws or explosive push ups, with no performance augmentation reported in either study (11, 15). In the present study a resistance of only 65% 1RM precipitated an increase in power output during the ensuing power set. This result would directly indicate that very heavy resistances are not required to enhance the contrast effect during upper body complex training. The use of very heavy resistances of 85-90 % 1RM in contrast loading for the upper body may not be as effective as for the lower body, possible due to the smaller muscle mass involved. Certainly some pilot work involved with this investigation found equivocal results when a resistance of 90% 1RM was used for the heavy resistance set. Perhaps any intervention resistance that is markedly heavier than the power resistance and hence provides a “contrast”, may be effective during complex training.

Another reason why power output was enhanced in this study and not in the other upper body studies may also be due to the very heavy resistance being performed at much slower lifting speeds (18). According to the “speed-control” theory (12) the neural output may have been attuned to the slower speed of very heavy bench pressing, reducing the possibility of favourable neural adaptations occurring during the ensuing, faster power exercise. Thus it is possible that very heavy resistances of >85-90% 1RM, with inherently slower lifting speeds, may not provide an optimal stimulus for upper body

complex training, as they may temporarily attune the neural output to a slower speed than is optimal for maximum power production. However, a resistance of 65% 1RM as used in this study still allows for high lifting speeds (18) and is also markedly heavier than the typical power training resistances. In the present study the alternated resistances were in sharp contrast to each other (mean resistance of 91.9 $\pm$ 9.3 kg during bench press alternated with 50 kg during bench throws).

Finally, the subjects in this study were trained power athletes who performed contrasting resistance complex training on a regular basis (1-2/wk) and were much stronger (by about an average of 50-60%) than the subjects in previous upper body studies (15). Young et al. (26) reported greater performance augmentation in the strongest subjects, indicating strength levels may be an important predictor of success for contrasting resistance complex training. For example, the two strongest subjects in the present study had an average augmentation to performance of 6.2% as compared to 0.8% for the two least strong subjects. This may partially explain the lack of significant results reported previously for the upper body (11, 15).

Based upon this result and research upon lower body power output, coaches need not have to rely upon extremely heavy resistances to provide a "neural training stimulus" during complex training. It is conceivable that any resistance that is markedly heavier than the power training resistance may elicit a favourable contrast loading training response (1, 2, 3, 5). The importance of this concept is that if strength coaches use a heavy-light system within the training week, they could easily integrate contrasting resistance training into the "light" training day of the week (eg. alternating "light day" bench presses of 65-75% 1RM with bench throws of 20-50% 1RM) .

It must be noted that the lighter power exercise should be an exercise in which full acceleration can occur through the full range of motion (eg. the weight does not need to be decelerated to remain in the subjects hand at the

completion of a repetition). If a traditional exercise such as squat or bench press is performed with low resistances of 30-45% 1RM, then the large deceleration epoch that occurs at the end of the range of motion severely compromises power output (18, 19, 21, 22). Therefore it may be better to perform bench press throws (in a Smith machine), explosive pushups, medicine ball throws and barbell jump squats or other jumps with the lighter resistances than to attempt to perform explosive versions of the traditional bench press and squat exercises. The traditional exercises of bench press and squat are reserved for the heavy resistance set and/or strength development. Full acceleration exercises (eg. throwing, jumping, weightlifting pulling movements) are required as the power training exercise. Based upon these results it is also recommended that future training and research for upper body power training utilize resistances of 60-70% 1RM for the heavy resistance set and 25-40% 1RM for the power training set to garner significant results.

Practical applications

An increase in power output can occur during upper body power training when sets of a heavy resistance, strength-oriented exercise are alternated with sets of a lighter, power-oriented training exercise. In this study a resistance of 65% 1RM, a resistance which is lower than is commonly recommended (11, 15, 26), was heavy enough to elicit an increase in power output during the performance of the ensuing power training exercise. Resistances of 65% 1RM are typical of the resistances that many coaches often prescribe on the lighter training day of a week and accordingly contrast loading complexes of exercises could be easily integrated into the training routine on this day (3). Typically, the heavy resistance set could be about twice the resistance of the power training set, which should be enough of a contrast to have the desired stimulatory effect upon the neuromuscular

system. Common examples for the upper body would be bench press alternated with lighter 1-hand or 2-hand bench press throws in a smith machine, various forms of explosive push-ups or medicine ball throwing exercises.

It is possible that acute augmentation to sport performance could be achieved by the use of contrast loading in the latter phases of the warm-up. The use of weighted bat donuts, slightly heavier than normal balls or throwing implements (shot-putt, discus, hammer) are examples currently used in upper body power-sports warm-ups. Astute coaches should be able to devise methods to use this technique in many other upper body sports.

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Paper 5.

"Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. "

by

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published in the

Journal of Strength and Conditioning Research,

19(1):202-205. 2005.

Abstract

It is known that the efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength. It has also been demonstrated that weak antagonists may limit speed of movement and consequently that strengthening the antagonist muscles leads to an increase in agonist muscle movement speed. However the effect of combining agonist and antagonist muscle exercises into a power training session has been largely unexplored. The purpose of this study was to determine if a training complex consisting of contrasting agonist and antagonist exercises would result in an acute increase in power output in the agonist power exercise. Twenty-four college-aged rugby league players who were experienced in combined strength and power training served as subjects for this study. The subjects were equally assigned to an experimental (Antag) or control (Con) group who were no different in age, height, body mass, strength or maximal power. Power output was assessed during bench press throws with a 40 kg resistance (BT P40) using the Plyopower training device. After warming up, the Con group performed the BT P40 tests three minutes apart to determine if any acute augmentation to power output could occur without intervention. The Antag group also performed the BT P40 tests, however an intervention strategy of a set of bench pulls, which is an antagonistic action to the bench throw, was performed between tests to determine if this would affect acutely power output during the second BT P40 test. While the power output for the Con group remained unaltered between test occasions, the significant 4.7% increase for the Antag group indicates that a strategy of alternating agonist and antagonist exercises may acutely increase power output during complex power training. This result may affect power training and specific warm-up strategies used in ballistic sports activities, with increased emphasis placed upon the antagonist muscle groups.

Key words: reciprocal inhibition, triphasic pattern, acceleration

Introduction

It is known that the efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength or torque (7, 9, 17). This appears to be achieved by a neural strategy of enhanced reciprocal inhibition of the antagonist musculature. However, little research has been conducted examining the role of agonist and antagonist muscle interplay in power movements. The faster lifting speeds involved in power training may make it more difficult (as compared to traditional strength training) to efficiently control unwarranted co-contraction between agonist and antagonist muscle groups, potentially reducing power output (18).

It has also been demonstrated that weak antagonist muscles may limit speed of movement (22) and that strengthening of the antagonist muscles leads to an increase in agonist movement speed (16). It would therefore seem prudent to strengthen the antagonist muscles involved in the power training action or movement. One method of integrating strength and power training into a training session has been labeled as complex or contrast training (1-5, 10, 11, 13, 14, 23). Traditional recommendations for contrast loading have included the alternating of sets of heavy and light resistances in similar agonist exercises or movement patterns (13, 14, 23). This method of alternating contrasting resistances to enhance power output has been substantiated for the lower body on a number of different occasions (1, 3, 4, 14, 23). It has also been shown that heavy resistance exercises increase the concentric rate of force development while lighter, plyometric type exercises enhance eccentric rate of force development (22). This combination of effects conceivably partially explains the success of this combined method of power training. With regards to upper body complex training, only one study to date has documented any significant effects (5) with other studies reporting no augmentation to power output or performance (11, 15).

While the traditional methodology of complex power training has entailed contrasting resistances in similar agonist exercises (eg. alternating heavy and light resistances in squats and jump squats), no research exists concerning complexes of contrasting muscle actions. If some augmentation to force output occurs due to a neural strategy of enhanced reciprocal inhibition of the antagonist musculature, then contrasting strategies involving the antagonist musculature may also prove fruitful for enhancing power output. In support of this, Burke et al. (8) recently reported that a high speed antagonist contraction immediately preceding an agonist contraction resulted in increased torque during the agonist contraction (isokinetic seated bench press/pull movements). As yet it has not been determined if the effect reported by Burke et al would transfer between alternating sets of agonist and antagonist exercises in typical isoninertial resistance training.

The purpose of this study was to examine the acute effect upon power output of alternating agonist and antagonist exercises during typical isoninertial complex power training.

Methods

Experimental approach to the problem

To determine if power output generated during an exercise could be acutely affected by the subsequent performance of an antagonist exercise, an intervention study was implemented. This entailed two groups of athletes performing a Pre test of power output during bench press throws with a standard resistance. The control group would then repeat this test three minutes later to provide data pertinent to whether power output could be acutely affected without some form of active intervention. The experimental group would perform the same tests, however an intervention strategy of performing a set of an antagonist exercise of bench pulls between power tests would be implemented to determine whether power output could be acutely

affected.

Subjects

Twenty-four college-aged rugby league players who possessed at least 1 year of resistance training experience and specifically at least 6 months of contrast/complex power training served as subjects for this study. They were informed of the nature of the study and voluntarily elected to participate in the testing and intervention sessions and were divided equally into an experimental (Antag) and control group (Con). A description of the subjects is contained in Table 1.

Table 1. Description of subjects. Mean (standard deviation).

	Age (yrs)	Height (cm)	Mass (kg)	1RM BP (kg)	BT Pmax (w)
Antag (n =12)	18.7 (.65)	184.5 (6.0)	87.6 (6.8)	111.2 (6.9)	522 (43)
Control (n =12)	19.0 (1.0)	184.1 (5.3)	93.0 (9.3)	115.8 (15.1)	554 (84)

Testing procedures

Power output was tested during explosive bench press style throws with an absolute resistance of 40 kg (BT P40) using the Plyometric Power System (PPS, Norsearch, Lismore, Australia), which has been described extensively elsewhere by various authors (4-6, 18-22). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a "Smith" weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide about two

hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power output in watts (w) of the concentric phase of the bench press throws based upon the displacement of the barbell, time of displacement and mass of barbell (* gravity) data (M * G * D / T=Power output in watts, where G = gravity). Test reliability of r = 0.92 was previously established with a group of 12 subjects.

Prior to pre-testing, subjects warmed up by performing five repetitions of both the bench press (60 kg) and bench throw exercise (20 kg). After three minutes rest, the subjects performed the pre-test, which consisted of five consecutive repetitions with the investigated resistance (Pre-BT P40). Only the repetition with the highest concentric average power output was chosen and recorded for analysis. The Con subjects were Post-tested after three minutes rest. This provided data pertinent as to whether any augmentation to power output may occur without active intervention.

The experimental Antag group performed the intervention strategy of a set of a moderately heavy resistance antagonist muscle action exercise. In this case the prone bench pull with a free weight barbell was used. For this exercise, the subjects lie prone upon a special high bench with the barbell placed upon the floor directly under their chest. The subjects were instructed to pull the barbell as forcefully as possible towards their chest-abdomen region for eight repetitions. The construction of the bench prevented any impact of the barbell with the subject’s body. The subjects were allowed to virtually drop the bar to the floor to lessen any potential effect of fatigue that may have arisen from the slow or careful eccentric lowering of the barbell. This meant about a 1-2 second rest existed between consecutive repetitions as the subjects re-gripped the bar. These strategies were implemented to

ensure the athletes performed the bench pulls in manner similar to the bench throws (ie. explosively and with loss of hand contact with the bar). The resistance of the barbell for the bench pull was set at 50% of each subjects 1RM BP. This meant the subjects were bench throwing a mass of 40 kg and prone bench pulling a mean barbell mass of 56.2 kg (+ 3.8 kg). The Antag group was then retested for BT P40 three minutes after completing the intervention strategy of bench pulls.

Statistical Analyses

To determine the effect of the intervention on test occasion, a repeated measures analysis of variance (ANOVA) was used. Significance was accepted at an alpha level of $p < 0.05$ for all testing.

Results

The results are detailed in Table 2. The 4.7 % increase in the Post-test BT P40 as a result of the intervention strategy of heavy antagonist bench pulls for the Antag group was statistically significant. The power output for the BT P40 remained unchanged in the Control group between test occasions.

Discussion

The experimental Antag group increased power output as a result of the intervention of a set of antagonist bench pulls between sets of the power exercise while the power output for the control group remained unaltered. The acute increase in power output as a result of the contrasting contraction strategy gives support to the effect reported by Burke et al (8). If this augmentation to power output was due to a neural strategy of enhanced reciprocal inhibition of the antagonist musculature, then the nature of these strategies might need to be discussed to provoke further research in this area.

Table 2. The acute effect upon power output of imposing a set of antagonist prone bench pulls between sets of bench press throws with 40 kg. Mean (standard deviation).

	BT P40 power output (w)	
	Pre	Post
Antag	468 (31)	490 (38)*
Control	508 (54)	505 (59)

* denotes significantly different from Pre test occasion, $p < 0.05$

During some rapid, ballistic movements of the limbs a particular neural pattern of motor unit firing known as the triphasic or "ABC" pattern becomes evident (16). This pattern is characterized by a large "Action" burst of activity by the agonist musculature followed by a shorter "Braking" burst of activity by the antagonist musculature of the limb and finally a short "Clamping" burst again by the agonists to complete the movement. As the net force produced during a movement is a trade-off between the force of the agonists and the counteracting force of the antagonists (7, 9), then the interaction between these bursts of myoelectrical activity warrant interest. Strength training reduces the interfering effect of co-contraction between agonists and antagonists in rapid movements (16). Therefore a more efficient control of the ABC pattern may benefit the power athlete.

For example, the "maximal resistance" theory of myoelectrical augmentation (10, 11, 13, 14, 23) in agonist complex training (eg. alternating very heavy squats and light jump squats) would rely on an increase in the

"Action" burst of activity in the agonists muscles (caused by enhanced neural stimulation resulting from the very heavy squats) to facilitate the increase in power during the ensuing exercise. This would be the "post-tetanic potentiation" advocated by Gulich & Schmidtbleicher (14). However, in this study a contrasting antagonist contraction was alternated with the power exercise and hence it is not readily conceivable how this strategy could directly affect the amount of activity of the Action burst of the agonists. It is conceivable that the heavy bench pull set effected the timing of the "Braking" burst of the antagonists during the agonist power exercise. A shorter, more succinct "Braking" phase would mean that the agonist Action burst could be continued for longer into the total contraction time (16). Given that the total concentric contraction time during bench throws with this sort of resistance is only around 500-650 msec (19), then any significant increase in action time and reduction in braking time could be beneficial. Indeed Jaric et al. (16) demonstrated that increased strength of the antagonists as a result of training resulted in increased speed during ballistic elbow flexion movements. They demonstrated that the increased strength allowed for a shorter "braking" period, a greater relative acceleration period and favourable alterations in the ABC myoelectrical patterns. Some evidence also suggests that increased power output could result without increased agonist or antagonist strength if a more synchronous firing of motor units within a muscle occurred within the first 60-100 ms of the contraction (18). Conceivably, complexes of agonist and antagonist exercises may aid in these situations.

While this study illustrated the acute effect upon power output of alternating agonist and antagonist exercises during complex training, it is unknown if this effect would transfer to greater increases in power output over long term periods. Longitudinal studies of many months duration need to be performed that compare the development of power through various intervention strategies used in complex training to the more traditional straight

sets method of power training. Conceivably this agonist/antagonist strategy could also be used as a specific warm-up strategy to acutely increase power output for sports activities. For example, baseball pitchers and tennis players could alternate antagonist shoulder external rotation exercises (eg. with rubber tubing) with their agonist pitching and serving drills.

When selecting antagonist power training exercises it may be even more appropriate to choose exercises that allow acceleration for the entire range of movement. For rapid upper limb movements this could mean throwing movements alternated with rapid pulling movements, such as the top pulls and power cleans from hang/boxes. The alternating of agonist and antagonist power exercises may be area for future exploration for strength coaches.

Practical applications

While traditional contrasting resistance/complex training recommendations have focused upon the alternating of heavier and lighter resistances in exercises of similar agonist movement patterns, the alternating of agonist and antagonist movement patterns may be useful in ballistic power training. The effect of directly stimulating the antagonist musculature in a power-training complex may be to reduce the time necessary for the braking phase that occurs about halfway through the ballistic limb movement in the ensuing agonist movement. In turn, this may increase resultant force, speed and power. Practical combinations of agonist and antagonist exercises for the upper body would be bench press throws and bench pulls, bench press throws and power clean from hang or various forms of explosive medicine ball throwing alternated with explosive pulling, shoulder external rotation and elbow flexion exercises (with resistance provided by dumbells, rubber tubing, medicine balls or sports implements in some cases).

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Paper 6.

