Frequency of in-season strength and power training for rugby league

Haydn Masters BHMS (Hons)

A thesis submitted in total fulfilment of the requirements of the degree of Master of Health Sciences in Human Movement (Research)

School of Human Movement
Faculty of Health Sciences

Australian Catholic University
Research Services
Locked Bag 4115,
Fitzroy, Victoria 3065
Australia

March 2001

Statement of Authorship and Declaration of Originality

Except where reference is made in the text of this thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person's work has been used without due acknowledgement in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

All research procedures reported in this thesis received the approval of the relevant Ethics committee.

Print Name ______________________________

Signature ______________________________ Date ______________

Acknowledgements

I am extremely grateful to the many people whom have assisted me in the completion of this thesis.

Firstly, I wish to thank the participants and staff from the North Sydney Bears Rugby League Football Club for their cooperation and persistence throughout this enduring research project.

To my research supervisor, Jodie Stocks, thank you for your guidance, the never ending challenges and questions, and the motivation to complete the task at hand. I wish you the very best in your future endeavours. A thank you also to Peter Wiebe for his input and assistance in this project.

A particular mention to my family, and Erin and her family, whom, once more, have supported me through the long arduous task of completing another thesis. It is a challenge I would probably not adhered to without the backing and encouragement from these special people. Thank you.

Haydn Masters

Abstract

The purpose of this study was to determine the contribution of different in-season strength and power training frequencies to strength and power performance over the course of a 22 week rugby league competition period. Twenty-eight male (n=28) participants, with both high and low strength pre-training status, were divided into three groups following a 15 week pre-season strength and power training programme. A four week periodised in-season strength and power training programme, with intensities ranging from 75-100%, was cycled for the 22 week competition season. Strength and power training was conducted one $day.week^{-1}$ by the first high pre-training status group (HTFL, n=11), and two $day.week^{-1}$ by the second high pre-training status group (HTF2, n=9). The low pre-training status group (LTF1, n=8) performed the same strength and power training frequency and programme as HTF1. Training intensity (% 1RM) and volume (sets x repetitions) of in-season strength and power training sessions were standardised for both groups during each training week. Strength, power, and speed data were collected pre-season, and four times during the in-season period.

No differences were found between HTF1 and HTF2 in performance variables throughout the 22-week in-season period. Both HTF1 and HTF2 displayed similar significant detraining effects in strength, power, and speed, regardless of in-season training frequency ($p<0.05$). LTF1 showed no change from pre-season strength and power performance following 22 weeks of the competition period ($p<0.05$). It was concluded that in-season strength and power training frequency may have a limited role in determining the success of the in-season strength and power training programme in

highly trained footballers. The results of the present study suggest a number of factors other than in-season strength and power training frequency may affect in-season strength and power performance and detraining in high strength pre-training status athletes. The effect the start of a competition period has on dynamic athletic performance needs further investigation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

- % 1 RM = Percentage of one repetition maximum.
- % change = Percent change in performance.
- 1 RM = One repetition maximum.
- 3 RM = Three repetition maximum.
- ANOVA = Analysis of variance statistical procedure.
- AR = Active recovery.
- AS = Assistant power exercise.
- CP = Core power exercise.
- CS = Core strength exercise.
- CYBEX II = The CYBEX II isokinetic muscle evaluation system.
- $day.wk^{-1}$ = Days per week.
- Deg C = Degrees centigrade.
- EP = Explosive power exercise.
- FFW = Free fat weight.
- HTF1 = High strength pre-training status group whom performed one day per week in-season strength and power training.
- HTF2 = High strength pre-training status group whom performed two days per week in-season strength and power training.
- Kg = Kilograms.
- LMM = Lean muscle mass.
- LTF1 = Low strength pre-training status group whom performed one day per week in-season strength and power training.
- m = Metres.
- MANOVA = Multiple analysis of variance statistical procedure.
- Min = Minutes.
- mm = Millimetres.
- n = number of participants.
- N/A = Not applicable.
- Not sign. = Not statistically significant.
- p = level of significance.
- Post- = Post intervention.
- Pre- = Before intervention.
- reps = Number of repetitions completed during resistance training.
- Sec = seconds.
- SD = Standard deviation.
- SEM = Standard error of the mean.
- Yrs = Years of age.

CHAPTER ONE

INTRODUCTION AND HYPOTHESES

1.1. Research problem

The maintenance of a desired level of strength and power during the competition period is possible only if adequate load, or training intensity, is administered at an optimal training frequency (Matveyev, 1981; Bompa, 1993). The importance of in-season strength training intensity (around 80-100% of maximal) for maximal neural activation has been established. A reduced in-season training intensity results in a decrease in maximal strength, with subsequent drops in Type II muscle fiber size, and maximal integrated electromyographical (IEMG) activity (Hakkinen *et al.,* 1985a; Schneider *et al.,* 1998; Legg and Burnham, 1999). In contrast, the exact prescription of in-season strength and power training frequency has not been elucidated, especially for sports with extensive competition periods, or for athletes with different strength and power pre-training status. It has been suggested that the frequency of high intensity training stimulus may have a considerable role in determining the success of an in-season strength and power training programme (Hakkinen *et al.,* 1985a; Hakkinen, 1993b).

When strength training ceases or is inappropriately decreased, which is often the case during the competitive and long transition phases of the annual training cycle, there is disturbance to the biological state of the muscle cells and body organs (Edgerton, 1976; Appell, 1990), resulting in a marked decrease in the athlete's physiological well-being and work output (Kuipers and Keizer, 1988; Fry *et al.,* 1991). The state of diminished or decreased training has been shown to leave the athlete vulnerable to "detraining syndrome" (Israel, 1972). The severity of strength loss experienced by the athlete depends on the training frequency, or the time elapsed between the administration of the last and next training stimulus (Bompa, 1990). The time course of these reversed training adaptations is unclear. It is hypothesised that the highest trained variable will be the first to suffer detraining (Hakkinen *et al*., 1985a; Hakkinen and Alen, 1986; Hortobagyi *et al*., 1993). In addition, losses in strength and power, due to an inappropriate training format or at the cessation of training, occur at an accelerated rate in highly trained strength and power athletes, compared to relatively untrained or previously sedentary subjects (Hakkinen *et al.,* 1985a; Hakkinen *et al.,* 1987; Graves *et al.,* 1988; Hakkinen, 1989; Hortobagyi *et al.,* 1993). In highly trained athletes, strength losses appear within five days of strength training cessation, and occur at a loss of about 6% a week for maximal free weight strength (Hakkinen and Alen, 1986; Hortobagyi *et al.,* 1993).

The effect of reducing strength and power training programmes has only been reported for competition periods up to 16-weeks (dos Remedios *et al.,* 1995; Kraemer, 1997, Schneider *et al.,* 1998; Legg and Burnham, 1999), which is considerably shorter than the 26-week rugby league season in Australia. High intensity/reduced frequency in-season programming has maintained pre-season strength levels during a short competition period in relatively inexperienced strength and power athletes (dos Remedios *et al.,* 1995). However, reductions in training frequency over a longer period of time, particularly in highly trained individuals, may result in a significant decline in maximal strength and power, even when intensity remains relatively high. Data are lacking comparing the in-season strength and power training frequency requirements of athletes with differing pre-training status. Therefore, only speculative programming guidelines exist for the prescription of in-season strength and power training frequency for athletes of varying levels, and for competition periods greater than 16 weeks. Furthermore, most in-season strength and power training recommendations suggest the application of monotonous training loads across the competitive season to maintain performance (Matveyev, 1981; Stone *et al.,* 1981; Bompa, 1994). This might be expected to lead to unwanted training staleness, including central nervous system over-adaptation if practiced over extended periods of time, such as the long competition period of rugby league.

Presently, the most reliable source of information for the development of in-season strength and power models arrives from non-specific investigations into seasonal variations in athlete physiological profiles (Hakkinen and Sinnemaki, 1991; Hoffman *et al.,* 1991b; Hakkinen, 1993a, 1993b; Kraemer, 1997b; Schneider *et al.,* 1998; Legg and Burnham, 1999), detraining investigations (Hakkinen *et al.*, 1985a; Hakkinen and Alen, 1986; Hakkinen *et al.*, 1987; Graves *et al.,* 1988; Hakkinen *et al.,* 1989; Hortobagyi *et al.* 1993), and some subjective analyses (Baker, 1998). However, these investigations have provided a mixture of findings, reducing the comparability and generalisation of the results. Compounding this problem, factors such as sport specific strength and power requirements, recovery between competition matches, and interference of other training activities, must be taken into consideration when programming the frequency of strength and power training in-season.

An investigation is required to examine the effect of different training frequencies on strength and power performance over the course of a long competition period, in both highly trained and less trained strength and power athletes. In conjunction, regular in-season testing of strength and power performance will allow a more in-depth understanding of the variations that occur as a result of a long competition period, and the extent and time course of strength and power performance changes. It remains to be determined if strength and power performance is affected by athletes becoming more familiar with the stress of weekly competitions. It has been hypothesised that the start of the competition season may have a marked effect on strength and power performance. Whether this effect will change as the competition period continues is unknown. Using the results of such an investigation, more accurate in-season training protocols may be developed for sports with varying length competition periods, and for athletes with varying strength and power pre-training status.

1.2. Research aims

It was the aim of this research project to determine the contribution of different strength and power training frequencies to in-season strength and power performance, in both highly trained and less trained strength and power athletes, over the course of a long competition season (22 weeks). This determined the length of time, and the type of reduced training frequency that could be utilised in-season to best maintain pre-season strength and power levels. At the completion of this investigation, an in-season strength and power training model, with specific references to training frequency and pre-training status, was developed for rugby league.

1.3. Hypotheses

It was hypothesised that:

1. Strength and power performance would be maintained at pre-season levels significantly longer in the highly trained two day.wk^{-1} training frequency group, and the less trained one day.wk^{-1} training frequency group, compared to the highly trained one day.wk^{-1} training frequency group.

2. A significant reduction in strength and power performance would be observed by the time of the first in-season testing period (five weeks) in the highly trained one day.wk^{-1} training frequency group compared to pre-season levels.

3. Performance of explosive power training one day.week^{-1} would be sufficient to maintain pre-season levels of explosive power.

4. The start of the competition period will have a marked negative effect on the strength and power performances of all three groups. This negative effect shall continue until the adaptation to competition stress is achieved at week-10 in-season.

CHAPTER TWO

LITERATURE REVIEW

2.1. Team sports

The prescription of training programmes for sport requires an understanding of the physiological requirements of the game (Docherty *et al.,* 1988). Time and motion analyses, and physiological profile investigations of footballers have been conducted in rugby league (Meir *et al.* 1993; Brewer *et al.,* 1994; O'Connor, 1996; Baker, 1998; Baker and Nance, 1999a, 1999b) rugby union (Maud, 1983; Docherty *et al.,* 1985; Davis *et al.,* 1992; Bell *et al.,* 1993), Australian rules football (Ackland *et al.,* 1985; Dawson, 1985), soccer (Mayhew and Wenger, 1985; Davis *et al.,* 1992; Green, 1992), American football (Gleim, 1984), and Gaelic football (Kirgan and Reilly, 1993; Doggart *et al.,* 1993). In general, football players of all codes require: moderate aerobic capacity (between 55-65 ml/kg/min depending on positional roles); the ability to sustain a moderate-to-high percentage of aerobic power for the duration of the match; a high anaerobic power; quick recovery between high intensity work bouts; high acceleration rate from a stationary position at speed; the capacity to change pace and/or direction at speed (agility); a high power to weight ratio; a superior vertical jump performance; and the capacity to resist fatigue during later stages of the match. In addition, the contact football codes require players to have a high degree of muscularity, combined with exceptional levels of upper and lower body strength and power.