"Acute negative effect of a hypertrophy-oriented training bout on subsequent upper-body power output."

by

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published in the

Journal of Strength and Conditioning Research,

17(3):527-530. 2003

Abstract

Athletes regularly combine maximal strength, power and hypertrophy-oriented training within the same workout. Traditionally it has suggested that power-oriented exercises precede strength and hypertrophy-oriented training within a workout to avoid the possible negative effects that the latter types of training may have upon power output. However, with regards to upper body training, little study has been performed to verify this commonly held belief. The purpose of this study was to determine the extent, if any, of a high repetition, short rest period, hypertrophy-oriented training dose upon upper body power output. Twenty-seven college-aged rugby league players were tested for average power output during bench press throws with a resistance of 40 kg (BT P40). The experimental group (Hyp, n = 15) then performed a typical hypertrophy-oriented work bout (3 x 10 at 65% one repetition-maximum bench press,1RM BP) before being retested for power output with the same resistance. In comparison to the control group (Con, n = 12), whose power output remained unchanged between the Pre- and Post-test periods, the Hyp group experienced a large, significant decrease in BT P40 power output. Even after further passive rest of seven minutes, power output remained suppressed from the Pre-test values. Furthermore, the strongest five subjects experienced significantly larger percentage declines in power output than did the five less strong subjects. This study shows that a high repetition, short rest period training can acutely decrease power out. Coaches should plan the order of exercises carefully when combining power and hypertrophy training.

Key words: bench press, bench throw, fatigue, strength

Introduction

Typical recommendations have suggested that power training should precede strength or hypertrophy-oriented training within a workout or training cycle (3, 21). It is thought that these other forms of resistance training may induce some acute fatigue that could compromise power output (21). However, those who advocate complex training embrace the alternating of strength and power exercises or sets within a workout (2, 3, 4, 11, 12, 14 15). The strength work recommended within contrast/complex training is typically of very low volume (3, 11, 14), which may not have a deleterious effect upon power output and indeed has been shown to increase power output (4, 6). However, hypertrophy-oriented training is usually distinguished from strength-oriented training by a much higher training volume (21). Theoretically this higher volume of training may acutely impair power output (21). In some support of this hypothesis is the recent work of Leveritt and Abernethy (18) who reported a decrease in squat strength and isokinetic knee extension torque following a bout of mixed aerobic and anaerobic exercise.

To date few studies exist that have examined the acute effect of higher volume hypertrophy-oriented training on upper body power output within a workout, despite the seemingly commonality of the “power before hypertrophy” edict. The purpose of this study is to report the acute effects of a dose of high volume, hypertrophy-oriented training on power output during upper body training.

Methods

Subjects

Twenty seven college-aged rugby league players, who were experienced in power training, served as subjects for this study. They were informed of the nature of the study and voluntarily elected to participate in the testing and intervention sessions. Fifteen were assigned to the experimental

group (Hyp), who were to perform the hypertrophy-oriented intervention strategy, while twelve served as controls (Con). There was no difference between the groups in any of the performance tests such as One-repetition maximum bench press (1RM BP) or bench press throw maximal power output (BT Pmax) that were conducted 72 hours prior to testing. Nor was there any difference in anthropometric data. The mean ($\pm$ standard deviation) height, body mass, age, 1RM BP and BT Pmax were 182.7 $\pm$ 5.5 cm, 88.1 $\pm$ 6.0 kg, 19.1 $\pm$ 1.2 yrs, 112.8 $\pm$ 8.2 kg and 523 $\pm$ 43 W for the Hyp group and 1823.2 $\pm$ 4.5 cm, 92.4 $\pm$ 9.7 kg, 18.8 $\pm$ 1.1 yrs, 116.0 $\pm$ 15.0 kg and 560 $\pm$ 88 W, for the Con group.

Testing

Power output was tested during explosive bench press style throws with an absolute resistance of 40 kg (BT P40) using the Plyometric Power System (PPS, Norsearch, Lismore, Australia), which has been described extensively elsewhere (2-10, 19, 20, 22, 23). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a "Smith" weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide about two hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average mechanical power output in watts (w) of the concentric phase of the bench press throws based upon the displacement of the barbell, time of displacement and mass of barbell (* gravity) data (M * G * D / T=Power output in watts). Test reliability (r = .92) was conducted using the Con group, who were retested after four days. Prior to pre-testing, subjects warmed up by performing five repetitions of both the bench press (60 kg) and bench throw exercise (20 kg). After three minutes rest, the subjects

performed the pre-test, which consisted of five consecutive repetitions with the investigated resistance (Pre-BT P40). Only the repetition with the highest concentric average power output was chosen and recorded for analysis.

The Con subjects were Post-tested after three minutes rest. This provided data pertinent as to whether any augmentation to power output may occur without active intervention.

The Hyp subjects performed three sets of ten repetitions of the free weight bench press exercise with a resistance of 65% of their 1RM BP, separated by a 1.5 minute rest between sets. This intervention strategy was chosen as a typical example of a hypertrophy-oriented workout. The Post-testing consisted of the athletes repeating the BT P40 test two more times (Post #1 BT P40 and Post #2 BT P40). A 1.5 minute rest period existed between the conclusion of the intervention segment (3 x 10 @ 65%1RM BP) and Post #1 BT P40 to determine the immediate effects upon power output of such a hypertrophy-oriented bout of resistance training. After five more minutes rest the subjects performed another test (Post #2 BT P40) to gauge the extent of recovery. Statistics

To determine if any difference existed between the Hyp or Con groups at any testing occasion a two-way analysis of variance (ANOVA) with repeated measures was used. To discern if absolute workload had a more deleterious effect upon power output in stronger subjects, two largely disparate sub-groups were identified. A factorial ANOVA based on each subjects absolute 1RM BP was used to identify two significantly different groups of five subjects (Strong and Less Strong). The percentage decline results for these two sub-groups were also compared using factorial ANOVA. Significance was accepted at an alpha level of $p \leq 0.05$ for all testing.

Results

The results are outlined in Table 1. All post-test scores for the Hyp

group were significantly different from each other ($p \leq 0.05$) and from those of the Con group, who remained unchanged. The intervention strategy of high repetition, short rest period, hypertrophy-oriented training had caused an acute 18% decrease in power output to be manifested 1.5 minutes after the cessation of the last intervention set. After a further five minute rest period (about seven minutes after the last intervention set), power output was still depressed by an average of 6.6%.

Table 1. Acute effect of performing high repetition, short rest period, hypertrophy-oriented training upon power output (w). Mean $\pm$ standard deviation.

	Pre-BT P40	Post-#1 BT P40	Post-#2 BT P40
Hyp group	479 ± 29	393 ± 41*	447 ± 32*
Con group	508 ± 54	505 ± 59	-

* denotes test scores significantly different to each other at all occasions

Discussion

The results detailing the deleterious effect of just three sets of hypertrophy-oriented training on power output support the common edict that power exercises should be performed before or separate from high repetition or hypertrophy-oriented training. The fatiguing effects of high repetition, short rest period training was quite pronounced and actually had a more pronounced effect than a much longer, more voluminous conditioning bout had upon muscle strength in previous research (1, 18).

Leveritt and Abernethy (18), who studied the acute effects of prior combined aerobic and anaerobic conditioning training upon squat and

isokinetic knee extension strength and Kramer et al (17), who reported large reductions in work capacity resulting from high volume, short rest period protocols, stated the source of such impairment in performance may be due to a combination muscle acidosis (high muscle lactates) or changes in the electrical/tissue properties of the muscle. Neither of these factors by themselves would appear to capable of the 18% decline in power in the current study and as such this study tends to support a multi-faceted fatigue approach. For example, as isokinetic strength can be impaired even four hours after an acute dose of such conditioning, by which time muscle acid levels should have returned to normal, then this may not be the only fatigue mechanism (1). In this study the prescribed intervention workload should not have depleted glycogen to such a level that it could account for the 18% decline in power output and the fact that power levels increased significantly after a further five minutes rest tends to support this. In light of Hakkinen's (16) research demonstrating acute “neural fatigue” within a training session consisting of multiple sets of maximal effort squats, this avenue of fatigue must also be considered. With increased rest (7 mins) there was a gravitation back towards pre-test power levels, indicating that simple rest offers some respite from the mechanisms inducing performance decrement. Simple rest may provide time for lactate clearance and neural “relaxation”, helping to restore power levels.

Another possible neural source for decreased power output may be, in part, due to the “Speed-control Theory” as enunciated by Enoka (13). The slower speed of the hypertrophy-oriented training may tune the neural system into performing the power test at a less than the normal speed, resulting in lower post-test power outputs.

An interesting observation of the results was the effect of absolute workload upon fatigue. While every subject lifted the same relative workload as the intervention strategy (3 x 10 @ 65% 1RM BP), stronger (in absolute

mass lifted) subjects performed a much higher absolute workload. To discern if this absolute workload had a more deleterious effect upon power output, two largely disparate groups of five subjects were identified, based upon absolute 1RM BP (a Strong and Less Strong group). This strategy of discerning disparate sub-groups of only 5 or 6 of the strongest or less strong subjects within a population has been performed before and yielded interesting results upon the adaptations to resistance training (6, 23). A significant difference ($p \leq 0.05$) in the degree of decline in power output from the Pre-BT P40 to the Post #1 BT P40 was observed between the Strong (24.4%) and Less Strong groups (13.1%). Thus the stronger subjects, performing higher absolute workloads for the intervention strategy (8000 kg v 6750 kg), fatigued to a significantly greater degree than their less strong counterparts. Previously it has also been shown that high-volume training accompanied by very short rest periods severely compromises work capacity in very strong athletes (17). This result would indicate that for stronger athletes, even greater care must be taken to ensure the negative effects of high repetition, short rest period training does not impact upon power training.

Practical applications

High repetition, short rest period hypertrophy-oriented training has a significant severe acute impact upon power output. This negative impact upon power output is still significant seven minutes after a mild dose (3 x 10) of such training. It could be posited that if a number of exercises were performed in such a hypertrophy-oriented training session, than the cumulative effects upon power output would be even more severe. As such it must be recommended that high repetition, short rest period training not be alternated with or performed before power training sets or exercises.

A significantly higher decline in power output was noted in the five strongest athletes, as compared to the five less strong athletes. Given that

stronger athletes perform higher absolute workloads than less strong athletes, strength coaches should be aware of the possible interfering effects that the compounding (eg. 5-10 exercises x 3 sets x 10 repetitions) of hypertrophy-oriented training may have upon power output within a session or training week. Consequently, strength coaches may need to curtail or carefully manage the hypertrophy-oriented training of their strongest athletes when in training cycles aimed at maximizing power output.

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Paper 7.

"Adaptations in upper body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes."

by

Daniel Baker and Robert U. Newton

published in the

Journal of Strength and Conditioning Research, 20(3):541-546, 2006.

Abstract

The purpose of this investigation was to observe changes in maximal upper body strength and power and shifts in the load-power curve across a multi-year period in experienced resistance trainers. Twelve professional rugby league players who regularly performed combined maximal strength and power training were observed across a four year period with test data reported every two years (years 1998, 2000, 2002). Upper body strength was assessed by the one repetition maximum bench press (1RM BP) and maximum power during bench press throws (BT Pmax) with various barbell resistances of 40 to 80 kg (BT P40-80). During the initial testing, players were also identified as Elite (n=6) or Sub-elite (n=6) depending upon whether they participated in the elite first division national league (NRL) or second division league. This sub-grouping allowed for a comparison of the scope of changes dependent upon initial strength and training experience. The Sub-elite group was significantly younger, less strong or powerful than the Elite group but no other difference existed in height or body mass in 1998. Across the four-year period significant increases in strength occurred for the group as a whole and larger increases were observed for the Sub-elite as compared to the Elite group, verifying the limited scope that exists for strength gain in more experienced, elite resistance trainers. A similar trend occurred for changes in BT Pmax. The changes in BT Pmax were highly correlated with changes in 1RM BP (r=0.75). This long-term observation confirms that the rate of progress in strength and power development diminishes with increased strength levels and resistance training experience. Furthermore, it also indicates that strength and power can still be increased despite a high volume of concurrent resistance and endurance training.

Key words: Bench press, bench throw, rugby league,

Introduction

It has been theorized that considerable gaps exist in our understanding of the long-term adaptations to resistance training due to the short term nature of most university based training studies (17, 39). Typically these training studies last 6-12 weeks and consist mainly of college students or athletes with limited resistance training experience serving as subjects (eg. 15). It has been demonstrated that the effectiveness of one program over another program may take at least 8-weeks to manifest itself (17, 28), limiting the extrapolative value of a number of studies. Furthermore, how the adaptations stemming from these shorter training studies reflect the adaptations that athletes training for many years may experience has been questioned by both experienced strength coaches and researchers alike (37, 39).

In light of these limitations Finnish researchers have garnered considerable data examining the adaptations resulting from participation in resistance training for periods longer than typically occur in American college-based studies. These studies have detailed the effects of training and detraining in periods of up to 6-months in athletes and various other population groups (19-26).

However, knowledge of long-term resistance training adaptations in elite athletes is scarce and tends to rely on cross-sectional data analysis (eg. 23). Very little longitudinal tracking data exists concerning the extent and nature of muscular adaptations resulting form prolonged resistance training over a multi-year period in elite athletes. To date only a few studies exist that track changes in maximal strength, force, power or various other muscular functioning tests across multi-year periods (16, 24, 25, 27). These studies reported that changes in muscular functioning reflect the nature of training, but also that the relative ease with which strength may be increased in novices

and those with a more limited training history is in stark contrast to the great difficulty that exists in trying to increase strength in experienced, elite strength athletes (17, 18).

Almost all of the multi-year data garnered from the above research has concerned lower body strength and power adaptations and little data exists concerning long-term upper body strength and power adaptations. The purpose of this study is to report upon the changes in upper body maximum strength and power levels as well as shifts in the load-power curve for a group of twelve highly resistance-trained professional rugby league players who performed combined maximal strength and power training for a four year period. Furthermore, the differential effects resulting from the initial resistance training experience of the athletes will also be examined.

Methods

Experimental approach to the problem

Three strength and power testing sessions conducted two years apart over four years in highly trained strength-power athletes (1998, 2000 and 2002). The subjects were professional athletes who performed combined upper body strength and power training on a regular basis. This repeated measures comparative analysis provide information pertinent to the long-term changes in strength and power output as a result of intense resistance training across a multi-year period. Differences in the extent of adaptations, based upon initial playing status and resistance training experience, would also be observed and compared.

Subjects

Twelve professional rugby league players who were experienced in strength and power training served as subjects in this investigation. All subjects were members of the same World Champion club team and underwent similar training (relevant to their playing position and individual

strength and power levels) during the four-year period. All subjects were aware of the methods and nature of the testing and voluntarily participated in the testing sessions, which were a regular part of their testing and conditioning regime. Of the twelve subjects, two disparate groups of six subjects each could be identified based upon resistance training experience and playing status at the commencement of the study. Researchers have been able to distinguish differences in the scope, magnitude or direction of adaptations to the same resistance training stimuli experienced by athletes with different starting levels of adaptation/strength (eg. 7, 8, 17, 38). These two groups were identified as an Elite group who were currently participating in the elite, first-division national league (NRL) in 1998 and had a resistance training experience entailing combined maximal strength and power training for a period of greater than three years and a Sub-elite group participating in the second division competition. The Sub-elite group was also training to become potential participants in the NRL. The Sub-elite group was younger than the Elite group and possessed a combined resistance training background of less than three years. Fortuitously, the disparate groups were matched exactly for playing position with three hit-up forwards, two outside backs and one hooker in each group. Descriptions of the group as a whole and of the two sub-groups are contained in Table 1.

Procedures

Training

Throughout the four-year period, training for the upper body was conducted on average, twice per week except in “end of season” periods where no training occurred (usually 4-6 weeks per year). The training program was periodized throughout the year with general preparation (usually 4-8 weeks per year), specific preparation (usually 6-10 weeks per year) and in-season competition (usually 24-32 weeks per year) periods. The

preparation period usually consisted of two linear periodization phases separated by a two-week transition period during the Christmas-New Year period. The general preparation phase contained only exercises that developed hypertrophy, basic strength and agonist/antagonist muscle balance. The specific preparation phase contained explosive power development exercises as well as strengthening exercises.

Table 1. Description of subjects as a whole Group (n=12) and as identified as Elite (n=6) or Sub-elite (n=6), based upon initial resistance training and playing experience in 1998. Mean (standard deviation).

	Body mass (kg)	Height (cm)	Age (years)
Group	97.8 (8.7)	186.7 (4.6)	20.2 (1.6)
Elite	95.5 (10.4)	186.3 (4.7)	21.3 (1.4)*
Sub-elite	100.7 (6.7)	187.2 (4.9)	19.0 (0.6)

* denotes significantly different between groups

In-season resistance training followed a wave-like periodization progression. The wave-like progression has been described previously (4), but briefly it entails repeating two cycles of three weeks with an additional introductory week emphasizing hypertrophy and a concluding week emphasizing peak strength and power (eight weeks in total). The first four-week block was geared slightly more towards developing basic strength and hypertrophy with a concomitant decreased volume of power exercises while the second four-week block was geared slightly more towards peaking maximum strength and power with an increased number of power exercises, increased training intensity and decreased training volume.

Within each training week, the first training day was oriented slightly more towards the development of maximal strength and the factors that affect strength (eg. hypertrophy, agonist/antagonist muscle balance) while the second training day was oriented slightly more towards the development of maximal power and other factors that affect power (eg. acceleration, rapid force development, ballistic speed). This alternating of strength- and power-oriented training days also caused an undulatory pattern (a higher load and lower load day) in the weekly periodization scheme throughout the year.

Typically upper body workouts lasted about 50 minutes in the preparation period and 30 minutes in the in-season competition period. Various other lower body (eg. full squats, jump squats, lunges, step-ups) and whole body exercises (eg. power clean, push press, jerks, 1-arm dumbbell snatches, Dominator whole body rotations) appropriate to rugby league (4) were also performed throughout the year following the same periodization scheme. Examples of how sets and repetitions were manipulated in different periods and phases are contained in Table 2.

As rugby league players cover distances of up to 10 km in each 80-minute game (30, 31), then endurance training is also of importance to the total preparation of the player. In the general preparation period, five conditioning sessions are performed each week (3 running, 1 wrestling, 1 mixed ergometry) with differing volumes, intensities and methods (continuous, fartlek, long interval, short interval). This is reduced to 2-3 endurance workouts in the specific preparation period with a concomitant increase in speed and agility training. Team tactical training sessions also entail running volumes of 2-5 km.

Table 2. Typical example of the sets and repetitions periodisation for upper body exercises for the maximal strength bench press (BP) and various assistant strength exercises (AS) and maximal power bench throw (BT) and various assistant power exercises (AP).

	General preparation		**Transition**	**Specific preparation**		
			Weeks			
	1-2	3-4	5-6	7-10	11-12	13
BP	4 x10	4 x 8	3 x 10-12	4 x 5	3 x2-3	Test
AS	3 x 10	3 x 8	2 x 10-12	3 x 8-10	3 x 5-6	
BT	N/A	N/A	N/A	4 x 5	4 x 2-4	Test
AP	N/A	N/A	N/A	3 x 5-8	3 x 3-6	

				In-season competition				
	1	2	3	4	5	6	7	8	9
BP	3 x 8	8-6-5	6-5-3	5-3-2	8-6-5	6-5-3	5-3-2	2-1-1	Test & repeat
AS	2x10	2x8	2x6	2x5	2x8	2x6	2x5	2x5	
BT	3 x 5	3 x 5	5-4-3	4-3-2	3 x 5	5-4-3	4-3-2	3-2-2	Test & repeat
AP	3x6	3x6	3 x5	3 x4	3x6	3x5	3x4	3x4	

Testing

Testing consisted of maximum upper body strength as assessed by the 1 repetition maximum bench press (1RM BP) according to the methods previously outlined (6, 7, 12). Testing of upper body maximum power (Pmax) was assessed during bench press throws (BT) using the Plyometric Power System (PPS, Plyopower Technologies, Lismore, Australia) and the methods

previously described (6-8, 13). Bench press throws in a Smith machine weight training device such as the PPS result in much higher power outputs than traditionally performed bench presses making this exercise more suitable for power testing (35, 36). Briefly, the PPS is a device whereby the displacement of the barbell is limited to the vertical plane, as in a "Smith" weight training machine. The linear bearings that are attached to each end of the barbell allow the barbell to slide up and down two hardened steel shafts with a minimum of friction. A rotary encoder attached to the machine produced pulses indicating the displacement of the barbell. The number of pulses, denoting barbell displacement, and the time of the barbell movement were measured by a counter timer board installed in the computer. The PPS software calculated the average power output of the concentric phase of each bench press throw based upon the displacement, time and mass data. Specifically, each subject performed three repetitions during bench press throws with 40, 50, 60, 70 and 80 kg (BT P40, BT P50, BT P60, BT P70 and BT P80), with only the highest power output at each resistance recorded. This battery of resistances allowed for generation of a load-power profile or curve (6, 8, 13, 35), similar to what has been done before for the lower body using jump squats with various resistances (19-21). The highest power output for any individual, irrespective of the resistance, was deemed the BT Pmax.

Statistical procedures

At the initial testing occasion, two disparate groups of six subjects could be identified based upon whether they were participating in the NRL team or the second-division team. These Elite and Sub-elite groups were compared using a factorial one-way analysis of variance (ANOVA) for performance and anthropometric data to discern if any differences existed between them (See Table 1).

The results for the whole Group 1RM BP, BT Pmax and BT P40-80 were compared using a repeated measures one-way analysis of variance

(ANOVA) to determine if any of the test scores in 2000 and 2002 differed from the base-line scores of 1998. Also the test scores for the Elite versus Sub-elite group were compared for the same variables. If a significant effect of test occasion was found, Fisher Least Squares Difference (PLSD) post hoc comparisons were performed to determine which test occasions produced significantly different results. Pearson's product moment correlations were used to determine the strength of relationships between variables. Statistical significance was accepted at an alpha level of $p \leq 0.05$. Due to the low subject numbers and difficulty of performing such research on elite professional athletes no adjustment of the alpha level was made for comparison of multiple variables.

Results

The results for changes in 1RM BP for the group as a whole and according to sub-grouping are contained in Table 3. The results for changes in BT Pmax for the group as a whole and according to sub-grouping are contained in Table 4. The changes in power output with various resistances ranging from 40 to 80 kg are displayed graphically in Figure 1 for the group as a whole and Figure 2 when compared according to sub-grouping. There was a significant increase in body mass up to 100.2 +/- 9.4 and 101.7 +/- 9.0 kg for year 2000 and 2002 respectively for the group as a whole. The Elite group increased body mass significantly by about 5% from 1998 to 2000 from where it remained statistically unaltered. The Sub-elite group's increase of 3% in body mass was only significant from 1998 to 2002. There was no significant difference between the sub-groups in body mass at any period.

Table 3. Results for 1RM BP for the group as a whole and according to sub-grouping as Elite or Sub-elite presented as mean (standard deviation).

	1RM BP (kg)		
	Group	Elite	Sub-elite
1998	129.6 (15.3)*	139.2 (11.6)+	120.0 (12.7)
2000	141.0 (15.6)*	144.6 (12.7)	137.5 (18.6)
2002	148.1 (16.5)*	147.5 (13.0)	148.7 (20.1)

* denotes that Group 1RM BP were significantly different at each test occasion,
+ denotes Elite group significantly different to Sub-elite in 1998 only.

Discussion

This study details the changes in strength and power across a 4-year period by a number of athletes who were members of a World champion team and who experienced in combined strength and power training.

Changes in subjects. Over the four years all Sub-elite players progressed to become "elite" players (by participating in the NRL competition), with the team winning two Championships. Seven of the twelve also earned selection into the national team, who were the World national team champions. Essentially by 2000, there were no differences between the sub-groups in performance data. These results merely reflect the high caliber of athlete involved in this observation.

Initial strength and power levels. The initial data from 1998 detailing the differences in strength and power between the Elite and Sub-elite group are to be expected and have been reported previously not just for upper body strength and power (6-9) but also lower body power (9) and abdominal strength (5) when comparing participants in the elite professional NRL to

participants in second and third division leagues (SRL and CRL). However the upper body strength levels of both groups appears to far exceed the average that had been previously reported for large groups of professional rugby league players (32), perhaps indicating the intensive resistance training history of the twelve subjects compared to other professional rugby league players. This is to be expected when it is considered that subjects in 1998 were World Champion club team members and could be expected to be stronger than less successful counterparts.

Table 4. Results for BT Pmax for the group as a whole and according to sub-grouping as Elite or Sub-elite. Mean (standard deviation).

	BT Pmax (w)		
	Group	Elite	Sub-elite
1998	611 (80)*	666 (61)*+	555 (55)*
2000	715 (81)	727 (55)	703 (105)
2002	696 (86)	699 (82)	693 (97)

* denotes BT Pmax in 1998 significantly different to year 2000 and 2002,
+ denotes Elite significantly different to Sub-elite in 1998 only

Changes in maximal strength. While the training group as a whole exhibited a 14.3% increase in 1RM BP across four years, the Elite group only exhibited a 6.0% increase compared to the 23.9% for the younger Sub-elite group. The results of this long-term observation suggest that maximum upper body strength can still be increased in experienced strength-power athletes, however there appears to be a diminishing degree of positive adaptation with increased training experience. Training experience and existing strength levels reduce the scope for strength improvement, even if both groups follow the same program (17). This becomes even more apparent by further

examining the progress over the last two years of the observation, from 2000 to 2002. During this two year period the Elite group exhibited only a 2.0% increase in 1RM BP, similar to the amount reported by Hakkinen et al (25) for the Finnish national Olympic weightlifting squad across a two-year period. The Sub-elite group exhibited an 8.1% increase in 1RM BP during this time period, further supporting the concept of diminishing progress with increasing training experience. In reality, the Sub-elite group are two years behind the Elite group in age and training experience in 1998 and hence the scope of adaptations experienced by the Sub-elite group for the final two year period from 2000 to 2002 are similar to the first two years of the Elite group. Thus it could be posited that the progress that the Sub-elite group make in the next two year period may also only quite small.

Changes in maximal power and the load-power curve. The results for changes in maximal power (BT Pmax) largely reflected the changes in 1RM BP, with diminished progress with increased training experience. For example, over the four year period the group as a whole significantly increased BT Pmax by 14%, with the Elite group improving only 5% compared to 25% for the Sub-elite group.

Power output with all investigated resistances (40 to 80 kg) also increased significantly from 1998 to 2000 and then remained unchanged. The emphasis on combined maximal strength and power training is reflected in greater increases in the heavier portion of the load-power curve. From Figures 1 and 2 it can clearly be seen that power output with heavy resistances such as 70 and 80 kg increases far more (13.7%) than power output with resistances of 40 kg (8.7%). This was one of the objectives of the training over the 4-year period as previous research has established that BT P70 and BT P80 significantly and strongly discriminate between rugby league players who participate in the NRL versus second and third division leagues (8).

Of interest is the fact that neither group's BT Pmax or load-power curve improved over the last two years of the observation. It is not clear why this occurred, but most simply it may again reflect the limited scope for improvement in power output with experienced athletes (17, 24-26).

Relationship between changes in strength and power. It has been well established that on a cross-sectional basis, maximum strength and maximum power are highly related (6-14). The relationship may reduce slightly with increased training experience or with the direction that training takes (eg. endurance training, strength-, hypertrophy- or power-oriented training may affect the relation, 7, 8). The results of this study tend to confirm this with a slightly diminishing correlation between 1RM BP and BT Pmax ranging from $r = .85$ to $r = .81$ to $r = .78$ at the three successive testing occasions for the group as a whole.

It is interesting to note is that changes in 1RM BP significantly correlated with changes in BT Pmax across the four-year period ($r = .75$, $p = .005$), which is in almost complete agreeance with the relationship ($r = .73$) that was reported across a 19-week in-season period in college-aged rugby league players (7). This suggests that increasing maximum strength is of extreme importance to athletes who need to increase maximum power. However, given the diminishing scope for strength improvements with increased training experience and the multi-faceted nature of power (34), other avenues of increasing Pmax, such as improving movement speed, must also be considered (8). When strength begins to plateau, such as for the Elite group after year 2000, then increases in maximum strength do not necessarily equate to increases in maximum power. Other methods of training may need to be embraced to enhance power output (3, 34).

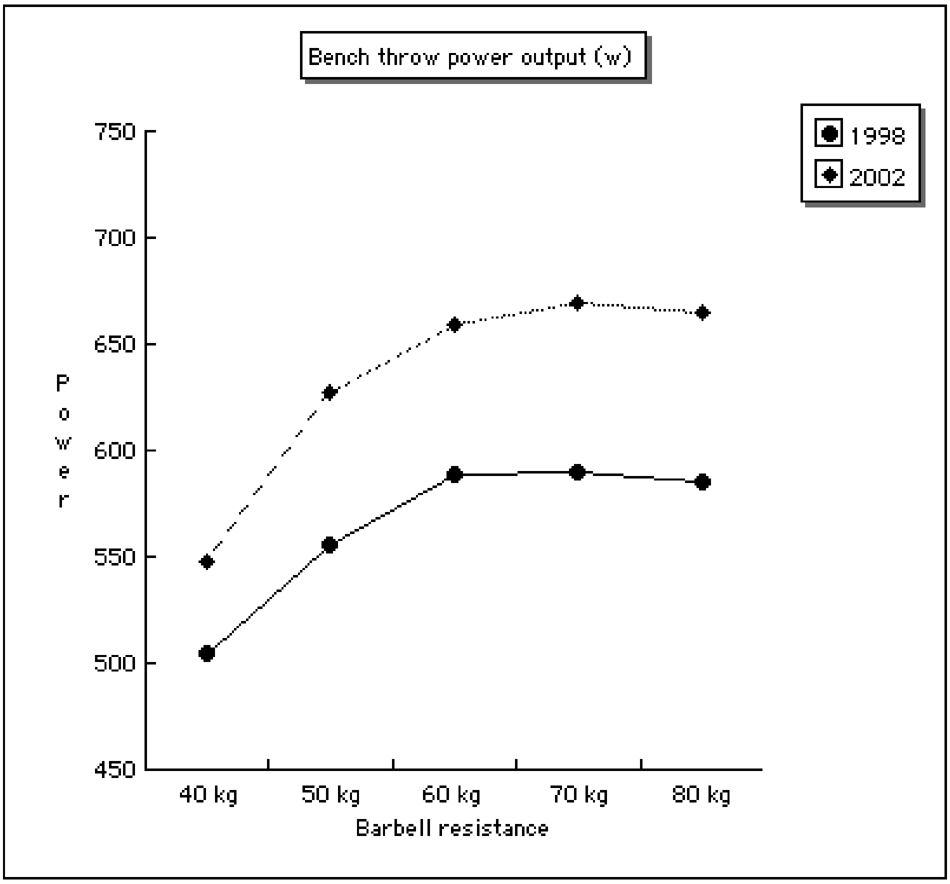

Figure 1. Shifts in bench throw load-power curve for the combined group (n=12) of rugby league players across a four-year period. All changes were significant. Because 2000 and 2002 were not different to each other, 2000 results have been omitted for clarity. SD bars omitted for clarity.

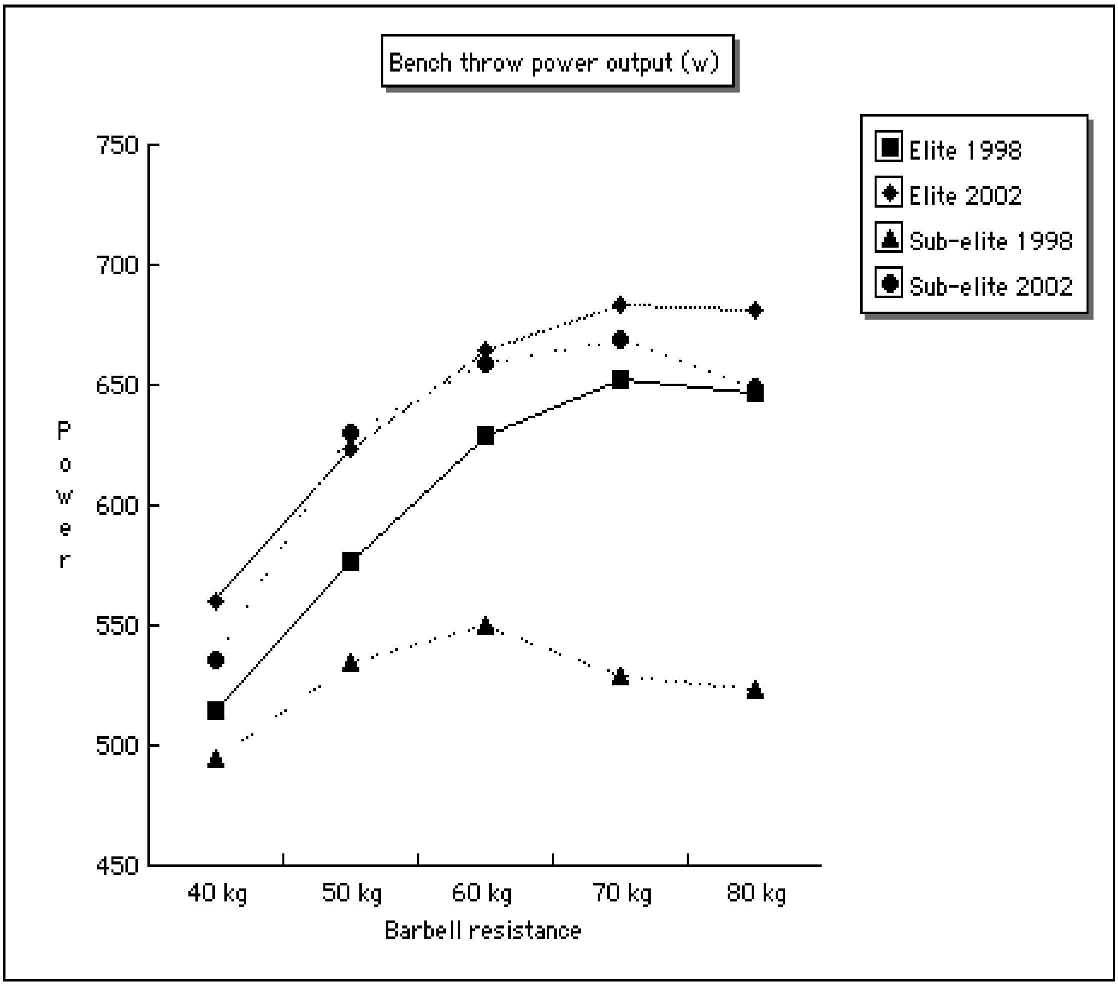

Figure 2. Shifts in bench throw load-power curve for the Elite and Sub-elite groups (n = 6 each) of rugby league players across a four-year period. All changes were significant. Because 2000 and 2002 were not different to each other, 2000 results have been omitted for clarity. SD bars omitted for clarity.