2.1.1. Rugby league

The game of rugby league is divided into 40 minute halves of play separated by a 10 minute interval. During an 80 minute game, the ball is in play for approximately 50 minutes (Larder, 1992). Players are involved in intermittent passages of play that last from five to 90 seconds throughout the 80 minute game period (Douge, 1988; Meir *et al.*, 1993). Low intensity activities, such as walking and jogging, make up the majority of the game activities (between 84-95% of game time), with ratios of 1:6 and 1:8 for periods of high-intensity to low-intensity work periods for forwards and backs, respectively (Meir *et al.,* 1993). As exercise intensity of an activity increases, the time spent on that activity decreases (Meir *et al.*, 1993). Cross sectional analysis demonstrates a moderate level of aerobic power for all positions (Davis *et al.,* 1992; Brewer *et al.,* 1994; O'Connor, 1996).

The unlimited interchange rule has led to training which emphasises dynamic strength, power, speed and agility, with aerobic power receiving less attention, although the effect of this rule change on player physiological profiles is to be determined. This rule allows the unlimited interchange of four reserve players throughout the course of a game. Prop and back row players, who perform a large number of hit-ups and tackles, are usually replaced by interchange players after 10-15 minutes of play, and return to play after a subsequent rest. While data are lacking, it appears logical to suggest that these rule changes would lead to an increase in the overall speed of play, higher intensity collisions, and the proportion and total amount of high-intensity running, with the more powerful players excelling as a result.

Tackling is a major skill, with players executing up to 40 tackles per game, depending on their positional role (Tosh, 1982). Players have stated that either making or receiving a tackle was the most fatiguing part of the game (Docherty *et al.,* 1985), as large amounts of physical strength and power are required to tackle the opposing players to the ground. High levels of muscular strength and power are required for all positions (O'Connor, 1996). However, props and back row players make the majority of tackles in a game, and for this reason, are on average taller, greater in body mass, and superior in all maximal strength measures, compared to the hookers, halves and outside backs (O'Connor, 1996).

Passing and running are the two primary means of transporting the football, with strategic kicking carried out on specific occasions by a small number of players (O'Connor, 1996). Players most frequently sprint distances of five to 20 m at a time. This places a greater emphasis on acceleration and explosive speed training, as players rarely sprint distances greater than 40 m (Meir *et al.,* 1993). The ability to accelerate quickly from the mark is essential for all playing positions (O'Connor, 1996). Nevertheless, the point scoring positions, such as outside backs and halves, are on average faster (10 m and 40 m sprints) and more powerful (vertical jump) than the prop, back row, and hooking positions (O'Connor, 1996).

The training and playing season of rugby league is approximately 46 weeks of the year. Off- and pre-season training is conducted from November until the start of the competition period in March. All elements of rugby league tactical and technical training, and player physical preparation is conducted in this 16-week off- and pre-season period. Weekly competition games are played over 26 weeks, with a four week finals series immediately following the regular season.

2.2. Strength qualities

There are three main categories of strength: maximum strength; speed/strength; and strength endurance (Young, 1995a). Research has shown maximum strength, speed/strength and strength endurance measures in the sport are poorly related to each other (Schmidtbleicher, 1992; Young and Bilby, 1993; Young, 1995b). This leads to a differentiation of strength qualities. Strength analysis is required to determine the strength qualities that contribute to high performance outcomes in specific sports, since high levels in one strength quality do not ensure high levels in another strength quality (Young 1995a).

Maximum strength, or absolute strength, is defined as the maximum force generated by a muscle group, with no consideration for force development speed, contraction time, or participant mass (Young, 1995a). The maximum weight that can be lifted only once (one repetition maximum, 1 RM) in a weight-training exercise has been widely used as a field indicator of maximum strength (Meir, 1993; Brewer, *et al.,* 1994; O'Connor, 1996; Kraemer, 1997a, 1997b). Hortobagyi *et al.* (1989) have demonstrated generality of concentric muscle forces obtained during isokinetic, hydraulic, and 1 RM bench press movements, with individuals able to achieve the same relative level of performance when evaluated by different contraction modes and devices.

Speed/strength, explosive strength, or rate of force development is a measure of the force increase per unit time in an explosive contraction (Young, 1995a). These terms are used to indicate the ability to reach a maximum level of strength output in a short time (Matveyev, 1981; Bompa, 1990; Young, 1995a). The maximum rate of force development is believed to be a function of the force and speed of motor unit activation (Schmidtbleicher, 1988). Explosive strength has been shown to improve with explosive jump training (plyometrics) (Hakkinen *et al.,* 1985b). When explosive strength is recorded under dynamic concentric contractions, such as a vertical countermovement jump, it is highly related to dynamic performance, especially sprinting (Pryor *et al.,* 1994; Young, 1995a). Vertical countermovement jumps have been used extensively as a measure of explosive leg extensor strength (Garhammer and Gregor, 1992; Wilson *et al.,* 1993; O'Connor, 1996; Schneider *et al.,* 1998).

Strength-endurance is described as the capacity to resist fatigue during repeated low-intensity contractions (Poliquin and Patterson, 1989). The application of strength-endurance is the ability to counter the fatigue produced by the strength load components of an activity over a prolonged period of time (Bompa, 1990; Young, 1995a).

Since performance levels are greatly reduced without the vital contribution of strength (Kuipers and Keizer, 1988; Fry *et al.,* 1991), it is an important physiological contributor to overall athletic performance (Bompa, 1990). Dominant strength qualities must be taken into account when setting and implementing the tasks of an athlete's strength training. Sport specific strength and power training programmes must attempt to establish the appropriate maximal strength, speed-strength, and strength endurance qualities (Matveyev, 1981; Bompa, 1990). For rugby league the dominant strength quality is speed/strength (power), where maximum strength and speed are integrated into the performance outcome of many match activities such as tackling, breaking tackles, side-stepping and off-loading the ball in a tackle (Baker, 1998, Baker and Nance, 1999a). Furthermore, the best predictor of acceleration during a sprint is the maximum force developed during the take-off in a vertical jump (Young *et al.,* 1995). Improvements in jumping ability, rate of force development, and stretch-shortening cycle activities will lead to improvements in sprinting ability (Young *et al.,* 1995), which is a fundamental activity in rugby league (Baker and Nance, 1999b).

2.2.1. Strength and power training

The basic principles of training for strength are frequency (sessions per week), duration (session length), intensity (percent of 1 RM), variation (altering training variables and conditions), and most importantly, specificity (Stone *et al.*, 1981). Numerous studies have shown the periodisation of strength training, which embodies and manipulates the basic training principles, results in optimum performance or peak strength levels (Stone *et al.,* 1981; Stowers *et al.,* 1983; O'Bryant *et al.,* 1988; Willoughby, 1992; Baker *et al.,* 1994; Kraemer, 1997). In addition, periodisation reduces the potential for overtraining and adaptation to monotonous unvarying training routines by the central nervous system (Kristensen, 1979; Tschiene, 1979; Hakkinen and Komi, 1981).

The optimal prescription of strength and power training for improvement in dynamic athletic performance is a progressive combination of weight training, using loads between 70 and 100 percent of maximum (70-100% of 1 RM), combined with plyometrics training to optimise muscular power output (Wilson *et al.,* 1993; Harris *et al.,* 2000). Results of several studies have shown that performances in a wide variety of dynamic athletic activities requiring strength, speed and power were superior as a result of combination training, compared to high force or high velocity weight training (Blakey and Southard, 1986; Bauer *et al.,* 1990; Wilson *et al.,* 1993; Lyttle *et al.,* 1996; Moss *et al.,* 1997; Harris *et al.,* 2000). This method of strength and power training appears the most relevant to the sport of rugby league, with the elements of speed, strength and power incorporated into almost all playing activities.

2.2.2. In-season strength and power training

The benefits of strength and power to sports performance are experienced by athletes providing the neuromuscular system maintains adaptations induced by training (Bompa, 1990). The need for concentration on technical and tactical components of a particular sport, and an emphasis on recovery before the next competition match, results in subsequent reductions in overall strength and power training volume during the in-season period (Bompa, 1990). Programmed strength and power training during the competition period is commonly referred to as maintenance training, where attempts are made to maintain strength and power performance at pre-season levels, as further increases are limited by the stresses of weekly competition matches (Matveyev, 1981). Stone *et al.* (1981) state that in sports where there is a competition season of considerable length, a strength and power maintenance programme is a necessity. This programme must be of sufficient volume and intensity to maintain reasonable strength and power levels throughout the playing season. However, the total load must not be so high that the combination of sport practice plus strength and power training produces overtraining and decreased performance (Stone *et al.,* 1981).

Research has highlighted that if the strength training induced stimulus to muscles ceases, or is drastically reduced, subsequent strength and power performances will decline (McMorris and Elkins, 1954; Rasch and Moorehouse, 1957; Campbell, 1967; Morehouse, 1967; Waldman and Stull, 1969; Rasch, 1971; Hakkinen and Komi, 1983; Hakkinen *et al.*, 1985a; Allen, 1989). The consequence is detraining, and a decrease in the contribution of strength and power to athletic performance.

A review of the literature reveals only the briefest of recommendations, and a multitude of different stances taken on in-season strength and power training. A number of in-season strength and power training models have been developed to sustain strength and power levels throughout the competition period (Matveyev, 1981; Stone *et al.*, 1981; Bompa, 1994; Wathen; 1994). However, most of these recommendations are for individual sports, or for sports with relatively short competition phases. This leaves a gap in the knowledge of in-season strength and power training for seasonal sports where lengthy competition periods are common. In addition, the pre-existing in-season strength and power training models have not been compared for their effectiveness in the application of in-season strength and power maintenance. These models provide generic in-season strength training prescription, with little specificity for different sports and training situations. Furthermore, these models prescribe non-varied monotonous training, with persistent high intensity training loads, which have been shown to lead to unwanted training effects, such as overtraining and decrements in strength and power performance during long unvaried training periods (Komi, 1986). The monotonous unvarying prescription of training volume and intensity in most of these models would appear to be inappropriate in providing variations in training stimulus over a long competition period, resulting in probable losses in neural and hypertrophic factors for muscle contraction.

In-season plyometrics training guidelines are limited, especially for athletes with varying levels of pre-training status. Moreover, the prescription of in-season combination training for dynamic athletic performance is yet to be determined. Considerable reductions in explosive power performance, measured through vertical jump tests, have been reported in basketballers and footballers due to a reduced intensity and lowered overall volume of explosive power training stimulus (Gillam, 1985; Schneider *et al.*, 1998). In contrast, female volleyball players increased explosive power performance over a 22 week competition period by combining explosive strength training two $day.wk^{-1}$, with one day of high intensity explosive power training every two weeks over the course of the competition period (Hakkinen, 1993a). While initial values for explosive strength and power characteristics of the participants indicate that pre-training status may have contributed to the positive outcome, the results suggest in-season plyometrics training must be of high intensity, if pre-season levels are to be maintained. In contrast, the training frequency of in-season explosive power training remains to be elucidated, especially in highly trained athletes over the course of a long competition period.

2.2.2.1. Variations in strength and power as a result of a competition period

Several studies have reported unintended decreases in the strength and power performance of athletes (Hakkinen and Sinnemaki, 1991; Hoffman *et al.,* 1991a; Koutedakis *et al.,* 1992; Hakkinen, 1993b; Schneider *et al.,* 1998; Legg and Burnham, 1999), whilst others have shown maintenance and/or increased strength and power variables over the course of a competition season (Neuffer *et al.,* 1987; Hoffman *et al.,* 1991b; Bell *et al.,* 1993; Hakkinen, 1993a; DeRenne *et al.,* 1996; Kraemer, 1997b; Utter *et al.,* 1998). The varied findings are a result of several methodological inconsistencies and research design flaws, inhibiting the evaluation of strength and power changes as a consequence of training alterations in-season. Pre-training status has been shown to have a considerable effect on strength and power training adaptations (Moritani and DeVries, 1979; Hakkinen and Komi, 198; Alen *et al.,* 1984; Hakkinen, 1985, 1989). However, no in-season investigation has sampled participants from the same population with varying pre-training status to determine if athletes with differing athletic training levels have different in-season strength and power training requirements. Furthermore, the strength and power requirements of the sports investigated vary considerably, reducing the ability to make comparisons. To further complicate the problem, the pre-training status of participants in many studies is not reported, with most studies neglecting to report pre-season strength training protocols, targeted strength qualities, and increases in strength and power performance as a result of pre-season training. These complications further highlight that the analysis and prescription of in-season strength and power training must be sport specific, as strength and power training requirements are markedly different between sports. In addition, in-season strength and power training prescription must consider pre-training status of athletes, increases in strength and power from pre-season protocols, and target dominant strength qualities.

2.2.2.2. Effect of in-season strength and power training programmes in football

Decreases in muscular strength and power during a long competitive football season are most likely due to a number of factors. One reason for reported declines in strength levels over the course of a competition period is that the level of strength achieved during pre-season training may represent peak levels. Fleck (1994) states that a loss of strength can be expected in athletes following an intense training programme that achieved peak levels prior to the start of competition. It can be hypothesised that strength decrements would be most pronounced at the start of the competition period when players are required to adapt to a combined competition and training schedule. It may be expected that once the initial stress of the combined competition and training schedule is overcome, the resulting strength and power performance decrements may plateau, with possible strength and power performance increases after this initial decline. However, most in-season football studies (dos Remedios *et al.,* 1995, Schneider *et al.,* 1998; Legg and Burnham, 1999) only provide pre- and post-season strength and power results, limiting the ability to identify the periods when strength decrements were most pronounced in-season. One study reported larger strength decrements during the first half of a 16 week college football season, which is a considerably smaller competition season than rugby league, compared to the changes from mid- to post-season (Kraemer, 1997b). Strength testing at more regular in-season intervals (four or five weeks), and over a longer competition period, may provide more insights to identifying the effect the start of the competition period has on peak strength and power performance.

Interference of other training variables may be another reason for strength and power decreases during competition periods. Negative interference between strength and endurance training has been reported in a number of studies (Hortobagyi *et al.*, 1991, Hickson, 1980; Hunter *et al.*, 1987). It may be possible that the extremely large physical demands of weekly training sessions and competition matches, especially in contact sports such as football, results in negative interference with in-season strength and power training adaptations. The increased number of tactical and technical training sessions mid-week, combined with the weekly competition match, greatly elevates the ratio of aerobic and anaerobic activities to strength and power activities. This may result in subsequent reductions in strength and power performance obtained through pre-season training practices.

To date, there is relatively little information on the detraining process associated with an overall reduced in-season strength and power training volume, frequency or intensity, which is the most probable cause for strength and power decrements resulting from a football competition period. Most studies that have attempted to maintain strength and power levels across a football season appear to have programmed inappropriate reductions in strength and power training volume, intensity and frequency in an attempt to maintain peak strength levels achieved during pre-season (Schneider *et al.,* 1998; Legg and Burnham, 1999).

Intensity of strength and power training appears to be the most important component of in-season prescription, as neural stimulation is the primary factor in maximal strength increases, once hypertrophy of muscle fibers had reached a ceiling point (Hakkinen and Komi, 1981; Alen *et al.*, 1984; Hakkinen, 1985). In addition, neural stimulation provides the main training effect when the pre-training status of athletes is high and significant muscle hypertrophy is already present at the start of training (Hakkinen, 1985). In-season football studies that used reduced strength training intensities (60-85 percent of 1RM) reported significant reductions in strength and power performances over a 16 week and 10 week season (Schneider *et al.,* 1998; Legg and Burnham, 1999). Similar reductions in strength performance have been reported in a sample of strength-trained individuals, where a reduction in maximum IEMG activity of trained muscles coincided with a one-month period of reduced training intensity (70% of 1 RM) (Hakkinen *et al.,* 1985a). Comparatively, dos Remedios *et al.* (1995) and Kraemer (1997b) were able to maintain strength levels in football players using high in-season strength training intensities over a 10 week and 16 week football season, respectively. In addition, training frequency and overall volume of strength training was effectively reduced by half from the pre-season. Studies of athletes in other sports using high in-season strength training intensities have also reported no changes in strength and power performance (Hakkinen, 1993a; Utter *et al.,* 1998). These results demonstrate the necessity for high intensity training stimulus in-season to keep muscles functioning at near optimal levels. Certainly, low in-season strength training intensities may provide an insufficient neural stimulus required for maintaining strength levels (Schneider *et al.,* 1998).

The frequency of a high intensity training stimulus may also have a considerable role in determining the effect of an in-season strength and power training programme. It has been suggested that a degree of the intensive training effect resides in the facilitatory and inhibitory neural pathways acting at various levels in the nervous system, and that not only the magnitude, but also the frequency of strength and power training during in-season is important to stimulate this effect (Hakkinen *et al.,* 1985a; Hakkinen, 1993b). Strength and power performance was unchanged in football players with a high pre-training status, as a result of using high intensity training two $day.wk^{-1}$ during the competitive season (Kraemer, 1997b). In contrast, significant strength reductions were reported in high pre-training strength status football players using one high intensity session and one low intensity strength training session each week (Schneider *et al.,* 1998). Although participants in both studies trained two $day.wk^{-1}$, it appears that the subjects studied by Schneider *et al.* (1998) may have lacked the required frequency of high intensity training to maintain strength levels throughout the competitive season, as the low intensity session each week may have insufficiently stimulated the neural adaptation mechanism of muscle contraction. It can be hypothesised that football players with high strength and power pre-training status require high intensity in-season strength and power training more than one $day.wk^{-1}$ to sufficiently maintain pre-season strength and power levels.

Football players with low strength and power pre-training status were able to maintain strength and power performance over 10 weeks of a football competition period using high intensity strength training one day.wk^{-1} (dos Remedios *et al.,* 1995). In comparison, significant reductions were reported in highly trained football players using one day.wk^{-1} of high intensity training, combined with one day of low intensity training (Schneider *et al.,* 1998). Although high intensity strength and power training is the main element for in-season training prescription, the frequency of in-season high intensity strength and power training may need to be greater in highly trained strength and power athletes, than in participants with a lower pre-training status. In contrast, the effect of a reduced training frequency on explosive power performance in football players has not been researched, leaving the prescription of in-season explosive power training frequency to be determined for all football player levels.

The effect of reducing strength and power training programmes has only been reported for competition periods up to 16 weeks which is considerably shorter than the Australian rugby league competition season. Most guidelines for in-season strength and power training speculate the training requirements over competition periods longer than 16 weeks (Stone *et al.*, 1981; Bompa, 1994; Wathen, 1994). It is impossible to determine if the in-season programme used by Kraemer (1997b) and dos Remedios *et al.* (1995), or those reported in other studies (Hakkinen, 1993b; Utter *et al.*, 1998), would have been sufficient in maintaining strength and power levels over an extended football competition period, such as five to seven months. Furthermore, training practices, exercise adherence, and interference of other training variables may have differed between these studies, reducing comparability. It is also unknown whether strength training programmes used in the pre-season of these in-season investigations were sufficient to elicit significant increases in strength and power prior to the start of the competitive season, or if the pre-season training programmes resulted in different training adaptations due to dissimilar programme variables, such as duration, intensity, frequency, and volume.

Most of the in-season studies above are descriptive case-series investigations, with repeated observations made on only one group using the same training intervention. Data is lacking to determine if different frequencies of high intensity in-season strength and power training result in dissimilar strength and power adaptations in a group of football players drawn from the same population, if all other training variables and interferences are controlled. Therefore, a longitudinal experimental study which spans the entire football season is required. Such a study must use different in-season strength and power training frequencies as the training intervention, using participants from the same football population with equivalent pre-training status.

2.3. Training and detraining of strength and power

Athletes are exposed to a detraining effect when strength and power training is not maintained, or is drastically reduced during the competitive phase, or during the transition phase at the end of the competition season. Training induced changes in neuromuscular performance can be characterised by specific enhancements in maximal strength, muscle fiber hypertrophy, isometric force-time, the force velocity curve, or maximal IEMG activity (Hakkinen, 1985). However, inactivity reverses the neuromuscular adaptations, and in due course, will reverse adaptations to the pre-training state (Thorstensson *et al.*, 1977; Staron *et al.,* 1981; Hakkinen *et al.,* 1985a, 1985b).

The changes in performance traits result from adaptations to the neuromuscular system caused by specific types of training (Hakkinen *et al.*, 1980, Hakkinen and Komi, 1983; Alen *et al.,* 1984). The selective adaptations include: increased number of motor units recruited (Caiozzo *et al.,* 1981; Sale *et al.,* 1983a); increased motor unit synchronization (Hayes, 1978; McDonach and Davies, 1984); increased frequency (rate) of motor unit firing (Hayes, 1978; McDonach and Davies, 1984); decreased degree of neuromuscular inhibition (Moritani and DeVries, 1979; Caiozzo *et al.,* 1981); and increased cross sectional area of muscle fibers through muscle hypertrophy (Moritani and DeVries, 1979; Gonyea, *et al.,* 1983; Sale *et al.,* 1983b). Collectively, these adaptations contribute to increases in muscular strength and power performance as a result of strength and power training (Edgerton, 1976; Hakkinen, 1989), provided training interference is minimised (Hickson, 1980; Dudley and Djamil, 1985; Hunter *et al.,* 1987; Bell *et al.,* 1988; Bell *et al.,* 1991; Hortobagyi *et al.,* 1991). Although the specific adaptations are highly related to learning, and are observed at their highest level during the first few weeks of training in beginners, they contribute to strength and power gains during the entire training career of an athlete (Edgerton, 1979; McDonach and Davies, 1984).

Inactivity, or inappropriate training reductions, result in a net decrease in the amount of force that can be generated, due to altered motor unit recruitment patterns (Edgerton, 1976; Hainaut, 1989; Houmard, 1991). This compromises motor skills requiring strength and power, as muscle tension depends on force and speed of stimuli, and firing rate (Duchateau and Hainaut, 1991). A reduction in speed is one of the first elements to be affected by detraining, as the breakdown of protein, and the deterioration of motor units causes a reduction in nerve impulses, reduces contraction rates, and thereby, decreases the power capabilities of muscle contraction (Edgerton, 1976; Hainaut and Duchateau, 1991; Houmard, 1991). A reduction in the number of motor units recruited and/or the synchronisation of motor units during repeated contractions leads to lower strength and speed of contraction (Edgerton, 1976; Houmard, 1991; Hainaut and Duchateau, 1991). Furthermore, when muscles are in a state of disuse, the body increases the process of protein degradation (Edgerton, 1976; Appell, 1990). Hakkinen *et al.* (1985a) indicate that significant decreases during detraining in muscle fiber areas, accompanied by concomitant changes in thigh girth and fat free weight (FFW), are obvious signs of atrophy due to the termination of strength training. Other studies support this claim (Allen, 1989).

Strength and power pre-training status affects the rate of detraining observed at the cessation of training. Experienced strength and power athletes suffer detraining at a faster rate than less experienced athletes at the cessation of strength and power training (Hakkinen *et al.,* 1985a; Hakkinen *et al.,* 1987; Graves *et al.,* 1988; Hakkinen, 1989; Hortobagyi *et al.,* 1993). The effect of pre-training status on strength and power training adaptations has been previously shown, with maximal strength and other neuromuscular adaptations of highly trained strength athletes being more limited than in those subjects with lower pre-training status (Moritani and DeVries, 1979; Hakkinen and Komi, 1981;

Hakkinen *et al.,* 1981, 1985a; Alen *et al.,* 1984; Hakkinen, 1985). This accelerated detraining and degree of strength loss is suggested to be due to the high levels of initial strength and muscle mass (pre-training status), and/or the type of strength training regimens used by participants (Hortobagyi *et al.,* 1993). Specific testing of dominant strength qualities during detraining is required to elucidate the effect detraining has on performance outcomes, as performance decrements will be most visible in highly trained strength qualities at the cessation or reduction of training (Hakkinen *et al.,* 1985a; Hakkinen, 1989).