Relationship between changes in body mass and changes in strength and power. While it has been shown that changes in body mass or lean body mass largely account for increases in maximal strength in males accustomed to resistance training, especially in regards to upper body strength (12), that finding was not confirmed in this research (ns). Clearly with the experienced athletes in this study mechanisms such as neural, fiber or other morphological adaptations must have largely accounted for the changes in 1RM BP and BT Pmax rather than simple increases in body mass. The extent and nature of these adaptations is beyond the scope of discussion for this paper (see ref. 17, 18).

Concurrent strength and endurance training. This current observation has shown that the group as a whole increased strength and power by around 14% across four years, despite the large total concurrent resistance and conditioning workloads. Despite some current beliefs that strength and power cannot be improved or are severely limited when a large amount of conditioning and heavy resistance training are performed concurrently (1, 54) the results of this and other long-term observations (7, 29) emphatically illustrate otherwise.

It has been suggested previously that better conditioned athletes and more efficient periodization and sequencing of training may allow athletes to perform concurrent strength and endurance training without significant negative results (1, 7).

Practical applications

This long-term observation of changes in upper body strength and power output in experienced resistance trainers has supported the earlier findings concerning the limited scope for improvements in lower body strength and power with increased training experience.

Maximum upper body strength and power can still be increased in advanced strength-power athletes, however the degree of improvement diminishes with increased strength/power levels and training experience. The time frames over which increases in strength/power may be observed may become quite lengthy in more advanced athletes.

For advanced strength/power athletes it would appear that when both types of exercises are performed concurrently in the training regime, then statistically at least, increases in maximum strength go hand-in-hand with increases in maximum power. Based upon this result, it is recommended that coaches prescribe both strength and power exercises in a periodized fashion to maximise the muscular adaptations in multi-year resistance training.

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Paper 8

"The effects of systematic strength and power training during the formative training years: A comparison between younger and older professional rugby league players."

by

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published in

Strength and Conditioning Coach.

Vol. 11, No. 2, pp.9–11. 2005.

Introduction

Maximum levels of strength and power distinguish between rugby league players of different levels (1, 2). Professional players competing in the national rugby league competition (NRL) are stronger and more powerful than those in the State leagues (SRL), who in turn are stronger and more powerful than players in city based leagues (CRL) (1, 2). This can be predominantly attributed to greater strength and power training experiences and probably some degree of natural selection.

However, of interest is a comparison between younger and older players at the NRL level. Systematic strength and power training did not gain much popularity in some NRL clubs until the early till mid-1990's. This meant that some of the current older (>28 years) NRL players may not have performed much, if any, systematic strength and power training in their formative training years (circa 16-17 up to 21-22 years). In comparison, younger NRL players (<24 years) have generally been performing such training during their formative training years.

Therefore while both older and younger groups of NRL players may possess a strength training age of greater than five years, a difference between them could be described as when this training was undertaken (eg. 17-23 years v 23-29 years of age). Thus it would be of interest to compare the strength and power results for players, matched for playing position, who could be described as having undertaken systematic strength training at a younger or older age.

Methods.

A total squad of 20 NRL players was investigated. Twelve subjects could be identified and matched into a Younger (N=6) or Older (n=6) group. These groups each consisted of three forwards and three halves/hookers players. No difference existed in body mass or height between the groups,

however the Older group were significantly older (29.5 ± 2.4 v 23.2 ± .8 yrs) and had played more NRL games (199.3 ± 42.4 v 59.8 ± 27.4).

Testing of maximum strength consisted of a 1RM bench press (1RM BP) and 1RM full squat (1RM SQ) using the methods previously described (1, 2, 3, 4, 5, 6, 7). Testing of upper body maximum power (Pmax) included a bench press throw test (BT Pmax) with various barbell loads using the methods previously described (1, 2, 6). Testing of lower body power output consisted of a jump squat (JS Pmax) test with various barbell loads using the methods previously described (3, 4,7).

The results for each group were compared using a one-way analysis of variance (ANOVA) to determine if differences existed between the groups in 1RM BP, 1RM SQ, BT Pmax or JS Pmax. In the event of a significant F-ratio, Fisher PLSD post hoc comparisons were used to determine where these differences existed. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The results for all tests are contained in Table 1. The Younger group was significantly stronger and more powerful than the Older group in all of the four tests. For lower body tests the magnitude of the difference was 19% for both tests, while for the upper body the percentage differences were 13% (1RM BP) and 28% (BT Pmax).

Discussion

This study compared two groups of players who were matched for playing position and had basically performed the same training for four to five years previously, but were differentiated by only two factors (apart from age). These factors were (1) total NRL games and (2) the age that they had commenced and/or consistently performed systematic strength and power training. The basic finding was that the group that commenced systematic

strength training during their formative training years (circa 17-23 yrs) were significantly stronger and more powerful in both the upper and lower body, despite no significant difference in body mass or height, than the group who had commenced such training at a later age (>23 yrs). Why these large difference existed in strength or power must then be ascribed as due to some aspects related to either of these two factors listed above.

Table 1. Strength and power testing results for the Older and Younger NRL players. Mean ± standard deviation.

	1RM BP	1RM SQ	BT Pmax	JS Pmax
Younger	143.3 ± 15.4	182.5 ± 23.6	670 ± 78	1881 ± 254
Older	126.7 ± 7.5*	153.3 ± 12.1*	548 ± 48*	1579 ± 197*

* denotes statistically difference between groups.

Whilst the total number of professional NRL games would be expected to impact upon the integrity of the neuromuscular system (through the accumulation of playing and training injuries etc), which in turn may negatively affect strength and power, it is arguable that this alone could not explain the magnitude of the differences between the groups. What effect (either negative or positive) an extra 130 games (5-6 seasons) would have upon strength and power is impossible to determine. Furthermore, recovery methods used after games and during the training week are now far more professional than six or more years ago. Therefore this discussion will focus more upon the impact that commencing strength and power training at an earlier age may have had upon the results.

This analyses is unique in that a situation may not exist again whereby players from the same football club can be compared based upon what age

they commenced systematic strength and power training. It is inconceivable that a situation will ever exist again whereby players may play a number of seasons of NRL level without performing systematic strength and power training, as was the case in the early 1990's, making a another comparison like this unlikely. This is due to increased player professionalism and the greater role played by strength and conditioning coaches in the physical preparation of players.

Basically both groups had performed the same training for four to five years prior to this analyses, but were differentiated by at what age this training commenced. With the advent of the "super" professionalism (i.e. the Super League wars and the ensuing explosion in player payments in the mid-1990's), coaches demanded greater training commitments from players. Previously players generally trained 2-3 times per week with strength training not being compulsory and rarely performed in-season. Thus the Older group of players in this study participated in this type of regime during their formative training years prior to the mid 1990's.

In opposition to this, the Younger group of players in this study was in their formative training years (17-23 yrs) from the mid-1990's till now. This period has entailed four strength and power sessions per week during the pre-season and two per week during the in-season for all players in this study. So despite similar recent training dosages since late 1995, the Younger group displayed greater strength and power.

From international powerlifting records (IPF, 2000), it can be shown that the world records for athletes older than 23 yrs are greater than those for athletes younger than 23 yrs. Generally strength levels do not peak or at least begin to decrease till about 30-35 years of age (10). Therefore the gross affect of simply being older by about five years could not explain the differences reported in this study.

Thus it appears that performing systematic strength and power training from about ages 17-18 onwards will be of greater benefit than commencing this training at a later training age. This may be due to the effect that such training has upon the still maturing neuromuscular system of athletes of this age. Performing strength and power training at such an age may lead to more lasting positive adaptations within the neuromuscular system. This "value adding" effect of training at age 17-18 onwards may gradually dissipate as the athlete ages (into their early to mid-20's). It is not known exactly what this "value adding" of the neuromuscular system may be, but it is worthy of future longitudinal study.

Conclusions and practical applications

Commencing systematic strength and power training during the formative training years appears to be advantageous as compared to commencing training at a later stage. This may be due to a "value added" effect that such training may have upon the still maturing neuromuscular system. It is recommended that rugby league players commence strength and power training whilst still in their teenage years, although at this stage it is not known if starting at an even earlier age (circa 14-15 years) would be even more advantageous than commencing this type of training at 17-19 years of age.

Balyi (8) has outlined different stages of the long-term development of the athlete and has commented upon the importance of physical preparation in the "training to train" or formative training age. This analyses tends to support that view.

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Paper 9.

"Methods to increase the effectiveness of maximal power training for the upper body"

by

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published in the

Strength and Conditioning Journal

27(6):24-32. 2005.

Introduction

A cursory glance at many resistance training programs or recommendations aimed at increasing muscular power would typically reveal a high proportion of Olympic weightlifting (eg. power cleans, pulls) or plyometric exercises (eg. jumping, bounding) (3, 19, 21). While these methods of training often produce tremendous increases in lower body power, methods for developing upper body power appear less explored. Maximal upper body pressing/pushing power is of importance to both American and rugby football players and as well as boxers and martial artists to enhance the ability to push away/strike opponents. The purpose of this article is to outline some practical methods that have been implemented in our program to develop maximal upper body pressing power in rugby league players. Astute coaches will be able to determine the relevance and application of these concepts and methods to the broader area of athlete preparation for other sports.

Maximal power (Pmax) for the purpose of this paper is defined as the maximal power output for the entire concentric range of movement/contraction (peak power refers to the highest instantaneous power output for a 1-msec period within a movement) (5-10). Upper body pressing Pmax is usually determined by measuring power output during lifting of a number of different barbell resistances in a designated exercise (eg. bench press, BP or bench throws, BT, in a Smith machine) using the Plyometric Power System software (PPS, see 5-10, 25, 26) or other software or testing modalities. The load-power curve or profile (see Figures 1 and 2) that is generated for each individual from this testing can aid in prescribing training (5-10). For example, an individual whose load-power curve was characterized by high power outputs with light resistances but also exhibited pronounced reductions in power output with heavier resistances would be prescribed more maximal power-oriented and heavy resistance strength training. Maximal strength has

been shown to be highly correlated to Pmax in both the upper- (5-10) and lower-body (11) for both elite and less experienced athletes. As the relationship between an individuals change in Pmax and change in maximal strength as a result of training is much higher in less experienced athletes than it is in elite athletes (6).

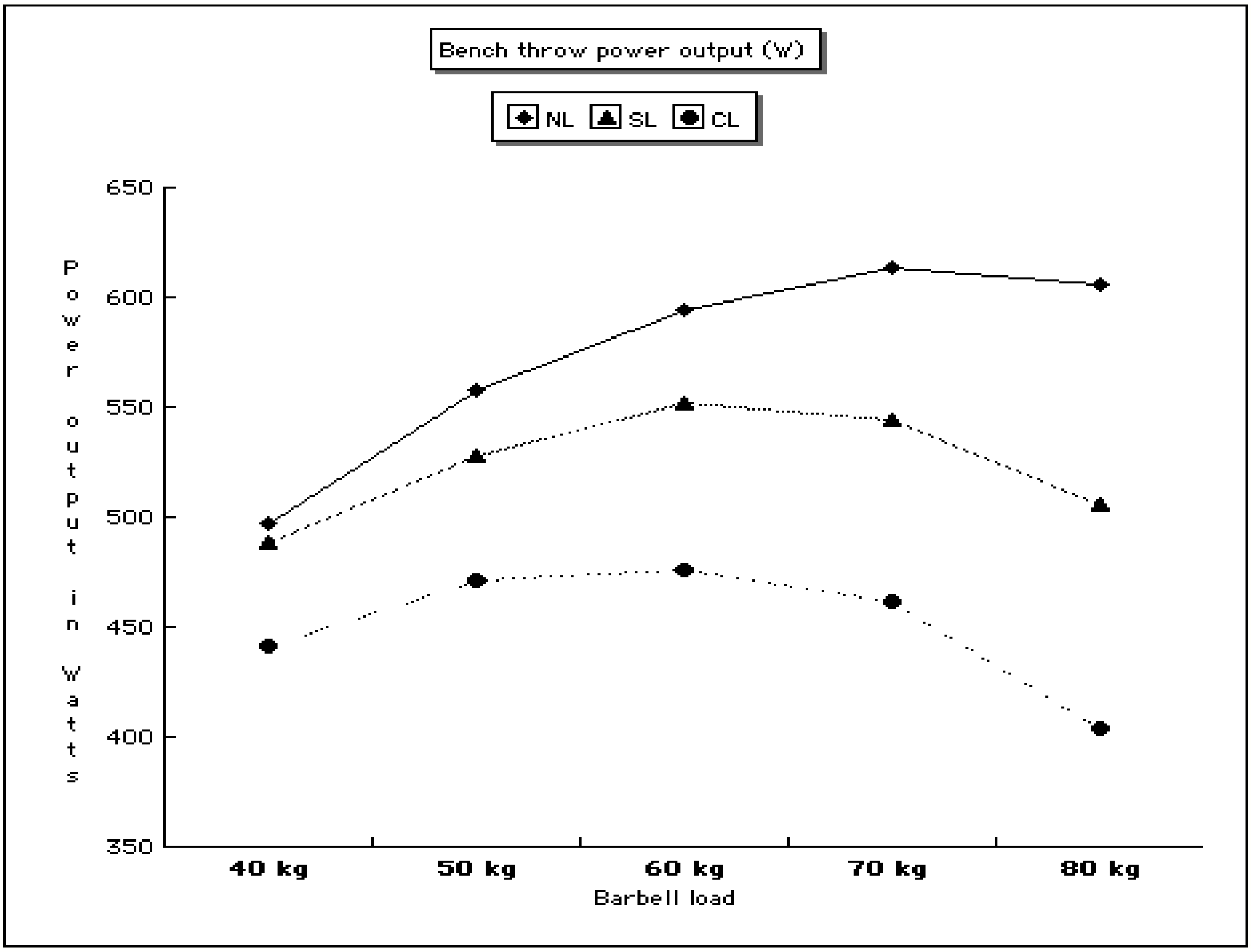


Figure 1. Load-power curves (average concentric power) for rugby league players participating in the professional National Rugby League (NL), or college-aged state leagues (SL) or city based leagues (CL). From reference 7.

However, as maximum strength is the physical quality that most appears to underpin Pmax, it is advisable that athletes who wish to attain high Pmax levels develop and/or maintain very high levels of strength in muscle groups important in the sport in both agonist and antagonist muscle groups. The strength of the antagonists should not be neglected for athletes who require rapid limb movements as research has shown that strengthening of agonists increases both limb speed and accuracy of movement due to favourable alterations in the neural firing pattern (22). It has been shown that some power training practices described below are only effective for stronger, more experienced athletes (14, 28). Once a good strength and muscle conditioning base has been established the following practices will be most useful.

1. Include full acceleration exercises as power exercises

It is important to differentiate exercises as being used primarily for the development of strength (or hypertrophy, depending on sets, reps, rest periods etc) or power. What differentiates between these two classifications of strength or power exercises is whether the performance of the exercise entails acceleration throughout the range of movement, resulting in faster movement speeds and hence higher power outputs (23, 25-27). Power exercises are those exercises that entail acceleration for the full range of movement with resultant high lifting velocities and power outputs. Strength exercises are those exercises that entail heavy resistances and high force outputs but also pronounced periods of deceleration resulting in lower lifting velocities and reduced power outputs (26). Performing an exercise where acceleration can occur throughout the entire range of movement (such as a bench throw in a Smith machine, see Figure 3, medicine ball throws, power pushups etc) allows for higher lifting speeds and power outputs (23, 25, 26). If athletes attempt to lift light resistances explosively in traditional exercises

such as bench press and squats, large deceleration phases occur in the second half of the movement, resulting in lower power outputs as compared to power versions of bench throw and jump squats (26, 27). Thus a heavy resistance bench press is considered a strength exercise whereas the bench throw is considered a power exercise.

Training to maximise upper body pressing/pushing power should entail both heavy resistance, slower speed exercises for strength development and exercises that entail higher velocities and acceleration for the entire range of movement for power development (eg. bench throws, medicine ball chest passes, plyometric pushups and other throwing exercises, ballistic pressing/pushing exercises) (3, 7). This approach should result in the musculature being to contract both forcefully and rapidly.

2. Alter the kinetics of some strength exercises to more favorably affect rapid-force or power output

Because heavy resistance strength exercises such as bench press typically entail slow movement speeds and low power outputs (23, 26), they alone are not specifically suited to developing Pmax (23). This phenomenon has been the subject of considerable research attention. There are power specific adaptations in terms of the neural activation, muscle fiber/contractile protein characteristics and muscle architecture (12) that must be considered. As discussed above, attempting to lift light resistance bench presses explosively also results in large deceleration periods (26). However, there are a number of strategies that the strength coach can implement to alter the force profile or lifting speeds of strength exercises to make them more suitable to rapid-force development.

For example, the performance of the bench press can be modified by adding chains to the end of the barbell to alter the kinetics of the exercise so that the acceleration phase can be extended further into the range of

movement. When the barbell is lowered to the chest, the chains are furled on the floor and only provide minimal resistance (see Figure 4). As the barbell is lifted, the chains unfurl and steadily increase resistance throughout the range of motion (see Figure 5). This method means that a lighter resistance (eg. 50-75% 1RM) can be lifted explosively off the chest but as the additional resistance (+10-15% 1RM in chains) is added by the constant unfurling of the chain links off the floor, the athlete can continue attempting to accelerate the bar but it will slow due to the increasing mass, rather than the athlete consciously reducing the push against the barbell. This alters the kinetic profile of the strength exercise to become more like a power exercise (acceleration lasts longer into the range of motion). A similar strategy is to use rubber tubing resistance (power bands) on the ends of the barbell to increase resistance throughout the range of motion. In this case the athlete pushes upward in the bench press and stretches the large rubber bands attached to each end of the barbell. The higher into the range, the more stretch and so the greater the elastic resistance. Similar to the chains example, this allows the athlete to explode upwards and continue to apply high force much later into the movement.

Another strategy is the use of Functional Isometric (FI) training (23). A FI exercise can be performed for the top half of a movement in a power rack or Smith machine, altering the force characteristics considerably (23). Other methods of altering the kinetic profile include partial repetitions in the top half or maximal force zone of the lift (24). Weighted adjustable hooks (periscope type design) that are constructed to fall off the barbell when the base of the apparatus contacts the floor during the lowest portion of the bench press can also alter barbell kinetics within a repetition. Their use allows for heavier eccentric and lighter concentric phases, conceivably resulting in enhanced concentric lifting velocities. The use of chains, power bands, FI, partials, hooks and other devices to alter the resistance/force production (and

acceleration) throughout the barbell trajectory and particularly the end of the range of movement (so that it more closely mimics power exercises) can be basically applied to any free weight barbell exercise used in upper body training.

3. Use complexes of contrasting resistances or exercises

A method of training where sets of a heavy resistance strength exercise are alternated with sets of lighter resistance power exercises is known as a complex (14-18, 28) or contrast training (1, 7, 14). This type of training has been shown to acutely increase explosive force production or jumping ability when implemented for lower body power training (4, 14, 18, 28), presumably through stimulating the neuro- or musculo-mechanical system(s) (14, 18, 28). Recent research also illustrates it is effective for acutely increasing upper body power output (1). This research found that bench presses with 65% 1RM alternated with bench throws (30-45% 1RM) resulted in an acute increase in power output (1). An agonist-antagonist complex may also warrant consideration from the coach as speed of agonist movement may be improved in these situations (13, 22). Thus a strength coach has a choice of implementing agonist strength and power exercises or antagonist and agonist strength and power exercises in a complex to increase power output.

It is recommended that if upper body resistance training is performed twice per week, then one day of the training week could emphasize strength development with heavy resistance training and another training day emphasize power development with training complexes alternating contrasting sets of light resistances (30-45% 1RM) and medium-heavy resistances (60-75% 1RM) (1, 7).

4. Periodize the presentation of power exercises and resistances

Many authors have suggested the periodization of resistance training exercises to enhance power output (7, 19). While prescribing resistances in a periodized manner is not a novel idea in relation to training for power as has traditionally been used with Olympic weightlifting style exercises, it has not been fully utilized for simpler, upper body power exercises such as the bench throw. Baker has previously suggested that the resistances used for the upper body (or lower body jumping) power exercises be periodized (7) to effectively stress the multi-faceted nature of muscle power (19). Four power training zones and their analogous strength training zones are outlined in Table 1. Across a training cycle the power training resistances can progress from lighter resistances where technique and ballistic speed are emphasized to the heavier resistances that maximize power output (about 50% 1RM = 100% Pmax). Table 2 details the last four weeks of an elite athletes bench press and bench throw training cycle aimed at simultaneously maximizing strength and power output. The progression in power training resistances (from 40 to 80 kg in bench throws) and concomitant increase in power output from 573 to 755 W can be seen.

If coaches don't have access to technologies that can measure the actual Pmax and the resistance at which it occurred, it is recommended assuming 50-55% 1RM BP for most athletes, 45%1RM BP for very strong athletes (eg. 1RM BP = >150 kg) and greater than 55 % 1RM BP for less experienced or strong athletes (7). This means that a resistance of 50% 1RM BP equals 100% Pmax (and hence this resistance is the Pmax resistance).

It is important to note that, for example, training with a 50% Pmax resistance does not mean the athlete will attain only 50% of their maximal power output. For example, from Table 2 it can be seen that the athletes Pmax resistance is 80 kg for bench throws, but that 40 kg, representing 50% Pmax resistance, actually allows for the athlete to attain a power output of 76-78% of the maximum. During week 2, training with a resistance of 50 kg

(representing 63% of his Pmax resistance of 80 kg) allowed the athlete to attain power outputs of around 600 w or 80% of maximum. Therefore an athlete can attain very high power outputs at lower percentages of the Pmax resistance. Because of the plateauing of power output around the Pmax (see Figure 1), it can be seen that the use of resistances of around 85% or more of the resistance used to attain Pmax will usually result in the athlete training at or very close to Pmax (eg. 70 kg in Table 2 = 84 % Pmax resistance but results in power outputs of up to 96% Pmax).

Table 1. Zones of intensity for strength and power training, modified from reference 7.

	Type and / or goal of training of each intensity zone	
	Strength	**Power**
Zone 1: < 50% *	General muscle & technical	General neural & technical (< 25 % 1RM)
Zone 2: 50-75%	Hypertrophy training	Ballistic speed training (25 - 37.5 % 1RM)
Zone 3: 75-90%	Basic strength training	Basic power training (37.5 - 45 % 1RM)
Zone 4: 90-100%	Maximal strength training	Maximal power training (45 - 55 % 1RM)

* For strength, percentage of maximum refers to 1RM (100%). For power, 100% = Pmax resistance (circa 45-55% 1RM if exact Pmax resistance not known). Equivalent percentage ranges based upon 1RM are included in brackets for cases where exact Pmax resistance is not known.

5. Use low repetitions when maximizing power output

Low repetitions are necessary to maximise power output. High repetition, high workload, hypertrophy-oriented training acutely decreases power output (2) and should not precede or be combined with maximal power

training. It would appear important to avoid fatigue when attempting to maximise power output and a simple method for achieving this is by using low repetitions for power exercises (and obviously ensuring the appropriate rest period is utilized).

Anecdotal evidence from training hundreds of athletes with the PPS shows that power output markedly decreases after three repetitions when using resistances that maximize power output (around 45-50% 1RM BP) during the BT exercise. Based on this evidence, for power exercises it is usually recommended that only 2-3 repetitions be performed when training in the maximal power zone, 3-5 in the general power and ballistic power zone and higher repetitions (eg. 8-10) are only performed when using lighter resistances in the technical/neural zone (learning technique or warming up).

6. Use “clusters”, “rest-pause” or “breakdown” techniques for some strength or power exercises

To increase force output, velocity and reduce fatigue within a set, some specific methods have evolved over the years (23). Recent research indicates that, compared to the traditional manner of performing repetitions, force or velocity can be increased when repetitions are presented in clusters (20) or by using the “rest-pause” or “breakdown” methods (23). Clusters are a method whereby a set of higher repetitions is broken down into smaller “clusters” of repetitions that allow a brief pause between performances of these clusters. For example, eight repetitions can be performed as four clusters of two repetitions with a 10-second rest between clusters. The rest-pause system is essentially similar but typically entails the breakdown of a lower repetition set (for example, 5RM) into single repetitions with a short pause (for example, 2-15 secs) between repetitions. A “breakdown” (aka “stripping”) set consists of small amounts of resistance being taken from the barbell during short pauses between repetitions. This reduction in resistance

to accommodate the cumulative effects of fatigue results in a decreased degree of deterioration in power output across the set as well as increased force in the initial repetitions as compared to the traditional manner of lifting a heavy resistance (23).

7. Use an ascending order of resistances when maximizing power output

Whether the resistances are presented in an ascending (working up in resistance) or descending (working down in resistance) order during power training has been cause of some debate (7). A recent study examining the effects of ascending or descending order on power output during bench throws reported that an ascending order resulted in the highest power output during BT (7). It was also recommended that an ascending order of resistances with the inclusion of a lighter "down set" may be an effective method of presenting power training resistances.

Rest periods

The rest period between sets or even repetitions will depend upon the objective of that set, the number of repetitions being performed, the intensity of the resistance, the type of exercise, the training state of the athlete and the periodization phase. When the objective of the set is maximise the power output that can be generated with the selected resistance, the rest period between sets of a power exercise should be one to two-minutes or as is long enough to ensure that the objective is met. When performing a complex of a strength and power exercise, anecdotal evidence suggests a four-minute turn-around period (eg. set of bench press then 90 s rest, set of bench throw then 120 s rest before repeating complex) has been shown to be adequate as evidenced by the power outputs measured by the PPS. Shorter rest periods (eg. < 1-minute between sets of a power exercise or < 3-minutes for a

complex) result in reduced power outputs, diminishing the effectiveness of the entire power-training process.

Long term progress

Maximal upper body pressing power can still be quite readily increased over the long term even in advanced trainers. Changes in the load-power curve for a group of twelve elite rugby league players as well as the individual progression of one young rugby league player (player X) across a four year period is depicted in Figure 2 (9). It is clear that even for advanced trainers such as this group that progression can still be quite pronounced, especially in power output against heavier resistances. The load-power curve for the group as a whole as well as for player X has shifted upwards and slightly towards the left. From the graph it is visible that while power output generated while lifting a resistance of 40 kg (BT P40) changes only slightly, power outputs with heavier resistances of 60-80 kg increased markedly, a favourable situation considering the strong relation between high power outputs generated while lifting 70 and 80 kg in the bench throw exercise and progress into the elite professional rugby league ranks (7). As power output with lighter resistances improved relatively less than power output with heavier resistances, it is obvious that increases in strength rather than speed accounted for the majority of change. Statistically Pmax is more related to maximal strength rather than speed in these athletes (7).

During this time player X progressed from playing in the city-based leagues into the ranks of the full-time professional national rugby league. His BT Pmax increased 39%, from 603 w to 836 w while his 1RM BP increased from 135 to 180 kg (33%) at a relatively constant body mass of 110 kg. For the group of twelve subjects as a whole, the BT Pmax increased from 611 w to 696 w. This 14% increase appears to be underpinned by a similar change of 14.3 % in 1RM BP (from 129.6 to 148.1 kg) (9). From this evidence it would

appear that the concept of combining maximum strength and power training, using the methods outlined above, can result in enhanced upper body power output over long-term training periods.

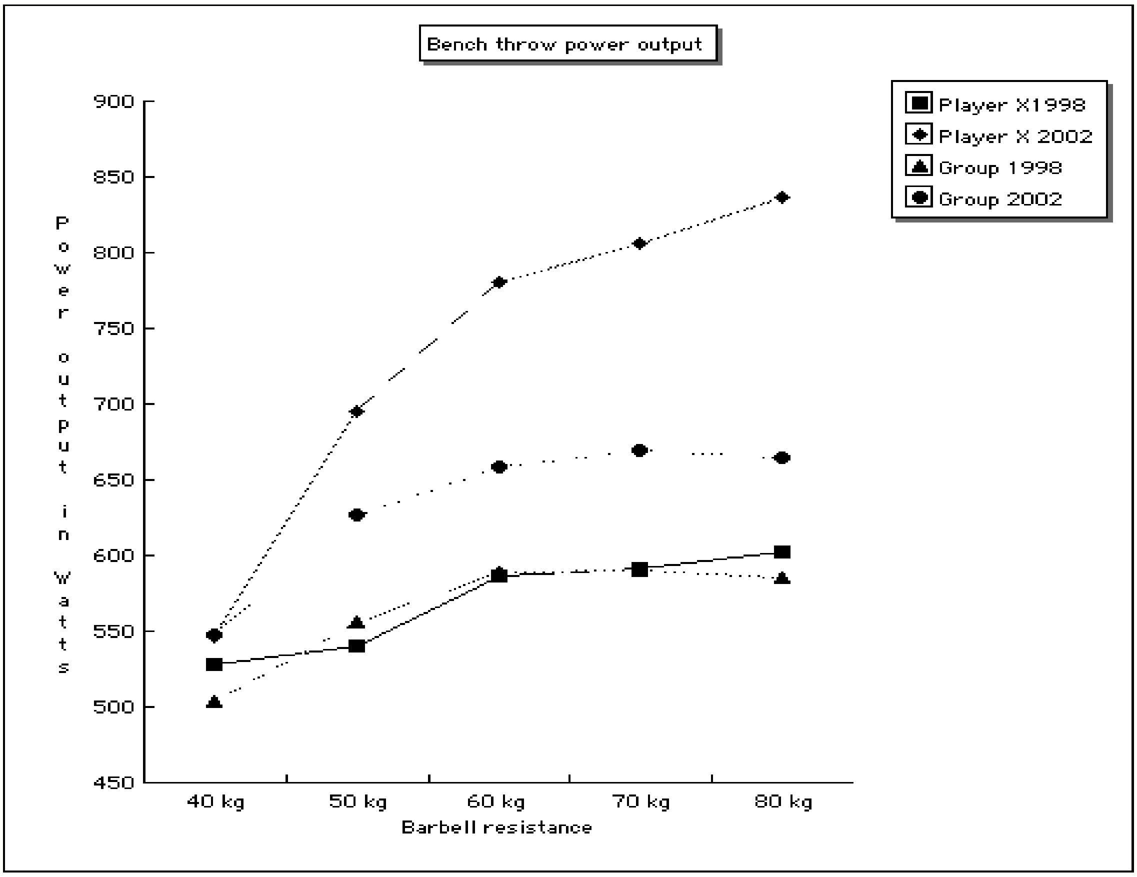


Figure 2. Change in the upper body bench throw load-power curve (average concentric power) across a four-year period in a group of twelve professional rugby league players as well as for one individual who made considerable progress (player X). The change in 1RM BP appears to underpin the change in BT Pmax during this time. From reference 9.

Practical applications

A number of practical methods used for increasing the effectiveness of upper body power training have been presented. It is not necessary to use all of these methods at one time to effectively develop maximal upper body pressing power. However, it is not difficult to implement a number of these methods simultaneously either. For example, a bench press and bench throw workout to maximize pressing power that entails six methods: full acceleration exercise; kinetically altered strength exercise; contrasting resistance complex; low repetitions; ascending order of resistances for the power exercise; and clustered repetitions is detailed in Table 3. Variation and periodization should influence if, when and how, any of these strategies are implemented.

This paper has addressed mainly the training for maximal power production and especially may be of value for athletes who must overcome large external resistances such as the body mass of opponents (eg. football, rugby league and union, wrestling, judo, mixed martial arts). Athletes who require a greater speed contribution rather than pure strength contribution in their power production (eg. boxing and related martial arts, tennis, javelin) may need to modify their training accordingly and their load-power curves would reflect this by perhaps showing increased power output with lighter resistances of 10-40 kg. However, many of the methods described above would be applicable to many sporting situations and it is the job of the astute coach to modify and implement them accordingly.

Table 2. Actual sample training content for bench press and bench throws across the last 4-weeks of a pre-season strength-power training cycle for an elite professional rugby league player. Testing occurred in week 5.

				Weeks		
		1	**2**	**3**	**4**	Test Pmax
Bench throws						
D1	Power	573 w	599 w	696 w	683 w	755 w
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 70 kg	@ 80k
%BT Pmax		76	79	92	91	100 %
D2	Power	588 w	605 w	722 w	746 w	
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 80 kg	
%BT Pmax		78	80	96	99	
Bench press						1RM BP
D1	Wt	130 kg	135 kg	140 kg	150 kg	=170
	SxR	3x5	3x5	3x5	3 x 3	
% 1RM		76.5	79.4	82.4	88.2	100%
D2	Wt	105 kg	110 kg	125 kg*	125 kg*	
	SxR	3x5	3x5	5 x 3	5 x 3	
% 1RM		61.8	64.7	73.5	73.5	

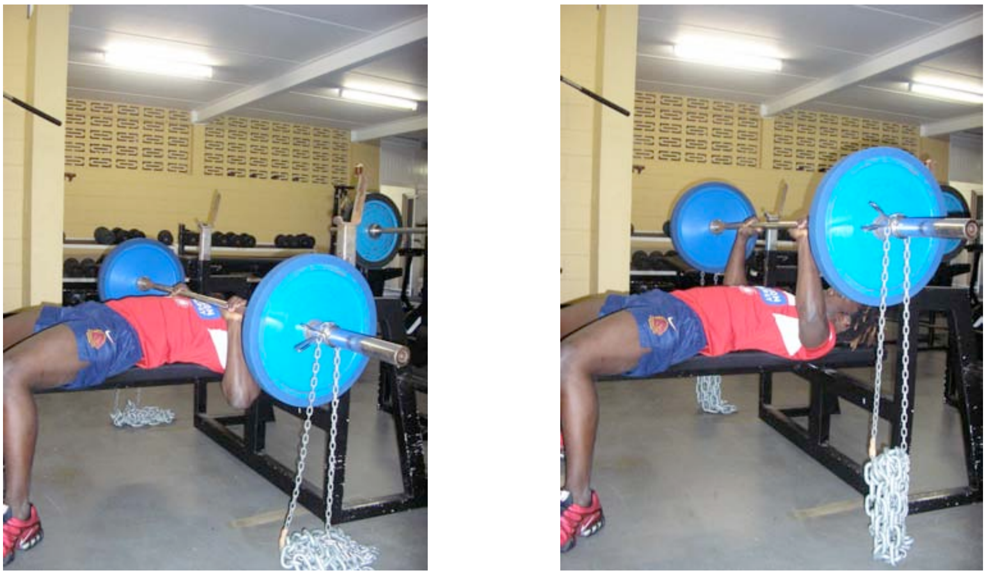
W = power output in watts, Wt = resistance in kilograms, SxR = Sets x Repetitions, D1 = Heavier, strength-oriented training day with BP performed before BT. D2 = Medium-heavy, power-oriented training day consisting of contrasting resistance complexes (alternating sets of BP & BT, same sets and repetitions). Denotes 110 kg barbell load plus 15 kg in chains attached to the sleeves of barbell. See text for a description of this bench press + chains exercise. Grip width was altered to a narrower grip for all D2 BP workouts.