There is a lack of literature investigating the extent of strength and power losses associated with reduced strength and power training over an extended competition period, or a period of training cessation at the end of the competitive season. One study monitored changes in body composition of professional rugby league players over three months of the competitive season, indicating that players had significantly reduced body fat and body mass levels during the competition period (Meir, 1994). However, strength and power tests, or other athletic performance tests, were not administered during the same period, reducing the applicability of the results to strength and power detraining. Allen (1989) has demonstrated significant reductions in muscle cross-sectional area due to six weeks of detraining in rugby league players at the end of the competition period. However, no corresponding reductions in strength and power performance were measured. The effect of a reduced in-season strength and power training programme on strength and power performance over an extended competition period has yet to be investigated. Furthermore, the effect of a reduced in-season strength and power training programme in football players with varying pre-training status has yet to be elucidated. It could be hypothesised that different strength and power pre-training levels, at the beginning of the season, may affect the degree of detraining observed throughout a long competition period in football players.

2.4. Summary

Strength and power are important physiological contributors to overall performance in rugby league. A large emphasis is placed on the development of strength and power qualities in the off- and pre-season periods of training, prior to the commencement of the competition season. However, the prescription of in-season strength and power training is somewhat limited by a combination of increased tactical and technical sports training, and an emphasis on recovery between weekly competition matches.

Training intensity appears to be the most important component of in-season strength and power training prescription. However, the frequency of high intensity training stimulus may have a considerable role in determining the effect of an in-season strength and power training programme. Football players with higher strength and power pre-training status may require greater frequency of high intensity strength and power training stimulu during the competitive season, compared to football players with lower pre-training status. However, it remains to be determined if different frequencies of high intensity in-season strength and power training result in varied strength and power adaptations in a group of football players drawn from the same population, if all other training variables and interferences are controlled.

CHAPTER THREE

METHODOLOGY

3.1. Participants

A total of 28 male (n=28) participants aged between 18 and 27 years (inclusive) volunteered for this study. The participants for this study were recruited through the North Sydney Bears Rugby League Football Club. The selection criteria were set for rugby league players participating in the NSW rugby league 1st Division and/or Jersey Flegg (U/20's) competitions, who had participated in high level strength and power training for a minimum of one football season (12 months). Each participant received a participant information package and provided informed consent before participating in this study. This recruitment process was approved by the Australian Catholic University Research Projects Ethics Committee. A total of 34 participants matched the selection criteria. Six of these participants were rejected as a result of screening for pre-existing injuries that would inhibit their participation in the study.

3.2. General procedures

The effect of manipulating strength and power training frequency during a competition season was investigated in three groups of rugby league football players (two groups with high strength and power pre-training status, and one group with low strength and power pre-training status), at the completion of a 15 week off- and pre-season strength and power training programme. In-season strength and power training was conducted one day.week^{-1} by the first high pre-training status group (HTF1), and two day.week^{-1} by the second high pre-training status group (HTF2), for the entire competition season. Training intensity (% 1RM) and volume (sets x repetitions) of in-season strength and power training sessions were standardised for both groups during each training week. This method of programming the same strength and power training volume and intensity at different training frequencies, with regular data collection periods, ascertained the effect of in-season training frequencies on strength and power performance throughout a 22 week competition period in athletes with similar pre-training status. The low pre-training status group (LTF1) performed the same strength and power training programme as HTF1 (one day.wk^{-1}) for the entire competition season, determining if pre-training status had any effect on strength and power performance throughout the competition season.

Strength, power, and speed data were collected pre-season, and several times during the in-season period, to determine the time frame of performance changes that occurred as a result of manipulating in-season strength and power training frequency. Data analyses were conducted to determine if changes in strength and power performances resulting from different in-season strength and power training frequencies were statistically significant.

3.2.1. Off- and pre-season training

All participants were involved in football training activities in the off- and pre-season training periods. Participants were required to attend three strength and power sessions, four football skills sessions, and two sessions for either speed or endurance each week (Table 3.1).

Table 3.1. Off-season and pre-season training schedule for entire group.

Day	Time (pm)	Session
Monday	5.00	Strength and power
	6.00	Football skills
Tuesday	5.00	Speed or endurance
	6.00	Football skills
Wednesday	5.00	Strength and power
Thursday	5.00	Speed or endurance
	6.00	Football skills
Friday	5.00	Strength and power
	6.00	Football skills

3.2.1.1. Off-season and pre-season strength and power training

The off- and pre-season strength and power training used was an undulating periodised programme (Poliquin, 1988), with short periods of high volume training, emphasising the hypertrophic factors, alternated with short periods of high intensity training, emphasising the neural responses. This has been shown to offer a better alternative to the periodised linear intensification model (Stone *et al.*, 1981; Stower *et al.*, 1983). Komi (1986) states that prolonged linear intensification can lead to neural fatigue, compromising strength gains. In conjunction, Bompa (1990) states that standard loading often leads to staleness and limitations in strength increments. Thus, by combining high intensity training with intermittent periods of high volume/low intensity training, optimal strength gains result (Stone *et al.*, 1981; Baker *et al.*, 1994; Stone *et al.*, 1999a, 1999b).

Combination strength and power training was used in the 15 week off- and pre-season periods. It has been shown that the optimal prescription of strength and power training for improvement in dynamic athletic performance results from a progressive combination of traditional weight training methods, using loads between 70 and 100 percent of maximum (70-100% of 1 RM), and plyometrics training (Wilson *et al.,* 1993; Harris *et al.,* 2000). All participants in the study were required to complete three supervised strength and power sessions per week. Training intensity was highest on Monday, and reduced by five percent and ten percent on Wednesday and Friday, respectively. Participants had individual training loads prescribed for the core strength and power exercises in each session, with the assistant strength and power exercise loads determined by the individual. The practice of prescribing individual training loads for the core exercises, and estimating the assistant exercise load is common, as testing 1RM in all lifts is extremely time consuming.

The 15 week off- and pre-season strength and power training period was divided into three distinct training phases: the four-week off-season programme emphasising general physical adaptations (hypertrophy); the seven-week pre-season programe emphasising maximal strength; and the four-week pre-competition programme emphasising power. Three weeks of the pre-season programme were unsupervised (weeks seven to nine), since participants were not required for formal training. All other training sessions were supervised. Unloading weeks, where the intensity and volume of strength and power training is reduced to allow for neuromuscular adaptation from the last training period, and recovery before the next training period (Bompa, 1990), were used at weeks four, seven, and 12 of the off- and pre-season training period. Rest periods between sets and exercises were altered as the intensity and objectives of training changed, according to the guidelines in the literature (Stone *et al.,* 1981; Bompa, 1990). Rest periods during the first four-week training off-season period were one and a half minutes between sets (hypertrophy stage), two and a half minutes between sets in the pre-season training period (maximal strength stage), and three and a half minutes in the pre-competition phase (power stage). The off- and pre-season strength and power training protocol used in this study is shown in Table 3.2 a-c.

Plyometrics were combined with the strength and power training programme from week five onwards in the off- and pre-season. The plyometrics programme did not start until

Table 3.2a. The 4 week off-season strength and power training programme.

Training week	1	2	3	4*
Core strength	5x10 @ 70%1RM	5x10 @ 70% 1RM	3x5 @ 85% 1RM	2x5 @ 75% 1RM
Assistant power	3x6 @ 70%	3x6 @75%	3x6 @75%	2x6 @70%
Assistant strength	3x10	3x10	3x10	2x10
Extras	Injury Prevention	Injury Prevention	Injury Prevention	Injury Prevention

Table 3.2b. The 7 week pre-season strength and power training programme.

Training week	5 & 6	7*	8 & 9	10 & 11
Core strength	3x5 @ 87% 1RM	3x5 @ 75% 1RM	3x5 @ 85% 1RM	5x5 @ 87% 1RM
Core power	3x4 @ 80% 1RM	3x4 @ 70% 1RM	3x4 @ 80% 1RM	3x4 @ 82% 1RM
Assistant power	3x5	3x4	3x4	3x4
Assistant strength	3x6	2x10	3x6	3x6
Plyometrics	Week 1& 2	Week 3	Week 4 & 5	Week 6 & 7

Table 3.2c. The 4 week pre-competition strength and power training programme.

Training Week	12*	13	14	15
Core strength	3x4 @ 80% 1RM	3x3 @ 92% 1RM	3x4 @ 90% 1RM	2x3, 2x2 @ 92-95% 1RM
Core power	3x3 @ 75% 1RM	4x4 @ 82% 1RM	4,3,3,2 @ 82-92% 1RM	3,2,2,1 @ 87-100% 1RM
Assistant strength	None	3x8	3x8	3x8
Plyometrics	Week 8	Week 9	Week 10	Week 11

Notes: * highlights an unloading week

week five, since the development of an appropriate strength base before starting a plyometrics programme was required for injury prevention (Bompa, 1994). The plyometrics programme used in this study had an undulating daily training volume (the number of ground contacts per session), with subsequent volume reductions as exercise intensity increased. Plyometrics training was combined with strength and power training two day.wk^{-1} (Monday and Friday) during the off- and pre-season training period. The off- and pre-season plyometrics programme is shown in Table 3.3.

3.2.2. In-season training

3.2.2.1. Group selection

In-season strength and power training groups were selected at the completion of the off- and pre-season training. Selection criteria were used to minimise the differences that would occur in strength and power adaptations and performance associated with different pre-training status during the in-season period. Participants with less than two years strength and power training experience were assigned to the low pre-training status in-season strength and power training group (LTF1). Participants with more than two years strength and power training experience were assigned to one of two high pre-training status in-season strength and power training groups (HTF1 or HTF2). The high pre-training status participants were sampled from two teams within the football club, whereas the low pre-training participants were sampled from one team. Low pre-training status participants were assigned to the same group (LTF1). Random assignment of the high pre-training status participants was inappropriate, as football-training sessions would be disrupted if players from the one team were separated into two different groups. It was

Table 3.3. Off- and pre-season plyometrics training programme for entire group.

Week	Training Week	Sets & Reps	Exercises	Volume
1	5	3x8	Split Squat Jumps	68
		3x8	Clap Push Ups	
		2x10	Tuck Jumps-Heel Back	
2	6	3x10	Tuck Jump-Heel Kicks	80
		3x10	Clap Push Ups	
		2x10	Lateral Cone Jumps	
3	7	OFF	Unloading Week	0
4	8	2x8	Diagonal Cone Hops	56
		2x6	Double Clap Push Ups	
		2x8	Single leg Push Offs	
		2x6	Box Jumps	
5	9	2x8	Single Leg Box Push Offs	44
		2x6	Drop & Catch Push Ups	
		2x8	Diagonal Cone Jump	
6	10	2x10	Lateral Cone Jumps	56
		2x10	Medicine Ball Chest Throw	
		2x8	Single Leg Box Push Offs	
7	11	2x8	Single Leg Box Push Offs	44
		2x6	Drop & Catch Push Ups	
		2x8	Diagonal Cone Jump	
8	12	OFF	Unloading Week	0
9	13	3x6	Depth Jump Rebound	55
		2x5	Overhead Medicine Ball Throw	
		3x5	Standing Triple Jump	
		2x6	Supine Chest Catch & Throw	
10	14	2x4	Single Leg Depth Jump	52
		2x6	Power Drop	
		2x4	Depth Jump Rebound to Box	
		2x6	Side Throw	
		2x6	Lateral Box Jumps	
11	15	2x3	Depth Jump to Long Jump	42
		2x4	Push Up Depth Drop Rebound	
		2x4	Single Leg Zig Zag	
		2x6	Underhand Throw	
		2x4	Standing Triple Jump	

decided, for practicality reasons, that high pre-training status participants from each team would perform the same frequency of in-season strength and power training. Therefore, players from one team were assigned to HTF1, and players from the other team to HTF2.