Table 3. Sample workout for combined bench press and bench throws on a power-oriented training day during the peaking maximum strength/power phase for an athlete possessing a 1RM BP of 130 kg.

		1	2	3	4
	Sets	1	2	3	4
	Wt (kg)	40	50	60	70
1a. Bench throws (Smith machine)	Reps	5	4	3	3
	Wt (kg)	60	100*	100*	100*
1b. Bench press + chains*	Reps	5	1,1,1	1,1,1	1,1,1

1a, 1b. = Alternate exercises as a contrast resistance complex.
* = 85 kg barbell resistance + 15 kg in chains attached = 100 kg resistance at lockout.
1, 1, 1= 3-rep cluster sets, rest 15 secs between each clustered repetition.

Figure 3. Bench press throw exercise in a Smith machine. Loss of hand contact with the barbell ensures acceleration throughout the entire range of movement.



Figures 4 & 5. Bench press exercise kinetically modified by adding heavy chains to the sleeves of the barbell. In the bottom of the lift the chains are furled upon the floor, adding little additional resistance. As the barbell is lifted through its range of movement, the continuous unfurling of the chains from the floor provides additional resistance acting upon the barbell.

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Paper 10

Cycle-length variants in periodized strength/power training

by

Daniel Baker

was accepted on 6th September, 2006

in the

Strength & Conditioning Journal.

Introduction

When designing resistance-training programs the strength coach has to consider a number of variables that can be manipulated to make programs different. These include choosing 1. the exercise 2. the repetitions 3. the sets 4. the resistance 5. the speed of performing the exercise 6. the order of exercises and 7. the rest periods between sets and exercises (6). The Australian Strength and Conditioning Association (ASCA) also accepts that coaches may choose to use a particular, specific variant of periodization (known also as a pattern, plan, strategy, method or model of periodization) for a training cycle (1). While there are similarities between these different variants of periodized training, the ASCA recognizes that some coaches prefer to use certain variants for certain athletes (eg. novices versus experienced trainers) or periods of the training year (preparation period versus competitive period). This approach of choosing a particular variant or method for periodized strength training, popular in Australia, was largely influenced by Poliquin (39, 40) and others (2, 13-16, 25) over the past 15 years. The purpose of this article is to outline some of the particular variants of cycles within a periodized training structure that a coach may choose from when designing a cycle-length strength/power training program.

Brief history of periodization

For the purpose of this article, periodization of training is defined as the methodical planning and structuring of training aimed at bringing or keeping an athlete at peak sports performance. Athletes have used periodization of training since ancient times. For example some ancient Greek athletes chose

to use a specific four-day training cycle, known as the tetrad, that included daily variations in volume, intensity and technical work (49). The concept of general and competitive training periods also seems to have been adopted by these athletes when training for the ancient Olympics or other important sports festivals (49). However interest in the concept of training periodization in more modern times in the sports science and training literature has been attributed to the work of the Soviet Matveyev (eg. 30). Earlier authoritive Soviet weightlifting coaches and authors stated the need for training variation to occur throughout different training time-frames (eg. weekly, monthly and multi-monthly time frames, 31, 32, 50). Different authors have differing definitions for terms used in periodized training, so to avoid confusion regarding the terms micro-, meso- or macro-cycle, for the purposes of this article, the terms week, block or cycle will be used to denote the different time frames typically referred to in periodized training. While the usual definition of week should suffice, it must also be noted that training “weeks” can vary in length (eg. 4-10 days) in some sports, with the tetrad mentioned above a prime example of a non-standard training “week”. A “block” (sometimes known as a mesocycle) may be 2-5 weeks in length and a training cycle (sometimes known as a macrocycle), is the sum of a number of “blocks” (or mesocycles) (30, 31, 50). The training cycle, which may typically consist of 2-4 “blocks” of training (eg. initially described as being hypertrophy, general strength and maximal strength blocks, 2, 23, 36-46), is the time frame of concern in this article.

Soviet and other former eastern bloc coaches and authors (eg. 30, 31, 50) were the main sources of information on the concept of strength training

periodization until the pioneering work of Stone and colleagues introduced periodization of strength training to western literature in the early to mid-eighties (42-44). Since that time the concept of periodization has undergone considerable study, with consequent debate concerning methods and effectiveness (7-25, 36- 46, 48, 51-53).

Wilks (52) believes the debate concerning the effectiveness of periodization (17, 19, 48, 53) can largely attributed to the patterns or variants of periodization used, the amount of variation inherent in each model (eg. 11, 20 versus 21, 36, 41-44) as well as the experience of the athlete and length of the study. Therefore rather than use a generic term such as “periodized strength training”, coaches and researchers in the future may wish to specify which variant or pattern of periodization of strength training was implemented.

Different “cycle-length” variants or patterns of periodized strength training.

While the ability to vary training sessions within a week by utilizing methods such as those outlined in Table 1 appear well known to most coaches, descriptions of different cycle-length variants of periodized strength training appear less frequently in North American literature. The ASCA has outlined a number of different cycle-length (eg. 6-16+ weeks) variants of periodization that a strength coach may choose from, which have been identified from the literature and from analysis of current practices throughout the world (1, 2, 16, 18, 34, 37-46). A few examples of these variants are described in Tables 2-4. The nomenclature the ASCA uses, which is based upon the method of intensification, has been source of some debate,

consternation or confusion in the NSCA (17, 22-24, 27, 28, 45, 46, 52, 53). Poliquin (40) first proposed that a training cycle whereby the intensity (%1RM) is increased each week of the cycle should be designated as a “linear” method of intensification (see the first two examples in Table 2). This classification of “linear” is made irrespective of the fact that intensity, volume, (training impulse), workload etc may be manipulated in a non-linear manner within the week by methods such as those outlined in Table 1 (eg. heavy intensity or light intensity days, high or low load-volume days etc). “Non-linear” intensification entails not increasing training resistances each and every week of the training cycle (eg. with heavier and lighter weeks in intensity at certain weeks in the cycle, 1-4, 12-15, 25, 39-43). For the purposes of this article, if a variant does not entail increasing %1RM or resistance each week, then it is not a linear intensification variant (1, 2, 16-18). This can be clearly seen in the two examples of variants of “block” periodization provided in Table 3 which are distinguished by either linear or non-linear intensification across 12-weeks. Figure 1 graphically illustrates differences between linear and non-linear intensification (Subtle Linear, Block (non-linear), Wave-like and Undulating periodized variants) while Figure 2 provides a more comparative example of training impulse (repetition-volume x relative intensity, %1RM) between the Subtle Linear, Block (linear intensification), Block (non-linear intensification) and Wave-like periodized variants. When using this method of description, it should be noted that it is the method of intensification across the length of the cycle that is being refereed to, not the progression across the overall training year. A training year may contain a number of cycles such

that overall the yearly progression is clearly non-linear, but this does not affect the description of the cycle-length pattern of progression.

By looking at week three from each of the specific variants in Tables 2 and 3, it can be seen that there are different prescriptions of sets, repetitions and resistances, despite all being examples of "periodized strength training". Great diversity exists in "periodized strength training" and coaches may wish to choose the variant(s) that they feel most appropriate to their circumstances (level of the athlete, period of the year etc).

Comparisons between different cycle-length patterns of progression

A paucity of data exists concerning comparisons upon the effects of different cycle-length patterns of progression as most research has tended to compare some form of periodized training to non-periodized training (36, 42-44) or to "pre-intervention" data (ie. comparing "pre-" and "post-training" scores in muscular functioning in response to a specific periodized training pattern, eg. 3, 4, 7-9). Baker et al. (11) found that a block pattern with linear progression and an undulatory pattern of progression (changing repetition demands after every 2-weeks) provided similar benefits in maximal strength across 12-weeks. Rhea et al. (41) found that a program that alternated training volumes and intensities within a week more effective than a block method with linear intensification and no within-week variation. No other data has been found that directly compares different progression patterns of cycle-length periodized strength training in order to gauge the relative effectiveness of one pattern against another.

Possible reasons for a lack of comparative data

Given that resistance-training objectives can vary for different athletes (eg. hypertrophy of muscle, maximal power, absolute strength are different objectives requiring somewhat different training prescriptions), it is not known why research into the relative merits of different patterns of periodized progression has been so limited. The references contain many articles outlining debate and theory concerning periodization but it appears little of this theory has been tested, unless against non-periodized training. It is of interest to note that Stone et al. (47) stated that the demise of sport science in the United States is in part attributable to Institutional Review Boards and academics not being "conceptually familiar with sports science". This then reduces what they call "monitoring studies", examples of which would be the analysis of the effects of different periodized variants/patterns of progression upon muscular functioning and sports performance. They also state that "politically correct" views of the academics may partly regulate research away from studies that investigate sports performance, to which comparative periodized strength training studies belong. For whatever reason, the level of research regarding the merits of different periodization variants/patterns has not equated with the overall theoretical literature on periodization.

When and why a coach may choose different cycle-length variants of periodized strength/power training.

Given these deficiencies in the literature, the ASCA has made some generalizations regarding when and why a coach may choose different cycle-length variants of periodized strength/power training. These generalizations

have been made mainly based upon the practical experiences of their elite coaches aligned with findings from the literature where possible.

Subtle linear-intensification patterns of progression. As these types of variants are characterised by fairly equivalent and small regular increments in training intensity each week (e.g. by $\leq$ 5% 1RM each week), it is thought these types of variants may be suited to novice and less experienced athletes who have not performed much periodized resistance training (1, 2, 13, 51, 52). This is due to the fact that other variants are characterized by more pronounced alterations in intensity which may not be as easily managed by less experienced athletes whose exercise technique may deteriorate under such situations (1, 6, 37). Hence the subtle variations in intensity (and workload) enable a more stable technique acquisition/refinement environment (37). Consequently these types of models may be best suited for lower level or less experienced athletes, irrespective of the training period (Preparation or Competitive Period) (1, 6).

Block or Step patterns of progression. The block or step patterns generally entail a training cycle being divided into three steps of repetition and intensity demands, each respectively signifying a hypertrophy block (a traditional term, though now this block may also be referred to as a consolidated strength-endurance block or “muscle training” block), basic strength/power block and peak-strength/power block (1, 2, 13, 22-24, 27, 28, 36-38, 41-46). As detailed in Table 2, the intensity progression could be linear or non-linear. As compared to subtle linear progressions, sharper drops in volume and rises in intensity when changing blocks characterize the block variants. These pronounced changes in volume and intensity may provide a

beneficial stimulatory “shock” to experienced athletes and allow for a delayed training effect (42, 43, 51), but the pronounced intensity changes may be too severe for less experienced athletes to cope with (physiologically and exercise technique-wise) (6, 37). Consequently the ASCA has recommended that these variants are generally recommended for use with more experienced athletes who possess stable exercise technique and predictable strength levels and who seem to benefit from the marked variation inherent in these models (1). These types of variants can be seen as a progression from the subtle linear variants (1). Aside from competitive lifters, the block variants are generally used for the preparation period as high volume blocks of strength training are often not compatible with in-season training in a number of sports (1). The coach will also need to choose a linear or a non-linear intensity progression when implementing this variant.

Undulatory patterns of progression. The Undulatory variant in Table 2 is characterised by 2-week changes in repetition demands and concomitant alterations in intensity, which sees an undulatory progression in intensity as training reverts from, lower intensity 2-week phases to higher-intensity 2-week phases back and forth, throughout the cycle (11, 39). It is not to be confused with simple within-week undulation of training (41) (see Table 1).

These changes that typically occur after a 2-week time frame are generally greater (in workload, intensification) than for subtle linear methods, but less pronounced that block variants. Accordingly this type of variant may be beneficial as a progression for athletes who have habituated to subtle linear methods of intensity progression or for athletes who favour alternating 2-week phases of hypertrophy-oriented (eg. 3-4 sets x 8-12 repetitions)

training with 2-week phases of general strength training (3-4 sets x 4-6 repetitions) on a continual basis.

Wave-like patterns of progression. The distinguishing difference between the undulatory and wave-like variants is the number of weeks that contain the variation. If the repetitions do not change till after every 2-weeks, then it is an undulatory model, as compared to every week for a "true" wave-like model used by a non-lifter (1). This means there are less variation in volume, intensity and load-volume in an undulatory pattern as compared to a wave-like pattern.

Wave-like patterns derive from the sport of weightlifting, where earlier Soviet coaches advised that weekly volume-load should be presented in a wave-like fashion over a month (eg. the monthly 100% total is distributed 35-36%, 26-28%, 21-23% and 13-18% per week, or 42-44%, 32-33%, 22-26% for a 3-week "month", 12, 31, 32, 50). Even the order that each of these weekly workloads is to be presented is not constant and the earlier Soviet coaches provided examples of different orders that the workloads could be presented (12, 31, 32, 50). Again the coach has to choose which workload order of the "wave" (ie. which variation of the wave-like pattern) would best suit their lifters (31, 32, 50).

The wave-like patterns have been adapted for use by non-lifters by mainly using the number of repetitions per set to alter weekly volume-load (2-4, 10, 40), although additional sets can obviously affect volume-load (34). In a basic wave-like pattern, the repetitions decrease weekly (with concomitant rises in intensity) for 3-4 weeks, whereby the general pattern is then repeated but at slightly higher intensities/lower repetitions as the athlete comes to the

peaking phase (2-4, 7-10, 25, 34, 40). A number of studies show that the wave-like variants are effective in maintaining or even increasing strength and power in both elite and moderately experienced athletes during long in-season periods (3, 7, 9), though case studies also reported good results with its use in during preparation periods (3, 4, 40).

Accumulation/intensification patterns of progression. Many introductory resistance-training programs can be loosely defined as, or based upon, the processes of accumulation/intensification. For example, an athlete may be prescribed a resistance they can lift for 3 x 10 repetitions and they do not increase the resistance (intensify training) until they have managed to perform 3 x 12 repetitions (ie. they have accumulated volume) with that constant resistance. Therefore these types of introductory programs are based upon the athlete accumulating training volume (volume load) at a steady or designated resistance before training resistances are increased and the volume is reduced (intensification). This most basic type of accumulation/intensification used by beginners (eg. continually training within a narrow specified range of repetitions such as 3 x 10-12 etc) does not really embrace the concept of periodization and is not to be considered a periodized variant.

Table 2 details a certain example of the accumulation/intensification pattern that is a distinct cycle-length periodized variant. This program may be more familiar to coaches as the “Russian squat cycle” (although it was actually developed in the now separate country of Belarus) and was taken from the sport of weightlifting (54). The original proponents stated that this particular variant was best suited to increasing maximal squat strength during

the preparation period, presumably due to the high workloads involved (54). Clearly this variant of accumulation/intensification was designed for competitive lifters and advanced athletes and may be less applicable to the vast majority of athletes or exercises due to its high intensities and workloads (1). However, modifications such as more moderate volumes and intensities (eg. Accumulation => Wk1 = 70%/3x9, Wk2 = 70%/3x10, Wk3 = 70%/3x11, Wk4 = 70%/3x12, Intensification => Wk5 = 80%/3x7, Wk6 = 84%/3x6, Wk7 = 88/3x5, Wk8 = 92%/3x4) may make it more suitable to a wider range of athletes to use.

Integrating different models?

As described above, choosing a specific cycle-length variant/pattern of periodization may entail choosing a designated training variable configuration. Coaches may find some variants/patterns work well with certain athletes (eg. novice athletes and subtle linear-intensification patterns of progression) or certain times of the year (eg. wave-like patterns and in-season periods). Another method is to prescribe patterns according to exercise classification. For example, Australian National Team Powerlifting Coach Robert Wilks proposed a block variant with linear intensity progressions for the three key powerlifts (but with large within-week variation in %1RM resistance and hence workload) and an undulatory approach for the assistance exercises (alternating between sets of 10 or sets of 6 repetitions every 2-3 weeks) (51). Baker and Newton reported changes in upper body strength and power for elite, professional strength-power athletes across a 4-year period, using

different periodized training variants according to times of the year and exercise classifications (10).

Accordingly a coach may ascribe to a philosophy of variant choice being determined by exercise classification, the training age/state of the athletes involved as well as the training period (General or Competitive periods). The overall periodized structure may reflect the integration of a number of different cycle-length variants.

Conclusions

Coaches can choose a cycle-length variant or pattern of presenting overload that largely determines the sets, repetitions, and relative intensity and so on to be used during each week of the cycle. Little consideration has been given to the effects that different variants or patterns of progression of periodized overload have upon strength, power, and size, and so on for different levels of athletes at different times of the training year. Hopefully this presentation of different variants of cycle-length periodized overload may provoke further research by academics or experimentation by coaches in a bid to determine the relative merits of this type of cycle-length training variation.

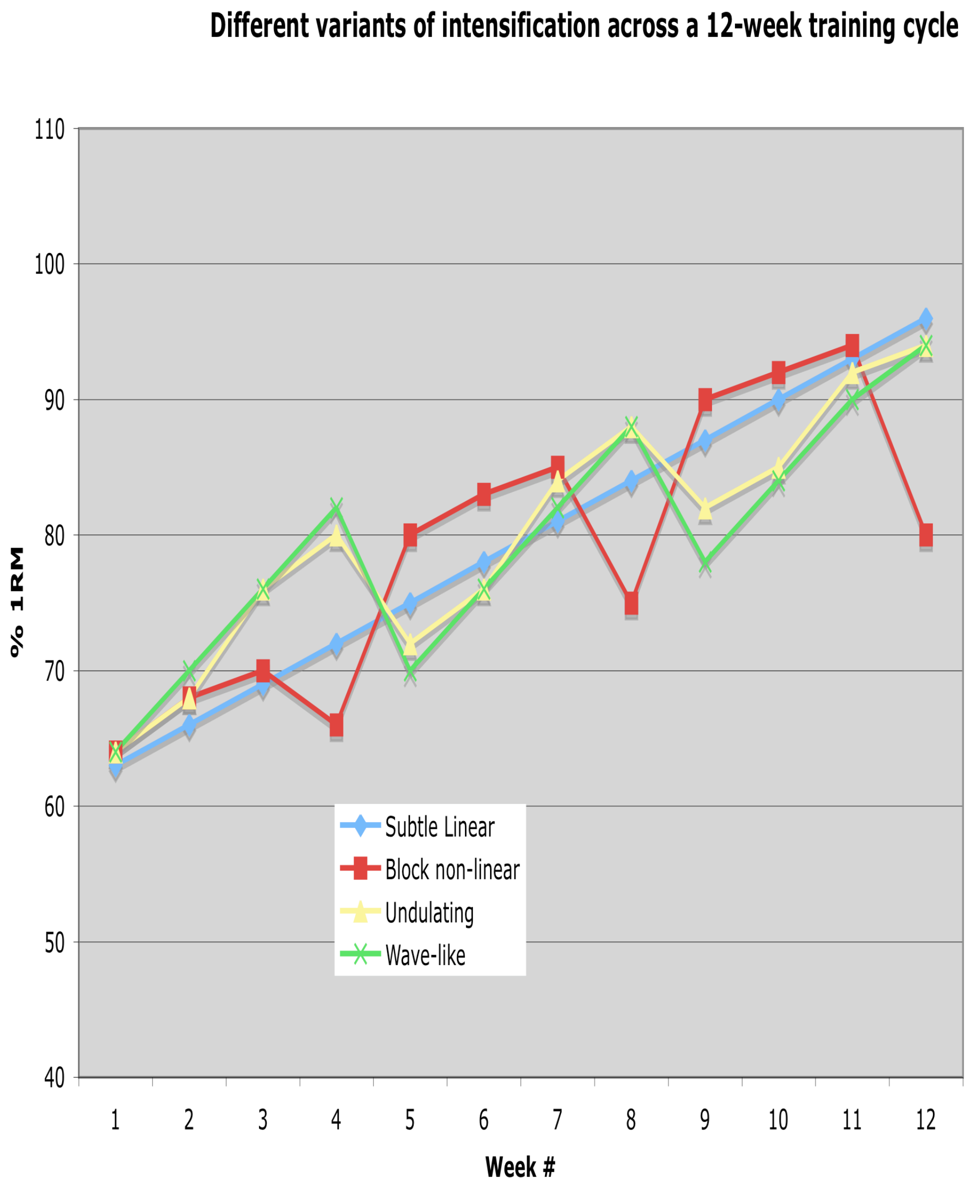

Figure 1. Graphic display of differences in the method of intensification (%1RM) across a 12-week cycle between a Subtle Linear, Block (non-linear), Wave-like and Undulating periodized variants outlined in Table 2.

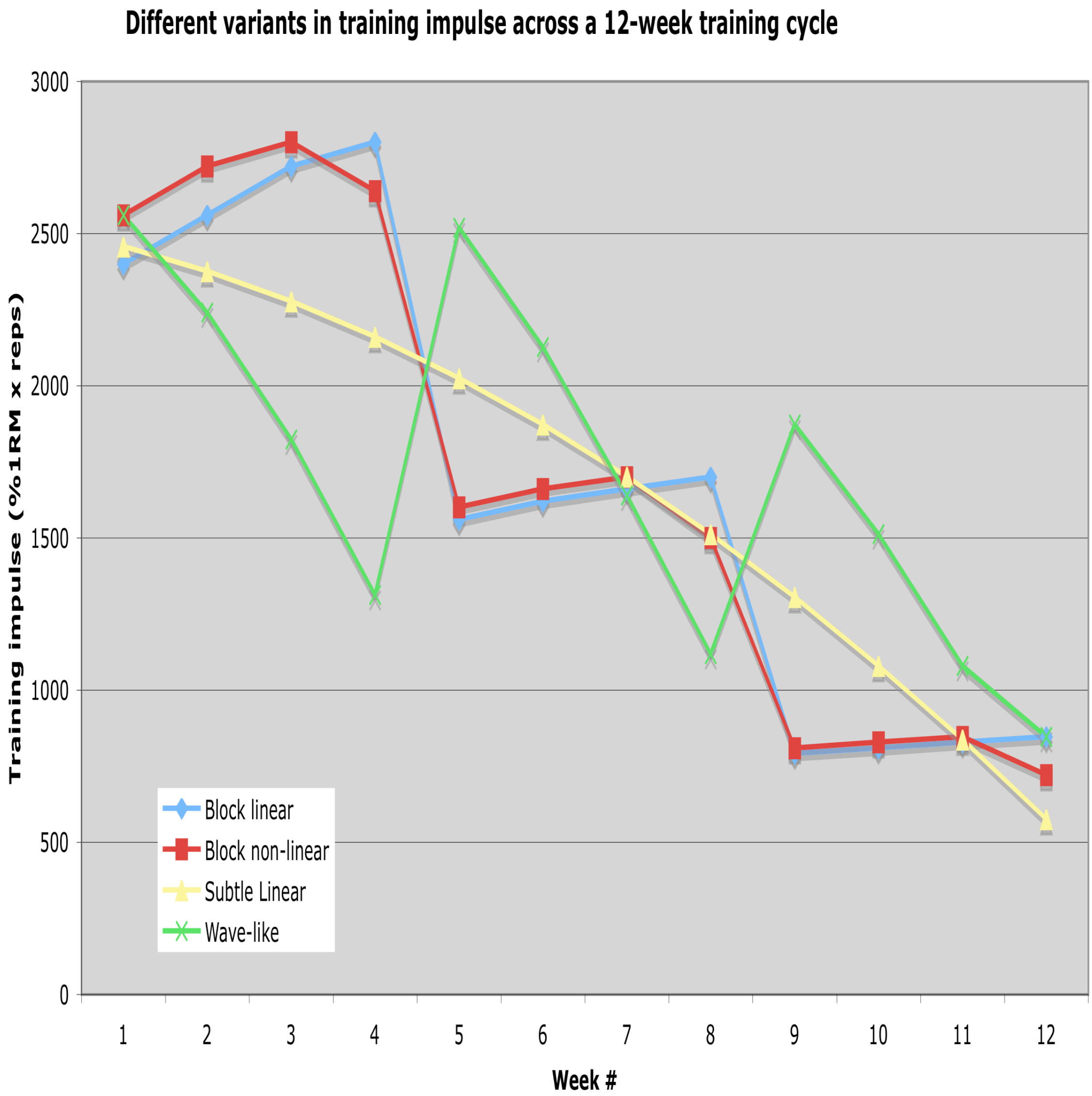

Figure 2. Graphic display of differences in training impulse (total repetitions per exercise x %1RM relative intensity) across an 12-week cycle between the Subtle Linear, Block (linear intensification), Block (non-linear intensification) and Wave-like periodized variants outlined in Table 2. Note the Subtle linear pattern entails a straight decline in training impulse across the 12-weeks as compared to the more varied patterns for the other methods.

Table 1. Nine methods ways of altering training load and difficulty within a training week.

Method of variation	Day 1 example	Day 2 example
1. Same exercises and other variables, increase repetitions and decrease resistance	Squat 3 x 10 @ 70 kg	3 x 15 @ 60 kg
2. Same exercises and other variables, increase or decrease the number of sets.	Squat 4 x 10 @ 70 kg	Squat 2 x 10 @ 70 kg
3. Same exercises, sets and repetitions, reduce the lifting speed and resistance.	Squat 3 x 10 @ 70 kg	Squat 3 x 10 @ 50 kg (4s/rep)
4. Same exercises and other variables, decrease rest periods and resistance	Squat 3 x 10 @ 70 kg (3m/rest)	Squat 3 x 10 @ 50 kg (1m/rest)
5. Same exercises and other variables, decrease resistance.	Squat 3 x 5 @ 100 kg	Squat 3 x 5 @ 80 kg
6. Same exercises and other variables, decrease repetitions.	Squat 3 x 5 @ 100 kg	Squat 3 x 2 @ 100 kg
7. Different strength exercises, but same for all other variables (same %1RM).	Squat 3 x 10 @ 70 kg	Front squat 3 x10 @ 55 kg
8. Perform a strength and power version of aligned exercises on different days.	Squat 3 x 5 @ 100 kg	Jump squat 3 x 5 @ 50 kg
9. Perform heavier and lighter versions of aligned power exercises on different days.	Power clean 3 x 5 @ 75 kg	Power snatch 3 x 5 @ 60 kg

Table 3. In-season model of periodization using Wave-like variants according to exercise classification as primary strength or power or assistant strength or power exercises (from ref. 7, 10).

Exercise classification	Week #	1	2	3	4	5	6	7	8
Primary strength eg. SQ, BP, PU	S x R % 1RM	3 x 8 66%	8-6-5 66-72-77%	6-5-3 72-77-82%	5-3-2 77-82-87%	8-6-5 70-75-80%	6-5-3 75-80-85%	5-3-2 80-85-90%	2-1-1 85-90-95%
Assistant strength	S x R % 1RM	2 x 10 65%	2 x 8 70%	2 x 6 75%	2 x 5 80%	2 x 8 75%	2 x 6 80%	2 x 5 85%	2 x 5 87%
Primary power eg. PC, J, BT JS	S x R % 1RM	3 x 5 65%	3 x 5 70%	5-4-3 70-75-80%	4-3-2 75-80-85%	3 x 5 75%	5-4-3 75-80-85%	4-3-2 80-85-90%	3-2-2 85-90-95%
Assistant power	S x R % 1RM	3 x 6 65%	3 x 6 70%	3 x 5 75%	3 x 4 80%	3 x 6 75%	3 x 5 80%	3 x 4 85%	3 x 3 90%

%1RM = Percentage of one repetition maximum strength, BP = bench press, PU = pull-ups, SQ = squats, PC = power clean from hang, J = jerks, JS = jump squats, BT = bench throws. * For squats, reduce intensity by about 10% 1RM. Third set may be optional for squats. ** Assistant strength and power exercises can be performed for 2 or 3 sets. Assistant power exercises include pull variations (eg. pulls to waist, high pulls, power shrugs), push press and power press/throwing variations, loaded jumping exercises etc.

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Assistant strength	S x R % 1RM	2 x 10 65%	2 x 8 70%	2 x 6 75%	2 x 5 80%	2 x 8 75%	2 x 6 80%	2 x 5 85%	2 x 5 87%
Primary power eg. PC, J, BT JS	S x R % 1RM	3 x 5 65%	3 x 5 70%	5-4-3 70-75-80%	4-3-2 75-80-85%	3 x 5 75%	5-4-3 75-80-85%	4-3-2 80-85-90%	3-2-2 85-90-95%
Assistant power	S x R % 1RM	3 x 6 65%	3 x 6 70%	3 x 5 75%	3 x 4 80%	3 x 6 75%	3 x 5 80%	3 x 4 85%	3 x 3 90%

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Chapter 4.

General Discussion

The structure of this thesis is in three distinct parts. First was concerned with testing of upper body strength, power, strength-endurance and speed. From this testing it was discerned that, in particular, upper body maximum strength (pressing and pulling) and power were of interest to professional rugby league players as these measures appeared best able to differentiate those who progressed to the elite professional ranks (NRL) from those in the second-tier (SRL) and third-tier (CRL) ranks. As a result of these findings, the rest of the studies focused upon training methods that effected power output within a workout (Part two = Acute effects of resistance training upon power output) or the nature, scope and magnitude of long-term changes in strength and power output in professional rugby league players as a result of chronic implementation of these methods (Part three = Chronic effect of training on strength and power output).

This first series of studies were concerned mainly with the testing of upper body strength and power was concerned with the relative importance, or otherwise, of upper body strength, power, speed and strength-endurance to professional rugby league players. The results of the first study fairly convincingly demonstrated that maximum strength was the most important muscular function of those investigated as it differentiated along team-rank and positional lines quite conclusively. However, the results for maximum power and strength-endurance were nearly as emphatic. Speed appeared to be less important in comparison to the other three attributes. However, all

performance attributes appeared better able to differentiate players than a simple body mass measure. In this study all investigated attributes were measured during a bench press type movement, reducing the generality versus specificity argument that can occur when different test movements occur (Baker et al. 1994). Thus the movement was the same, but the resistance and repetition demands were manipulated to differentiate maximum strength, power, speed or strength-endurance demands. The findings of this study clearly indicate that maximum strength is the key to upper body training of rugby league players. From the base of maximum strength, training can then be directed also towards either maximum power or strength-endurance, both of which require distinctly different resistance training variable manipulations.

The second study in this first part was concerned with investigating both pressing and pulling strength and further, did a distinct strength ratio exist between the two roughly antagonistic movements. Similar to the results for pressing strength, pulling strength was found to differentiate NRL from SRL players. More importantly a concise strength ratio between pressing and pulling strength was observed that was significantly more equivalent in the NRL as compared to the SRL players. While the levels of strength differences are easily explained by training experience and natural selection (to a degree), it is not fully understood why a difference in the strength ratio would occur. It was initially theorized that perhaps the NRL squad may have had players who performed unbalanced (pressing versus pulling) training early in their careers. However, the results did not bear this out. The NRL squad

overall exhibited a very concise ratio and the players who were more than one standard deviation difference in the ratio possessed a ratio in favour of pulling, not pressing. Further investigation revealed that these players tended to have suffered from contact injuries to the anterior musculature, typical in a physical collision sport like rugby league. These injuries may have suppressed pressing strength, but not pulling strength (which is more dependant upon the posterior musculature), affecting the strength ratio.

The third study was concerned with the validation of a less time-consuming test methodology that may be more suitable to strength coaches of lower level teams. Typically these coaches do not have the time, personnel, experience and perhaps physical resources and equipment to implement a test battery like those implemented in Studies 1 and 2. Therefore this study aimed to validate the popular method of estimating 1RM performance via extrapolation from one exhaustive set in the bench press and pull-up using multiple repetitions till fatigue (RTF). Typically these tests take less than a minute to perform per person and provide, via a suitable regression formula or conversion table, not only an estimate of 1RM, but also due to the higher repetitions performed a measure of high-intensity strength-endurance.

The bench press test performed was the NFL 225 lb (102.5 kg) whereby the athletes performed as many repetitions as possible with this resistance. In the pull-up test, body mass served as the chosen resistance. Instead of a regression equation to extrapolate 1RM, a unique table of conversion factors similar to the NFL table was used. It is believed that regression equations are fundamentally flawed in estimating 1RM because

they assume a linear relationship between fatigue (repetitions performed) and 1RM performance levels. The evidence in the cited literature suggests a more curved-linear or part-parabolic relationship. The results from actual 1RM testing in these two exercises were compared to the predicted results, with high correlations reported. Based upon these findings, it was recommended that coaches working with athletes of lower level would be able to implement a pressing and pulling strength test battery by using a one set RTF test with an appropriate resistance utilizing the bench press and pull-up exercises. While body mass is the obvious resistance for the pull-up exercise, for the bench press exercise coaches of lower level athletes may have to utilize a lighter resistance of, for example, 80 kg for college-aged athletes and 60 kg for high-school athletes as 102.5 kg is in excess of the maximum capabilities for many athletes. By implementing these two one-set tests a coach may be able to test sixty athletes in less than one hour. This scenario is suited to high-school coaches.

Based upon the results of these studies coaches involved with rugby league players should implement some form of upper body test battery aimed at assessing the pressing and pulling strength. This testing may be via direct 1RM testing or by estimating 1RM via a RTF test with sub-maximal resistance. The RTF test may also serve as a test of strength-endurance. If the resources are available, then a maximum power testing battery may also be implemented. Overall this data should highlight a pathway of upper body muscular performance progressions for rugby league players who wish to progress to the elite professional NRL ranks.

The second part of this thesis entailed studies that lead directly on from the above findings. Having determined that levels of upper body strength, power and strength-endurance are of importance to success in rugby league, then methods that affect their development is of interest. These may be acute methods that affect strength and power within a training session or the chronic methods that affect development of strength, power and endurance over longer periods of time. In particular, the interaction between muscle power and muscle endurance is of interest given that endurance training is believed to attenuate power development.

The next three studies focused upon acute training interventions; specifically how power output could be affected by various resistance training variable manipulations that occur within a workout.