One-way ANOVA showed no significant differences between the two high pre-training status groups (HTF1 and HTF2) for strength and power performance at off- and pre-season data collection periods, with a MANOVA showing similar changes in performance resulting from the off- and pre-season strength and power training programme. These results indicate that participants in the two high pre-training status groups were statistically matched for pre-training status at the start of the in-season period. Repeated measures analysis could only be conducted between the two high pre-training status groups (HTF1 and HTF2) for the off- and pre-season data, and for further in-season analyses, since significant differences existed between the two high pre-training status groups (HTF1 and HTF2) and the low pre-training status group (LTF1) in a number of strength and power performance measures at the start and end of the off- and pre-season training. Furthermore, the off- and pre-season strength and power training protocol of this study resulted in much greater adaptations in LTF1 participants compared to HTF1 and HTF2 participants. This highlights the pre-training status differences of the high pre-training status participants (HTF1 and HTF2) and the low pre-training status participants (LTF1). Hakkinen (1989) has also shown that different pre-training status results in a marked difference in the magnitude of strength and power adaptations using the same training protocol. The adaptations in strength and power performance from off-and pre-season strength and power training for each group, and the statistical analyses are shown in Table 3.4.

3.2.2.2. In-season training schedule

All participants were involved in similar football training skills sessions, speed sessions, and endurance sessions throughout the competition period. However, HTF2 performed strength and power training two days.wk^{-1}, whilst HTF1 and LTF1 performed strength and power training one day.wk^{-1}. The weekly training schedules for the three groups during the 22 week competition season is shown in Table 3.5.

The in-season strength and power training programmes for this study were a combination of guidelines provided by existing in-season strength and power training models (Matveyev, 1981; Stone *et al.,* 1981; Bompa, 1993; Wathen, 1994; Baker, 1998), using rugby league specific programming factors. The in-season protocol was a four-week periodised linear intensification model, based on the concept of training periodisation (Matveyev, 1981). This four-week structure had a large initial volume at a moderate intensity, with progressive increases in intensity whilst working toward a peaking of intensity, and a reduction in total volume (Baker *et al.,* 1994). Stone *et al.* (1981) theorised that the early high volume period emphasises the hypertrophic adaptations and that later intensity periods stress the neural responses, thus, providing a more efficient training structure for strength gain. The four-week model was cycled throughout the competition season, with intermittent periods of active recovery weeks included at certain

Table 3.4. Off- and pre-season data and statistical analyses.

Variable	Group	N	Off-Season mean ± SEM	Pre-Season mean ± SEM	Percent change	Change within-groups	Changes between-groups
Mass (kg)	**HTF2**	9	90.54 ± 8.86*	90.51 ± 9.60*	0.1%	Not sign.	Not sign.
	HTF1	11	89.49 ± 9.62*	89.06 ± 9.73	0.3 %	Not sign.	
	LTF1	8	79.59 ± 5.02	80.14 ± 5.87	0.7 %	Not sign.	N/A
Vertical Jump (cm)	**HTF2**	9	51.9 ± 3.01	55.2 ± 3.12	6.4 %	Not sign.	Not sign.
	HTF1	11	52.1 ± 1.90	54.0 ± 2.60	3.6 %	Not sign.	
	LTF1	8	49.8 ± 1.25	55.3 ± 1.52	11.1 %	P<0.01	N/A
1RM Bench Press (kg)	**HTF2**	9	119.44 ± 5.17*	124.4 ± 5.23*	4.2 %	p<0.001	Not sign.
	HTF1	11	115.0 ± 4.16*	119.3 ± 3.75*	4.1 %	p<0.01	
	LTF1	8	90.0 ± 4.01	102.5 ± 3.13	13.8 %	p<0.01	N/A
3RM Back Squat (kg)	**HTF2**	7	136.4 ± 4.33*	155.0 ± 4.36*	13.6 %	p<0.001	Not sign.
	HTF1	11	130.0 ± 3.69*	147.3 ± 3.84*	13.3 %	p<0.001	
	LTF1	7	102.9 ± 4.61	125.7 ± 3.35	22.3 %	p<0.01	N/A

HTF2 (n=9), HTF1 2 (n=11), and LTF1 (n=8) off-season & pre-season strength and power performances. * Significant difference between the two high pre-training status groups (HTF1 and HTF2) and the low pre-training status group (LTF1) for off- and pre-season data sets Results from a MANOVA for HTF1 and HTF2 shown for variations between groups as a result of off- and pre-season training.

Table 3.5. The weekly in-season training schedule.

Day	Time (pm)	Session HTF2	HTF1 & LTF2
Monday		OFF	OFF
Tuesday	5.00 6.00	Strength and power Football skills	Strength and power Football skills
Wednesday	5.00 6.00	Speed or endurance Football skills	Speed or endurance Football skills
Thursday	5.00 6.00	Strength and power Football skills	Football skills
Friday		OFF	OFF
Saturday		Game day or Recovery	Game day or Recovery
Sunday		Recovery or Game day	Recovery or Game day

intervals. Combination training, which was used in the off- and pre-season, was continued throughout the competition period. Table 3.6 and 3.7 show the strength and power training component and the plyometrics component of the combination training programme, respectively. The sequencing of the strength and plyometrics exercises was altered for each session. However, the sequences were consistent for all group sessions, minimising differences in groups arising from dissimilar exercise sequences. The volume of plyometrics (the number of foot contacts per session) was also reduced as training intensity increased, in conjunction with the strength training programme.

The strength and power training programmes were repeated throughout the 22-week in-season period. That is, the exercise programme for week one was repeated in week six, week 12, and week 18 for all groups (Figure 3.1). Data collection always took place the week immediately following week four of the in-season cycle, which replaced strength training for that week. Active rest periods, where strength and power training was substituted for another physical activity, such as indoor cricket and indoor soccer, were conducted in week 11 and week 17 of the 22 week in-season period. These active rest periods allowed for the physical and mental regeneration of the athletes during the long competition season, as well as providing a period of injury rehabilitation for players with persistent minor injuries.

3.2.2.3. Daily in-season strength and power training programmes

The daily strength and power sessions for HTF1 and LTF1 were equivalent. The sessions for HTF2 were similar (Table 3.8), however, strength exercises were predominant on day

Table 3.6. Four week in-season strength-training component of the in-season strength and power training protocol.

Training Week	1	2	3	4
Session Intensity (% 1RM)	75-80% 1RM	85% 1RM	90% 1RM	95-100% 1RM
Session Volume (sets x reps)	90-95	60-70	45-55	20-30
Core strength	3x8	3x5	3x3	2x2,1x1
Core power	3x5	3x4	3x3	2x2,1x1
Assistant strength	2x10	2x8	2x6	2x5
Assistant power	2x6	2x5	2x5	2x4
Plyometrics	Week1	Week 2	Week 3	Week 4

Table 3.7. Four week in-season plyometrics component of the in-season strength and power training protocol.

Week	Exercises	Sets & Reps	Volume
1	Rocket jumps	3x10	60 contacts
	Lateral cone jump	3x10	
2	Split cycle squat jumps	3x8	54 contacts
	Lateral box jumps	3x10	
3	Multiple box jumps	3x6	48 contacts
	Diagonal cone hops	3x5 each leg	
4	Depth jump to standing long jump	3x5	33 contacts
	Medicine ball squat throw	3x6	

Figure 3.1. Cycling of the 4 week in-season strength and power training model during the rugby league competition season.

New South Wales Rugby League Competition, 22 weeks

Competition week:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
--	4-week cycle		--	T	--	4-week cycle		--	T	AR	--	4-week cycle		--	T	AR	--	4-week cycle		--	T

Notes:

-- 4-week cycle -- = 4-week in-season strength and power training cycle (see Table 3.6)

T = testing period for data collection

AR = active recovery week

one of training, and power exercise predominant on day two of training. This training method was used to minimise eccentric muscle actions close to the competition day in the HTF2 group (Bompa, 1990), whilst maintaining high training intensity two days a week. Although there were small alterations in exercise programming for HTF2 compared to the HTF1 and LTF1, the volume and intensity of each strength and power session were consistent for all groups for the programmed week. With strength and power training intensity and volume, along with other football training practices standardised throughout the competition season, any resulting differences in strength and power performance may be attributed to different in-season strength and power training frequencies.

3.3. Data collection

3.3.1. Experimental standardisation

All measurements were taken and recorded by the researcher for each test throughout the period of the study to reduce the likelihood of measurement error. All attempts were made to standardise conditions for the testing sessions, with all testing sessions taking place at 5:00 PM on Tuesday and Wednesday evening on the pre-determined test week. A testing sequence was standardised for all testing sessions. The sequence for Tuesday's testing was skinfolds, vertical jump, back squats, bench press, and power clean. Forty metre sprint testing was conducted on Wednesdays.

External environmental conditions during field-testing are difficult to control, especially in seasonal sports where off-and pre-season training is carried out in a different season

Table 3.8. Strength and power sessions for the four-week in-season training cycle.

Week	HTF1 & LTF1 session	HTF2 session 1	HTF2 session 2
1	Dead Lift Bench Press Power Cleans Push Press Dumbbell Row + Week 1 plyometrics **Volume = 95**	Dead Lift Bench Press Power Snatch Push Press Dumbbell Row + Week 1 plyometrics **Volume = 95**	Leg Press Power Cleans Power Jerk Dips Torso Throw + Week 1 plyometrics **Volume = 94**
2	Back Squats Power Clean Military Press Push Press Chin Ups + Week 2 plyometrics **Volume = 68**	Back Squats Military Press Power Snatch Push Press Chin Ups + Week 2 plyometrics **Volume = 68**	Power Clean/ Push Press Loaded Squat Jumps Bench Press Throw Upright Row Dips + Week 2 plyometrics **Volume = 66**
3	Power Cleans Power Jerk Dead Lift Bench Press Dips + Week 3 plyometrics **Volume = 46**	Power Cleans Push Press Dead Lift Bench Press Dips + Week 3 plyometrics **Volume = 47**	Power Snatch Loaded Squat Jumps Power Jerk Good Morning Torso Throw + Week 3 plyometrics **Volume = 47**
4	Back Squats Power Cleans Military Press Power Jerk + Week 4 plyometrics **Volume = 20**	Back Squats Power Cleans Military Press Power Jerk + Week 4 plyometrics **Volume = 20**	Snatch Pulls Power Snatch Bench Press Split Jerk + Week 4 plyometrics **Volume = 25**

to the competition season, and where field-testing may be affected by weather conditions. Air temperature can have an affect performance in different test procedures during different seasons. However, the effect of air temperature on strength, power and speed performance is minimised if appropriate clothing and warm-up procedures are followed prior to testing (Faulkner *et al.,* 1987). The average monthly temperatures for Sydney are shown in Figure 3.2.