Studies 4 and 5 involved manipulations of training variables to investigate if power could be increased within a workout through the interaction of a strength training oriented training dosage. Study 6 was implemented to determine the effect upon power output of combining strength and power training within a work-out.

For Studies 4 and 5 a method of training called complex or contrast training was investigated to determine if it was an effective power training strategy. Complex training entails the alternating of contrasting resistances/exercises (e.g. heavy bench presses with 100 kg alternated with lighter bench throws with 50 kg). Theoretically this results in some enhancement of power output via some tension dependant mechanism that has yet to be fully determined. Despite being a common power training

methodology for over twenty years, the results for previous complex training studies have been mixed to say the least. While some positive results have been reported for some lower body studies, two previous upper body studies had yielded no significant change in upper body power output or performance as a result of utilizing a complex of contrasting resistance/exercises (Ebben et al., 2000; Hrysomallis and Kidgell, 2001). The reasons for these mixed results may lay in the findings of some of the studies. It appears that stronger, more experienced athletes may benefit form this type of training but that less experienced athletes may find this method detrimental to their power performances. Fortuitously the athletes in Study 4 were strong and experienced athletes who had been performing contrast complex training for over one year prior to the investigation. The significant increase in power output as a result of alternating heavier bench presses with lighter bench throws in Study 5 also illustrated a fundamental difference in the ideology of complex training. Most authors attempt to explain this method via a mechanism of post-activation potentiation (PAP (eg. Schmidtbleicher, D. and Buehrle, 1987; Ebben and Watts, 1998; Young, et al., 1998; Duthie et al., 2002). Therefore the contrast resistance they utilize is extremely heavy (> 85-90 % 1RM), in order to invoke maximum recruitment and rate coding. However, in Study 4 a resistance of 65% 1RM was used as the contrast resistance because pilot work by the lead author also revealed equivocal results with extremely heavy resistances (90% 1RM). Heavy resistances of > 85% 1RM may recruit more muscle fibers but they also may attune the neural system to a slower speed of lifting (the “speed control” theory). Therefore it

was decided for Study 4 that a contrast resistance merely had to be heavy enough to be in stark contrast to the power testing resistance so that it would evoke the positive effects (neural or otherwise) without the potentially negative effect of attuning the neural network to a slow lifting speed. The findings of Newton et al. (1996) illustrated that resistances of around 60% 1RM still allowed for high lifting speeds. In Study 4 65%1RM was equivalent to 92 kg, which is distinctly heavy in comparison to the power test resistance of 50 kg. This disparity in resistances was apparently enough to warrant some significant post-intervention increase in power output. Consequently very heavy resistances do not or perhaps should not be used for complex power training. It was recommended that if athletes wish to utilize contrast complexes of strength and power exercises/resistances, then they should be performed in a training session with moderate strength training resistances (60-75% 1 RM) and lower repetition demands. Heavier resistance strength training (> 80% 1RM) can be performed in another training session. Therefore training days could be differentiated as being primarily concerned with development of maximal power (including the power complex training) or maximal strength (including heavy resistance training). Furthermore, based upon the results of Study 4 and the failure of other researchers to report enhancement in power output when using resistances of > 85% 1RM, it is recommended that further complex training research be conducted using more moderate resistances and more advanced athletes.

As the results of Study 2 illustrated that pulling strength and a concise strength/muscle balance ratio are of importance to rugby league players, it

was theorized that combining pulling strength and pressing power training in a complex would warrant investigation. As a result, Study 5 investigated if a non-traditional complex of contrasting movement actions, rather than contrasting resistances, also had an acute effect upon power output. It was conceivable based upon previous research into rapid limb movements and the associated triphasic muscle activation patterns.

After measuring power output during the BT, the intervention strategy of a pulling movement was introduced in the experimental group. The small, but significant increase in power output for the experimental group suggests that this method of complex training also deserves consideration.

Again the reasons why the results for Studies 4 and 5 were positive as opposed to those of previous studies (Ebben et al., 2000; Hrysomallis and Kidgell, 2001) may be due to three reasons. One, the athletes in these studies were stronger and experienced in contrast/complex training. Secondly, the resistances used in the strength exercise were not extremely heavy, so as to attune the neuromuscular system to a slower speed of lifting. Finally, the most important reason is the philosophy behind choosing the contrast exercise or resistance. All previous authors have desired to maximally recruit muscle fibers because they believed that full recruitment was the key to complex training success. The philosophy behind Studies 4 and 5 was that the exercise or resistance has to be in contrast to the power training exercise. A resistance of 65% 1RM, being 92 kg in the case of Study 5 is in stark contrast to 50 kg, but is not an intensity to evoke tetanus. There are a myriad of neural interactions at play and evoking tetanus may not be the

reason why complex training can have a positive effect upon power output. The results for Study 5 confirm this as the intervention resistance was only about 16 kg heavier than the BT resistance, but the exercises were in contrast (agonist and antagonist movement actions). There would have been no effect if the reasons for the positive results reported for complex training were due to post-tetanic potentiation as many authors have surmised.

Based upon the results for Studies 4 and 5 it should be clear that some form of neural interplay is acutely affecting power output within a work-out. The nature of this neural interplay is not fully understood, but it is not simply as a result of full motor unit recruitment and firing. Future research upon power output in these types of studies may consider other methods of providing a contrast effect within a workout, rather than continually and more often than not fruitlessly exploring the very heavy resistance/post-tetanic potentiation theory of augmentation.

The third of these acute intervention studies (Study 6) revealed that a hypertrophy-oriented training bout (high repetitions, short rest periods) drastically reduced power output for over 7 minutes post the intervention. Therefore training to improve hypertrophy (the cornerstone of long-term maximal strength improvements) and strength-endurance (also characterized by high repetition, short rest period training) must be planned judiciously if increasing maximum power is also a goal of training. The question of how best to combine maximum power and strength-endurance training is quite pertinent. One small dosage of 3 x 10 repetitions @ 65% 1RM can reduce power output by 17%. The effect was even more pronounced for a sub-

grouping of stronger (performing higher total absolute workloads) versus less strong athletes involved. This result raises even more research questions. How much more severe would the cumulative effect upon power output of doing 4-6 exercises with the same sets and repetitions be? If athletes performed such hypertrophy-oriented or strength-endurance oriented (15-20 reps @ 40-50% 1RM) training 3-4 days per week for a chronic period of 4 weeks, then what would be the degree of decrease in power output (cumulative fatigue)? For how long would training need to be periodized (reduced volume, increased intensity) so that super-compensation could occur and power output would increase back to or above preliminary levels? Would the lower body running endurance demands impact greatly upon the upper body power levels?

Certainly, given the need for high levels of strength-endurance (and running endurance) the periodization of resistance training for rugby league players would be more varied than that for American football players and may more closely resemble the training plans for wrestlers and mixed martial artists.

Due to the fact that Studies 4-6 established that power output could be "easily" increased or decreased if exercise order, sets, repetitions, resistances/loads and rest periods were manipulated in certain ways, future studies may pursue the effects of other training variable manipulations upon power output. The need for more research in the area of strength, power and strength-endurance interaction appears obvious. This study has shown that hypertrophy–oriented training (and by extrapolation strength-endurance

training) should not precede power training within a work-out. Questions that arose from this study were concerned with effective periodization of resistance training and the interaction between strength, power and strength-endurance training. Specifically a) the interaction of heavier strength training (lower volume) and power training within a work-out b) within a training week in-season (with a game on the weekend) c) across longer time periods of many years.

The third part of this thesis dealt with the chronic adaptations in maximal strength and power resulting from prolonged long-term resistance training. In the first paper in this section (Study 7), twelve professional rugby league players were tested for maximal power and strength across a 4-year period and were analyzed as a group or according to their initial designation as Elite (already participating in the NRL) or Sub-elite players (being developed to participate in the NRL within 1-2 years). The results of this investigation illustrated that experienced resistance trainers can still make gains in maximal strength and power but that the magnitude and scope for increases in strength and power diminishes with increased training experience. Furthermore, changes in maximal power were heavily dependant upon changes in strength and the extent of the relation between changes in strength and changes in power suggests the communal experience of strength plateaus in experienced athletes will also be manifested in power plateaus. The magnitude of the changes for the Sub-elite group mirrored the changes exhibited by the Elite group in the first two years (the groups were approximately 2-years apart in chronological and training age). Based upon

this result it was thought that the age that these athletes commence such regimented training may be a variable that could affect strength and power levels in long-term training. The question is, would commencing combined strength-power training at a younger training age lead to greater gains in strength and power in the long-term?

The second paper of this section investigated this unique situation; that is the effect of the chronological age at the start of systematic strength and power training upon the ensuing changes in strength and power 3-4 years later. In Study 8, a squad of 20 NRL players was analyzed and two groups of 6 players, who could designated as Young or Old, were identified. These two groups had performed the same training for the 3-4 years previous and were not different in body mass or height. What differentiated the groups were the age of the subjects (29 yrs v 23 yrs) and more importantly the age at which they commenced regimented strength-power training.

The results illustrated that the Younger group were 13 % stronger and 28% more powerful in the upper body than the Older group. This finding highlighted the importance of commencing regimented strength-power training at an earlier age ~ perhaps 17-19 years based upon these results.

The results of Studies 7 and 8 highlight some major findings for sports athletes who must perform strength-power training as an adjunct to their other sports training (endurance, speed, skill and team/tactical training). Firstly advanced athletes can still make gains in strength and power, however the magnitude and scope for changes in strength and power diminishes with increased training experience. These large changes in strength and power

can be attained despite high overall training volumes and specifically, concurrent endurance training. Nonetheless increases in strength and power will begin to diminish and the time periods over which changes in strength and power might manifest themselves might be quite long (e.g. a 2.5 kg increase in strength across 1-year). Given that there may be a ceiling for strength and power development and the results for Study 8, it appears prudent to implement strength-power training during the formative training years (17-23 yrs) to extract the maximum benefit from such training. Delaying the onset of such training until the athlete is fully matured (> 23yrs) may reduce the full benefits of this training.

The last two papers of the third part of this thesis were concerned with practical methods to increase the effectiveness of upper body maximal power training and the implementation of different periodized training strategies or variants. It included relevant literature reviews and practical suggestions based upon the previous papers in this thesis and other relevant publications. Therefore Paper 9 can be seen as an abbreviation of this entire thesis and provides training recommendations suitable for not only rugby league players, but also any athlete concerned with increasing maximal power. Study 10 deals with a review of different methods, in particular, of the configuring of sets, repetitions and intensity progressions across training cycles.

Specifically Paper 9 illustrated that, while maximal power relies heavily upon maximal strength, there are acute practical methods of training that specifically influence power output. These include the following:

1. Include full acceleration exercises (power exercises) as well as strength exercises. Full acceleration exercises are distinctly different from heavy resistance strength exercises that entail a deceleration component.

2. Alter the kinetic profile of exercises by utilizing chains, power bands etc (attached to the ends of the barbell). By implementing these procedures acceleration will last further into the movement and the normal deceleration component that exists in strength exercises is reduced.

3. Use complexes of contrasting exercises and resistances, as was determined by the results of the studies in this thesis.

4. Periodize the presentation of power exercises and resistances so that the multi-faceted nature of power development can be addressed.

5. Use low repetitions. Study 4 in this thesis illustrated the severe impact upon power output that high repetition training produces. To maximize power output repetitions must be kept low (less than 5-6).

6. In line with above, use “clusters” of repetitions, “rest-pause” and “breakdown sets” to reduce intra-set fatigue and hence improve power output. Even moderate repetition sets can be split up so a small respite to reduce muscle fatigue occurs during the set. Speed of muscle contraction and therefore power output can stay high.

7. Ascending order of resistances produces higher power outputs. Whether resistances in consecutive sets are presented in an ascending order (eg. 40 kg, 50 kg and then 60 kg) or descending order (60 kg, 50 kg, and then 40 kg) was previously investigated (Baker, 2001c). The results suggest that if

maximizing power output is the goal of training, then the ascending order is a more productive strategy.

8. Because fatigue severely impairs power output, then the rest periods between sets must be adequate to ensure restoration of work capacity. This may depend upon the nature of the exercise, the resistance used, periodization stage and so on. Generally it was recommended that 1-2 minutes between sets of a power exercise should suffice if repetitions are low (5-6 or less). If the power exercise is alternated with a strength exercise in a complex then the turn-around time for the complex may need to be of the order of 3-4 minutes.

Paper 10 illustrated that there are a number of different periodized training strategies a coach may choose from when designing resistance programs aimed at developing strength and power. These variants have been described by the method by which intensity is progressed along the training cycle, although this method of description is contentious. Nonetheless periodized variants such as Subtle linear, Block (linear or non-linear progressions are possible), Undulating, Wave-like and Accumulation/intensification were identified and described. As there is scant comparative data in the scientific literature regarding the relative merits of each type of variant, most recommendations for their implementation and applicability for different levels of athlete or at different times of the training year, were based upon the opinions of experienced strength coaches. The applicability of different periodized variants for different levels of athletes definitely warrants further research.

Chapter 5.

Conclusions and Primary Findings

This thesis was concerned with investigating, principally, strength and power training in professional rugby league players. However, the sport of the subjects is of less importance than the fundamental questions posed concerning strength and power performance levels and training. Essentially the subjects could have been any experienced strength-power athletes and the questions remain unchanged.

The purpose of the initial part of this thesis was to determine if testing of various aspects of upper body muscular functioning could determine three basic questions.

1. How do the upper body muscular function qualities such as maximum strength, power, speed or strength-endurance relate to success in a sport (e.g. professional rugby league players or any other athletes)?
2. Are there any significant differences between elite participants (NRL) and lower level participants in this sport (SRL and CRL) in any of these qualities?
3. Are there any significant differences in upper body muscular functioning qualities within a team and between teams according to positional grouping?

The results of these investigations clearly indicate that of the four upper body tests assessed in this thesis, maximum strength appears the most highly related to success in rugby league but maximum power and strength-endurance were closely and similarly descriptive of elite NRL participation. Furthermore, upper body pulling strength and a concise and equivalent pressing-pulling strength ratio are also of importance to NRL participation.

Based upon these results it was recommended that younger rugby league players who desire to attain higher playing levels should strive to increase upper body maximum strength, which appears to underpin performance in other key muscular performance factors such as maximum power and strength-endurance. Once the maximum strength base has been established training can be further directed to either (or both) maximum power or strength endurance training. Coaches could implement either an extensive test battery (such as in Study 1) or perhaps simple RTF tests (such as in Study 3, which may be more suitable to high-school coaches and athletes), in an effort to pinpoint where upper-body training efforts need to be directed. As these two muscular qualities of maximum power and strength-endurance require quite divergent and seemingly contradictory training prescriptions, it may be best to train them in separate work-outs.

To this end the rest of the series of studies focused upon training methods and the nature and scope of changes in strength and power in response to the manipulations of resistance training variables across different time periods.

The second part of the thesis was concerned with acute training variable interventions ~ specifically how power output could be affected by various resistance training variable manipulations. The questions asked were:

1. Does the combination of strength-oriented and power-oriented training into a complex affect power output?
2. Does the combination of strength-oriented and power-oriented training with contrasting movements into a complex affect power output?

3. Does high-volume, short-rest period hypertrophy (or by further extrapolation, strength-endurance) training performed before maximal power training affect power output?

The results of these studies illustrated that when combining strength-oriented and power-oriented training, coaches should avoid high-volume, short-rest period training (also used in strength-endurance training) before power training. Combining lower repetition, strength- and power-oriented training in an alternating fashion (known as complex or contrast training) can be an effective power training strategy provided the athletes are strong and experienced in resistance training. Also strength-oriented intensities and volumes must not be extreme during the complex (higher volumes and intensities can be performed for strength development at other times or on other days). Importantly this thesis included a methodology of contrasting exercise movements (agonist and antagonist) that has not been performed previously. Contrasting exercise complexes may prove to be an area of further research.

The third part of the thesis was concerned with the chronic adaptations from long-term resistance training in experienced athletes. The questions asked were:

1. What are the nature, scope and magnitude of changes in strength and power in chronic long-term training in experienced athletes?

2. Does the age at which athletes commence such intense strength-power training affect the levels of strength and power in the longer-term?

3. Based upon this and other relevant research, what are the practical methods that athletes and coaches may implement to enhance the effectiveness of their long-term maximal power training?

One study was a longitudinal tracking study that monitored strength and power adaptations consequent to 4-years of professional sports training and participation. The other study was a retrospective cross-sectional analysis investigating whether the age at which athletes commence regimented strength-power training could affect the resultant strength and power results. These studies revealed that advanced athletes could still increase strength and power but that there was a diminishing scope for strength and power improvements with increased training experience and/or the chronological age at which training commences.

Based upon the results and findings of all these studies, the final papers addressed practical methods to increase the effectiveness of upper-body maximal power training and the configuration of training variables across a training cycle. Athletes and coaches who have attained a base level of strength and muscle conditioning would most benefit from the methods outlined in these papers.

In conclusion, this thesis has addressed upper body strength and power in a very practical manner on three levels: 1. testing 2. acute training interventions and 3. chronic adaptations. From these three levels of investigation, recommendations for training were developed in the final two review papers. Irrespective of the fact the subjects in this thesis were rugby league players, researchers, athletes and coaches should be able to discern a

large amount of information that is relevant to the development of strength and power from the included papers and the overall thesis.

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