3.3.2. Testing dates

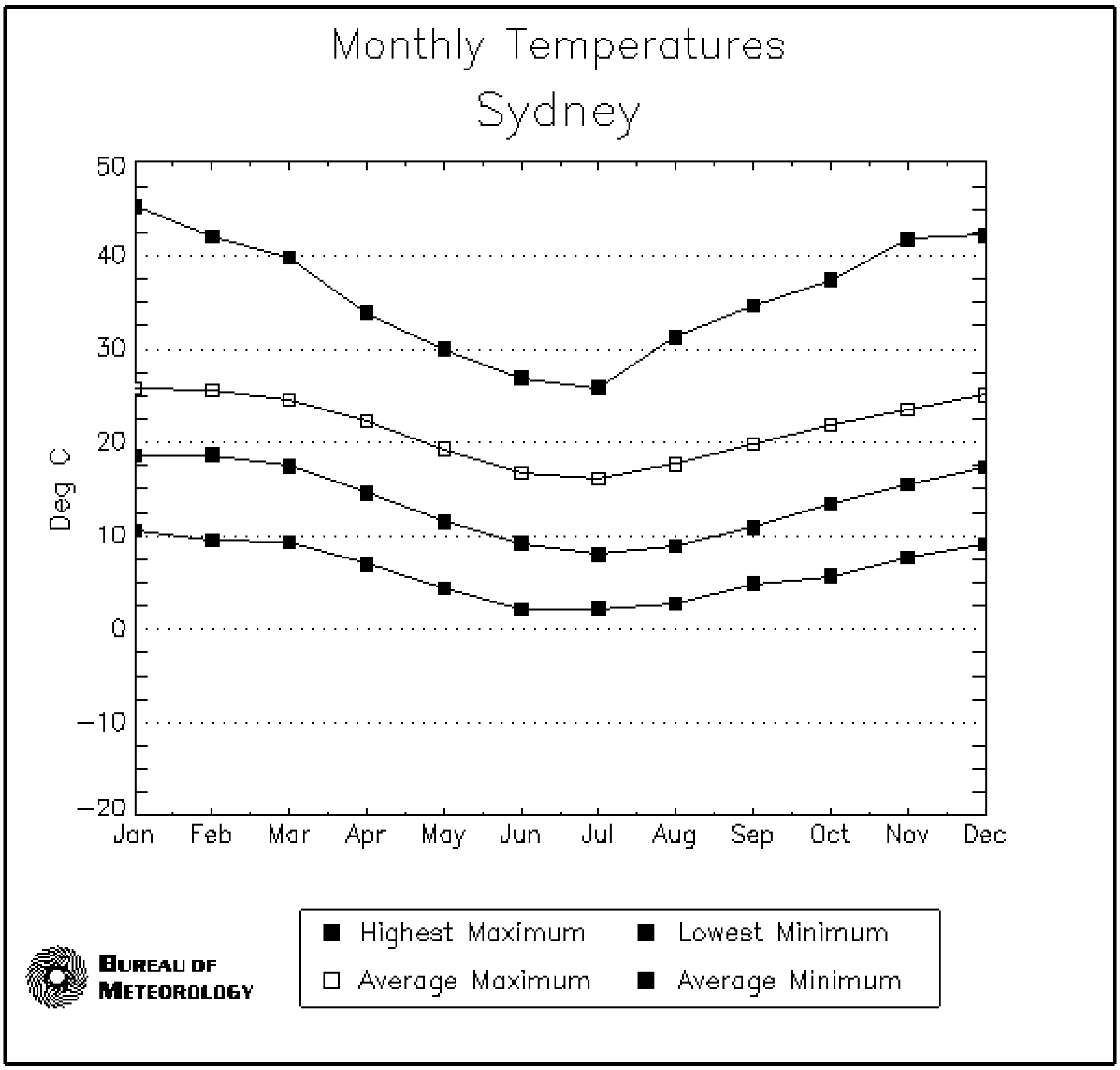
Data were collected at the start of the off-season training period and at the end of pre-season training. The data collected during this period allowed for the evaluation of the pre-season training programmes and the subsequent selection of participants into training groups. The pre-season data were then used as the baseline data for the evaluation of the in-season strength and power training programmes. Subsequently, data were collected four times during the competition season at week five, 10, 16 and 22 of the in-season training period. The last in-season data were then used as the baseline data for the post-season detraining data to be collected at two and four weeks from the end of the competition season.

3.3.3. Procedures

3.3.3.1. Absolute strength

Upper and lower body 1 RM strength tests were used to collect data on the absolute strength of participants. One repetition maximum (1 RM) testing has been used

Figure 3.2. Average monthly temperatures for Sydney (Australian Bureau of Meterology, 1999).



extensively in the evaluation of rugby league players (Meir, 1993; Brewer *et al.*, 1994; O'Connor, 1996) and in a number of other sports (Kraemer, 1997a, 1997b). The 1 RM bench press and 3 RM parallel back squat are considered appropriate assessment methods of absolute upper and lower body strength, respectively (Meir, 1993; Willoughby, 1993; O'Connor, 1996), and were used as the criterion measures of absolute upper and lower body strength in this study. The CYBEX isokinetic dynamometer has been considered a valuable tool in the assessment of strength and power. However, since rugby league players spend considerable time in the gym using free weights, free weight strength testing was used as the method of strength evaluation in this population. Hortobagyi *et al.* (1989) have provided evidence for generality of concentric muscle forces obtained during isokinetic, hydraulic, and 1 RM bench press movements, showing that individuals who performed well (or poorly) on one type of upper body strength test were able to achieve the same relative level of performance when tested by different contraction modes and devices.

Participants performed a warm-up set of seven repetitions at low resistance, gradually increasing the resistance so that 1 RM for bench press was obtained within five attempts, and 3RM for the squat was obtained with four attempts. Each participant's score for both exercises was measured within 2.00 kilograms of the maximal effort.

3.3.3.2. Power

As in previous football studies (Kraemer, 1997a; Baker and Nance, 1999a), the 1RM power clean was used as a measure of muscular power in this study. The power clean is a training lift that is a measure of loaded power (Kraemer, 1997a) because it combines high levels of strength (maximal contraction) at high speeds of execution (shortest possible time). The same procedure for obtaining the 1RM for the bench press was used for the power clean (see Section 3.3.3.1). Each participant's score was measured within 2.00 kilograms of the maximal effort.

3.3.3.3. Explosive power

Vertical countermovement jumps have been used extensively as a measure of explosive leg extensor strength (Garhammer and Gregor, 1992; Wilson *et al.*, 1993; Schneider *et al.*, 1998). A number of different instruments have been used to evaluate vertical jump height (Komi and Bosco, 1978; Garhammer and Gregor, 1992; Wilson *et al.*, 1993). With the participants in full standing reach position, a mark was made on the vertical jump board with chalk. This was recorded as the standing reach height. Following this, participants were given three attempts to achieve their highest vertical jump. With the arm outstretched, participants crouched and jumped as high as possible marking the maximum height with chalk. Vertical jump was recorded as the maximal jump height minus the standing reach height.

3.3.3.4. Speed and acceleration

Speed and acceleration are fundamental elements of rugby league (Meir *et al.*, 1993). Observations made during rugby league matches revealed players were rarely required to sprint distances greater than 40 m (Meir *et al.*, 1993). A sprint test over 40 m, with times taken at 10 m and 40 m using electronic timing gates and an electronic touch starting pad, was considered a fair estimate of speed and acceleration in this population. Longer distances would disadvantage the forwards (Meir, 1993). Sprinting 40 m provides a measure of a player's speed and acceleration qualities off the mark (Mero *et al.*, 1981; Alexander, 1989; Young *et al.*, 1995).

The sprints were conducted on a grass running track with the distances measured using a fiberglass measuring tape to the nearest centimetre, to reduce measurement error at each trial. Timing was conducted using infrared timing gates set at precisely 10 m and 40 m connected to an electronic touch sensor pad, which players touched and released at the start of the sprint. Prior to each trial, the participants completed an 800 m slow jog followed by five minutes of general and specific warm-up exercises. A 3 point crouch start (crouched over with one hand on the ground) was used by all participants, with the grounded hand on the sensor start pad. The test began when the sensor pad beeped, indicating that the timer was ready. At any time after the beep, the player could start the clock by taking their hand off the sensor pad, whilst sprinting at maximal effort to the 40 m mark. The total time to 0.01 of a second, from when the hand left the touch pad until the infrared beam was broken, was recorded for the 10 m and 40 m times. Flying 30 m time was the time taken between the 10 m and 40 m gates. Participants were given two attempts, with the best time recorded for the distances of 10 m and 40 m, and the flying 30 m performance.

3.3.3.5. Body composition

The sum of skinfolds was measured prior to each test period, and was used as an absolute measure of body fat. The sum of skinfolds was determined by the sum of seven sites outlined by Ross *et al.* (1982) using harpenden skinfold calipers: biceps brachii (vertical fold at the mid-acromiale-radilae line on the anterior surface of the arm); triceps (vertical fold at the mid-acromiale-radiale line on the posterior surface of the arm); subscapular (fold beneath the inferior angle of the scapula at an oblique angle of 45^o running downwards from the horizontal); axilla (vertical fold on the mid axillary line at the level of the xiphoid process with the right hand placed on the head); suprailiac (oblique fold running at an angle 45^o downward from the anterior superior iliac spine); abdominal (vertical fold that is raised 5cm lateral to, and at the level of the omphalion); supraspinale (fold 7cm above the spinale on the line to the axillary border). Three measurements were taken at each site, with the average of these taken as the measure of skinfold thickness. All measurements were taken on the right side of the body.

Mass was determined by using electronic scales. The scales were calibrated before each testing date. Participants were required to remove shoes and socks, and be dressed in shorts and training shirt only. Mass was recorded at the same time of day for all test periods.

3.4. Data analyses

Mean, standard deviation, frequency distributions, standard error, and variance were obtained for all measured variables for the purpose of exploratory analysis. To conform to the assumptions of analysis of variance with repeated measures statistical procedures, the Shapiro-Wilks and K-S (Lilliefors) statistics were used to investigate the assumptions of normality ($p<0.05$) for all variables. An F-max value was obtained to determine if group variances were equal or unequal, allowing for examination of homogeneity of variance in each group. Maunchy's test was used to test sphericity of the samples. A non-significant ($p>0.05$) Maunchy's test of sphericity must be obtained, otherwise the obtained F-ratio must be evaluated using new degrees of freedom. Descriptive statistics were also conducted to conform to the statistical assumptions underlying the use of MANOVA. Univariate and multivariate normality was assumed for each group. The Shapiro-Wilks and K-S (Lilliefors) statistics were used to investigate the assumptions of univariate normality ($p<0.05$). Multivariate normality was identified using Mahalanobis distance, evaluated using chi-square with degrees of freedom equal to the number of dependant variables. Homogeneity of variance-covariance matrices were tested using Box's M test, which must not be significant ($p>0.001$), for statistical assumptions to be met.

Multiple analysis of variance (MANOVA) with repeated measures was used to determine if any significant between-group differences existed at data collection periods for the two high pre-training status groups (HTF1 and HTF2) during the in-season (in-season data at weeks five, 10, 16 and 22). Statistical significance was set at $p<0.05$. No post hoc analysis was used, since only two groups were used in the analyses. Statistically significant results demonstrate differences in strength and power performance of the two high pre-training status groups during the competition season. Therefore, significant differences in strength and power performances between the two high pre-training status groups, at any stage during the competition period, can be attributed to different in-season strength and power training frequencies.

Analysis of variance (ANOVA) with repeated measures was used to determine if the three groups experienced significant within-group changes to strength and power performance variables during the in-season training period at test-weeks five, 10, 16 and 22. Statistical significance was set at $p<0.05$. Tukey's post hoc analysis was used to identify the significant within-group differences for strength and power variables at the different in-season test periods. ANOVA with repeated measures was also used to examine the within-group effect of detraining, using the two sets of post-season data collected at the cessation of training and competition, in the highly trained and the less trained group. Tukey's post hoc analysis was used to identify the significant within-group differences for strength and power variables at the different post-season test periods.

CHAPTER FOUR

RESULTS

4.1. Comparison of groups for strength and power variables

4.1.1. Comparison of groups at pre-season

Similar pre-season scores were observed in all test variables for the two high pre-training status groups ($p>0.05$). Both high pre-training status groups were expected to display similar strength and power adaptations from pre-season training. The similarity of the two high pre-training status groups was displayed in the strength and power training adaptations (see Table 3.4) following the 15-week pre-season programme. Both pre-training status groups displayed a four percent and 13 percent improvement in bench press and squat performance, respectively, at the completion of pre-season training. There were also no pre-season differences between the two high pre-training status groups for mass, skin-fold measurements, and pre-training status age (Table 4.1). In contrast, a significant difference existed in mass between the low pre-training status group and HTF2 ($p<0.05$) at the beginning of the competition period, and for pre-training status age ($p<0.05$, Table 4.1). Significant differences also existed between the two high pre-training status groups and the low pre-training status group for the strength measurements at pre-season ($p<0.05$, see Table 3.4). The adaptations in strength and power performance tests following the 15-week pre-season training were reflective of low pre-training status athletes. The improvements in strength and power performance variables from pre-season training were two-to-three fold that of the high pre-training status groups (13.8% and 22.3% for bench press and squat). As a result, statistical

Table 4.1. Age, pre-training status, and body composition

	HTF1 Mean ± SD	HTF2 Mean ± SD	LTF1 Mean ± SD
Age (years)	19.46 ± 0.38	22.65 ± 2.13	18.84 ± 0.58
Pre-training status (years)	3.04* ± 0.70	3.78* ± 1.28	1.34 ± 0.23
Mass (kg)	89.06 ± 9.73	90.51* ± 9.60	80.14 ± 5.87
Skinfolds (mm)	72.25* 18.67	71.21* 24.34	60.75 15.48

The two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group (LTF1) (n=8) mean & SD of sample for age, pre-training status, and body composition (* = significant difference between a high pre-training status group and LTF1).

assumptions were violated and the comparison of the low pre-training status groups with either high pre-training status group was not possible, allowing between-group analyses to be conducted for the two high pre-training status groups only.

4.1.2. Comparison of groups for in-season body composition

The means and SD for body composition measurements over the in-season period are displayed in Table 4.2. Body mass for each group remained unchanged from pre-season to post-season. In addition, there were no significant changes within each group from pre-season to any of the in-season test periods. The sum of the skinfolds remained unchanged for all groups from pre-season to post season. The HTF1 group displayed a significant increase in skin-fold measurement from pre-season to week 10 ($p<0.05$), however, this increase was reversed by the post-season.

4.1.3. Strength and power performance from pre-season to post-season

The three groups were exposed to a 22 week rugby league competition period following the initial 15 week pre-season training period. At the end of the 22 week competition period both high pre-training status groups displayed significant decreases in vertical jump ($p<0.01$), bench press ($p<0.05$), and squat ($p<0.01$) performances from pre-season test values (Table 4.3). Nevertheless, there were no differences between the high pre-training status groups for any strength and power variables following the 22 week competition period ($p>0.05$, Table 4.3).

Table 4.2. In-season body composition.

	Group	n	Pre-season mean ± SD	In-season 1 mean ± SD	% change	In-season 2 mean ± SD	% change	In-season 3 mean ± SD	% change	In-season 4 mean ± SD	% change	Total % change pre-post
Mass (kg)	**HTF2**	9	90.51 ± 9.60	89.90 ± 9.63	-0.7%	90.16 ± 9.58	+0.4%	89.93 ± 9.57	-0.3%	90.41 ± 9.80	+0.5%	-0.1%
	HTF1	11	89.06 ± 9.73	90.28 ± 10.18	+1.4%	90.74 ± 10.36	+0.5%	90.97 ± 10.38	+0.3%	90.68 ± 10.60	-0.3%	+1.8%
	LTF1	8	80.14 ± 5.87	80.93 ± 5.5	+1.0%	80.86 ± 5.17	0.0%	80.01 ± 5.10	-1.1%	80.85 ± 4.62	+1.0%	+0.9%
Skin-fold (mm)	**HTF2**	9	71.21 ± 24.34	71.94 ± 21.24	+1.0%	73.91 ± 21.23	+2.7%	73.30 ± 22.30	-0.8%	75.02 ± 23.92	+2.3%	+5.4%
	HTF1	11	72.25 ± 18.67	74.50 ± 19.45	+3.1%	78.24* ± 22.96	+5.0%	72.85 ± 20.15	-6.9%	79.26 ± 26.42	+8.8%	+9.7%
	LTF1	8	60.75 ± 15.48	61.78 ± 15.08	+1.7%	65.73 ± 14.08	+6.4%	65.13 ± 12.67	-0.1%	66.33 ± 14.62	+1.8%	+ 9.1%

The two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group LTF1 (n=8) mean & SD for pre-season and in-season body composition. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value).

Table 4.3. In-season strength and power test variables.

	Group	N	Pre-season mean ± SEM	In-season 1 mean ± SEM	% change	In-season 2 mean ± SEM	% change	In-season 3 mean ± SEM	% change	In-season 4 mean ± SEM	% change	Total % change pre-post
Vertical jump (cm)	**HTF2**	9	55.2 ± 3.12	53.44 ± 2.79	-3.3%	54.22 ± 3.04	+1.5%	53.89 ± 3.09	-0.6%	53.44* ± 2.99	-0.8%	-3.2%
	HTF1	11	54.0 ± 2.60	50.54* ± 2.84	-6.8%	50.82* ± 2.31	+0.5%	49.73* ± 2.43	-2.2%	49.73* ± 2.39	0.0%	-8.5%
	LTF1	8	55.3 ± 1.52	52.25* ± 2.01	-5.8%	53.38 ± 2.36	+2.1%	55.25 ± 2.07	+3.5%	53.38 ± 1.66	-3.5%	-3.6%
1 RM bench press (kg)	**HTF2**	9	124.4 ± 5.23	120.56* ± 5.49	-3.2%	120.44* ± 5.37	-0.1%	120.22* ± 5.07	-0.2%	119.33* ± 5.07	-0.7%	-4.2%
	HTF1	11	119.3 ± 3.75	115.18 ± 4.16	-3.6%	115.91 ± 3.98	+0.1%	112.64* ± 3.95	-2.9%	112.64* ± 4.01	0.0%	-5.9%
	LTF1	8	102.5 ± 3.13	101.88 ± 3.65	-0.6%	101.13 ± 4.06	-0.7%	99.88 ± 2.75	-1.3%	100.88 ± 3.17	+1.0%	-1.6%

The two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group LTF1 (n=8) mean & SEM for pre-season and in-season strength and power performances. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value). $^{\#}$ injured player at time of off-season testing.

Table 4.3. continued…

	Group	N	Pre-season mean ± SEM	In-season 1 mean ± SEM	% change	In-season 2 mean ± SEM	% change	In-season 3 mean ± SEM	% change	In-season 4 mean ± SEM	% change	Total % change pre-post
3 RM squat (kg)	**HTF2**	7#	155.0 ± 4.36	152.14 ± 3.76	-1.9%	150.29* ± 4.32	-1.2%	148.57* ± 4.59	-1.2%	147.86* ± 4.34	-0.5%	-4.8%
	HTF1	11	147.3 ± 3.84	145.18 ± 4.13	-1.5%	142.91* ± 4.02	-1.6%	141.36* ± 3.70	-1.1%	138.18* ± 3.18	-2.3%	-6.6%
	LTF1	7#	125.70 ± 3.35	125.71 ± 3.69	0.0%	123.57 ± 3.89	-1.7%	122.86 ± 4.86	-0.6%	126.43 ± 4.19	+2.9%	+0.6%
1 RM power clean (kg)	**HTF2**	8#	89.38 ± 2.58	89.00 ± 2.73	-0.4%	86.88 ± 2.30	-2.4%	89.25 ± 1.76	+2.7%	89.36 ± 1.75	+0.1%	0.0%
	HTF1	11	89.73 ± 3.49	92.73* ± 5.81	+3.3%	94.73* ± 3.46	+2.1%	93.64 ± 2.95	-1.2%	92.46 ± 3.43	-1.3%	+3.0%
	LTF1	8	80.00 ± 2.83	83.75 ± 2.06	+ 4.7%	81.50 ± 2.45	-2.8%	81.50 ± 2.79	0.0%	80.25 ± 2.33	-1.6%	+0.3%

The two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group LTF1 (n=8) mean & SEM for pre-season and in-season strength and power performances. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value). # injured player at time of off-season testing.

Although the performance results were not significantly different, performance trends were evident in the results for squat, bench press, and vertical jump performances from pre-season to post-season for the two highly trained groups, with the HTF2 group showing smaller decreases in the strength and power variables (1.8 cm for vertical jump, 5.2 kg for bench press, and 7.4 kg for squat performance), when compared to the HTF1 group (4.6 cm for vertical jump, 7.0 kg for bench press, and 9.7 kg for squat performance, respectively, $p>0.05$) at the completion of the 22 week competition period (see Table 4.3). Both high pre-training status groups displayed no change in power clean performance from pre-season to week-22 in-season ($p>0.05$).

The low pre-training status group displayed the smallest decreases in strength and power performances over the 22 week in-season period. Possible outcomes of statistical analyses comparing the different pre-training status groups would mean little due to the significant pre-season differences in the high and low pre-training status groups. Table 4.3 highlights the large differences in performance decrements from pre-season to week-22 in-season between HTF1 and LTF1 groups (not statistically tested). Using the same in-season strength and power training protocol as HTF1, LTF1 produced no changes in strength and power performances from pre-season to week-22 in-season ($p>0.05$), compared to the significant decreases displayed by HTF1 ($p<0.05$, Table 4.3).

4.1.4. Strength and power performance from pre-season to in-season test periods

The largest alterations for the groups in vertical jump and bench press performances occurred at the first in-season test period (Table 4.3). At the week-five in-season test period there was a significant decrease in vertical jump performance in HTF1 and LTF1 (p<0.05) compared to pre-season, with no change for the HTF2 group. The HTF1 vertical jump performance was further significantly decreased (p<0.01) from the pre-season value at weeks 16 and 22. In comparison, the LTF1 group displayed no further changes in vertical jump performances from week-five to week-22. The HTF2 group only displayed a significant decrease (p<0.01) in vertical jump performance at week-22 in-season. These results highlight the importance of investigating the effect of the in-season period on strength and power performance. A trend was evident in the data collected for vertical jump from pre-season to week-22 in-season for the two high pre-training status groups (Figure 4.1), with the pattern of the performance alteration in vertical jump similar for the two high pre-training status groups from pre-season to post-season (Figure 4.1). There were no statistical differences in the vertical jump performance between the two high pre-training status groups at any in-season test period. However, HTF1 displayed a significant decrease in performance from pre-season testing at all in-season test periods (p<0.05), corresponding to a 4.5 cm decrease in vertical jump height from pre-season to week-22 in-season, whilst HTF2 vertical jump performance decreased significantly at week-22 only (p<0.05), corresponding to a 1.8 cm decrease in vertical jump height. The different shifts in vertical jump performances between HTF1 and HTF2 from pre-season to week-five, and again from week-10 to week-16 (Figure 4.1), show the periods when performances were most affected by different training frequencies. In comparison to HTF1, the LTF1 group vertical jump performance was significantly decreased from pre-season levels at week-five in-season (p<0.05), with a trend showing non-significant alterations in performance

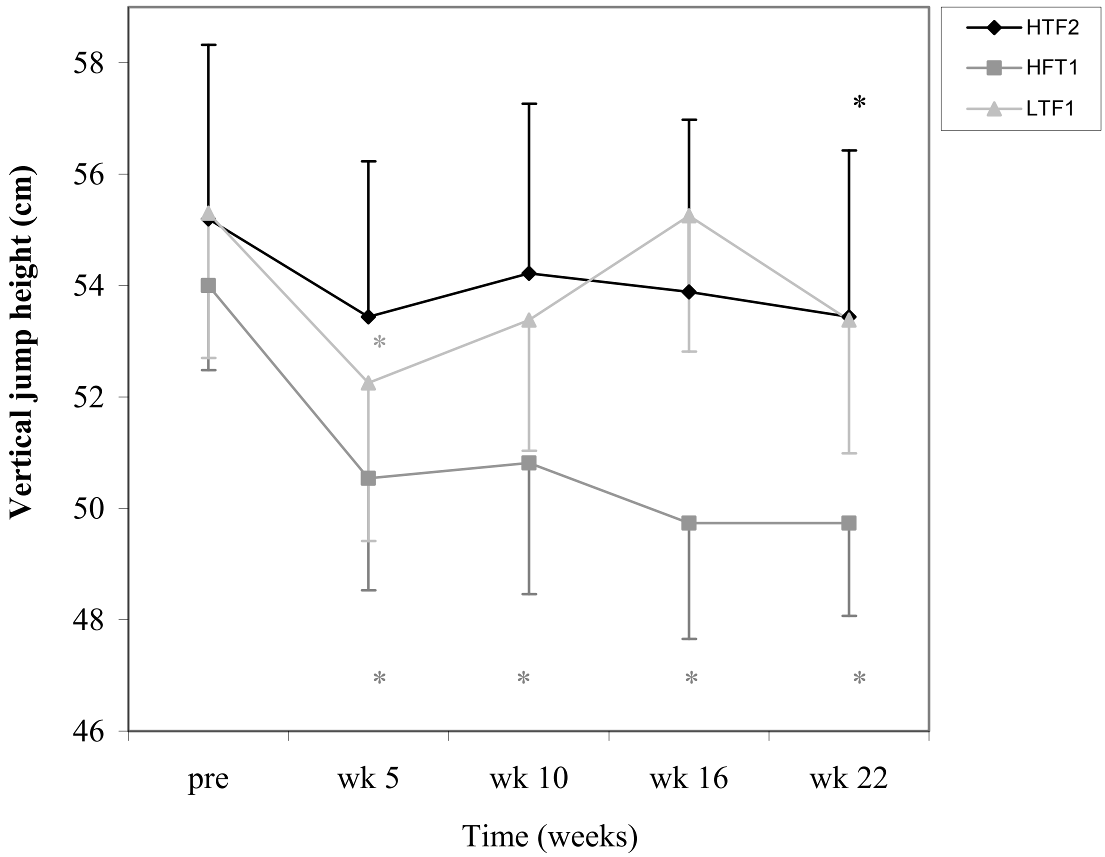


Figure 4.1. Vertical jump performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group (LTF1) (n=8). Data are means ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significant from corresponding pre-season value).

from week-five to week-22 in-season (Figure 4.1). Shifts in the performance curve of LTF1 and HTF1 at week-10 to 16 indicate the degree of change experienced by athletes with differing pre-training status using the same in-season strength and power training frequency.

There were no significant differences for bench press performances at any stage during the competition period for the two high pre-training status groups (Table 4.3). The HTF2 group displayed a significant difference from pre-season testing to all in-season test periods ($p<0.05$), whilst the HTF1 group showed a significant ($p<0.05$) decrease in bench press performance from pre-season levels at weeks 10, 16 and 22 in-season test periods. There were no alterations in bench press performance by LTF1 from pre-season levels to any in-season test periods. The performance patterns were similar for the high pre-training status groups from pre-season to week-10 in-season (Figure 4.2). The bench press performance pattern (Figure 4.2) for HTF1 did show a trend (2.9% decrease equating to 3.3 kg drop in 1 RM performance) from in-season week-10 to week-16, although it was not significant ($p>0.05$). During the same period, the HTF2 group displayed no alteration in performance. The performance pattern for the LTF1 group displays a slow non-significant decline (2.6 kg) in bench press performance from pre-season to week-16 in-season ($p>0.05$), with a non-significant increase of 1.2kg from week-16 to –22 ($p>0.05$). If the performance lines of LTF1 and HTF1 are compared, it appears that the low pre-training status group was able to maintain bench press performance for a longer period than the high pre-training status group using the same protocol, although the result was not statistically proven.

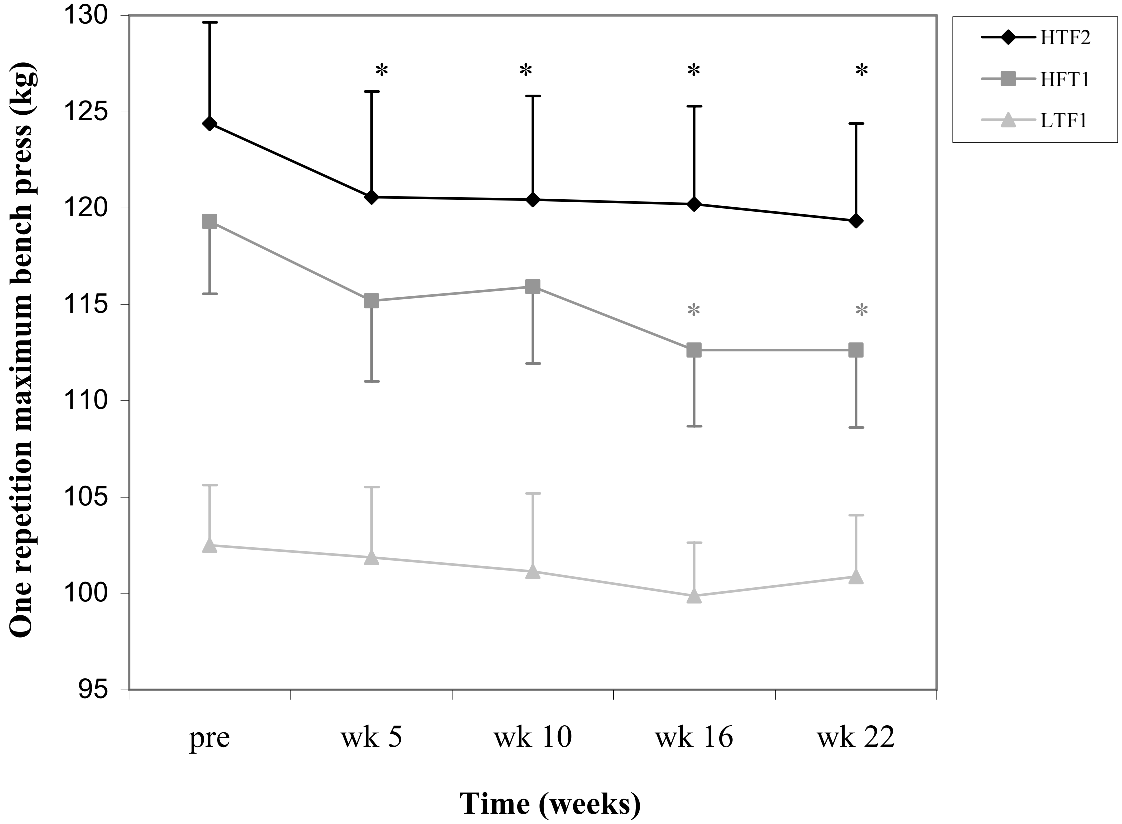


Figure 4.2. One repetition maximum bench press performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group (LTF1) (n=8). Data are means ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significant from corresponding pre-season value).

Both HTF1 and HTF2 displayed a significant decline in squat performance from pre-season to week-10 (4.6 kg, and 4.8 kg, respectively, $p<0.05$), with further significant declines in both groups at week-22. In total, the HTF1 group declined 9.7 kg ($p<0.05$), and the HTF2 group declined 7.4 kg ($p<0.05$) from pre-season to post-season. The performance patterns for squat tests from pre-season to in-season test periods for the two high pre-training status groups were similar up to week-16 in-season (Figure 4.3). On the other hand, performance changes between HTF1 and HTF2 were evident from week-16 to week-22, with HTF1 displaying a further significant decline of 3.4 kg, compared to no change by the HTF2 group during the same period. The LTF1 group squat performance remained unchanged from pre-season to week-22 in-season (Table 4.3). Alteration in the performance activity pattern for the LTF1 group squat tests were similar to the two high pre-training status groups from pre-season to week-16 in-season (Figure 4.3). However, a statistically non-significant increase of 3.6 kg from week-16 to week-22 by LTF1 indicated a contrasting performance pattern to the high pre-training status groups for the last test period. The HTF1 group displayed increases in power clean performance from pre-season to week-five (4.2 kg, $p<0.05$), with a further statistically significant increase of 1.9 kg from week-five to week-10 ($p<0.05$, Table 4.3). Comparatively, the LTF1 group showed no change in power clean from pre-season to week-22.

The performance patterns indicate the similar trend in the power clean measurements

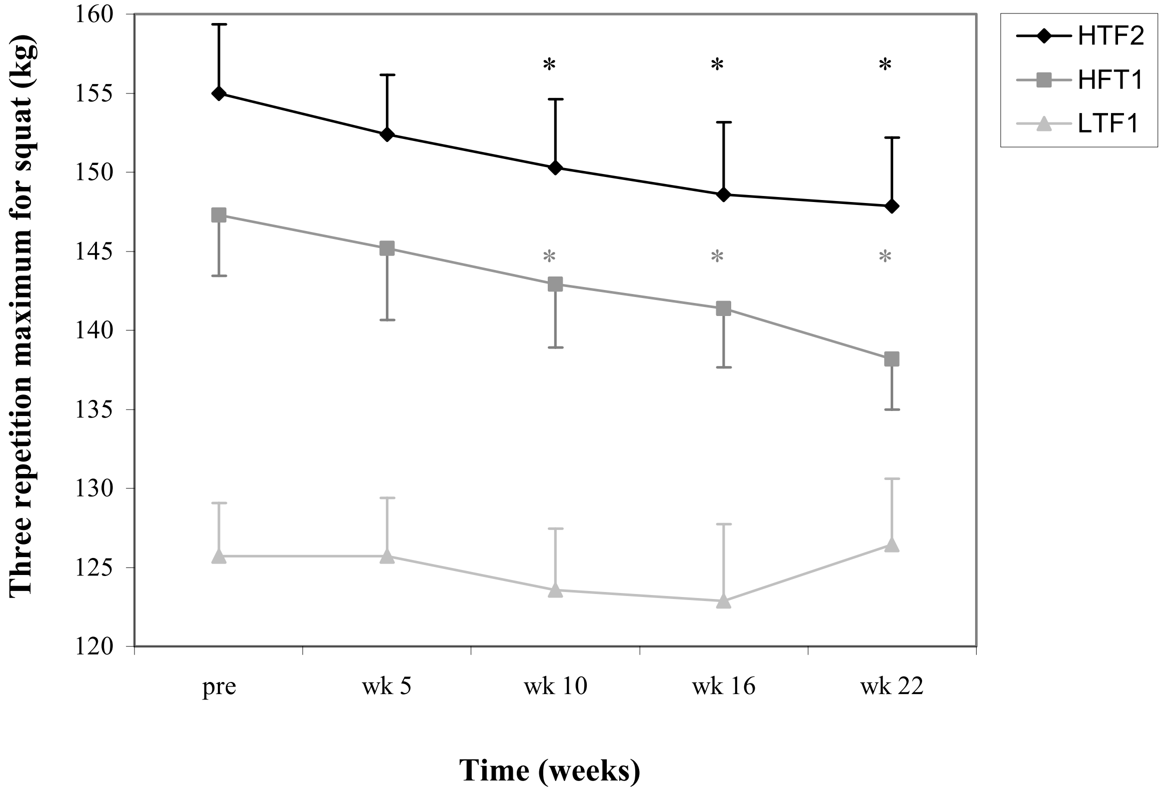


Figure 4.3. Three repetition maximum squat performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group (LTF1) (n=8). Data are means ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significant from corresponding pre-season value).

throughout the in-season period, with an initial incline from pre-season results followed by a subsequent decline in performance for HTF1 and LTF1 (Figure 4.4). However, both HTF1 and LTF1 power clean measurements at week-22 in-season were not different from the pre-season levels ($p>0.05$). There was no statistical difference in the power clean performances of the HTF2 group from pre-season to any in-season period. There were no differences between the two high pre-training status groups at any stage of the in-season period for power clean performance.

4.2. Comparison of groups for speed variables

4.2.1. Sprint performances from pre-season to post-season

Both high pre-training status groups displayed similar significant decreases in sprint performance from pre-season to post-season, with no significant differences between the two high pre-training status groups at any test period during the competition season (Table 4.4). For the 10 m sprint, the HTF2 group and the HTF1 group displayed a significant decrease in performance ($p<0.05$) from pre-season to post season, whilst the LTF1 group displayed no change in 10 m sprint performance. Significant decreases of 0.21 sec ($p<0.05$) and 0.18 sec ($p<0.05$) from pre-season scores to week-22 in-season were displayed by HTF2 and HTF1 for the 40 m sprint, respectively, with the LTF1 group showing no change.

Significant decreases of 0.17 sec ($p<0.05$), 0.15 sec ($p<0.05$), and 0.13 sec ($p<0.05$) for the flying 30 m performance were recorded for the HTF2, HTF1 and LTF1 groups from pre-season to week-22 in-season, respectively (Table 4.4).

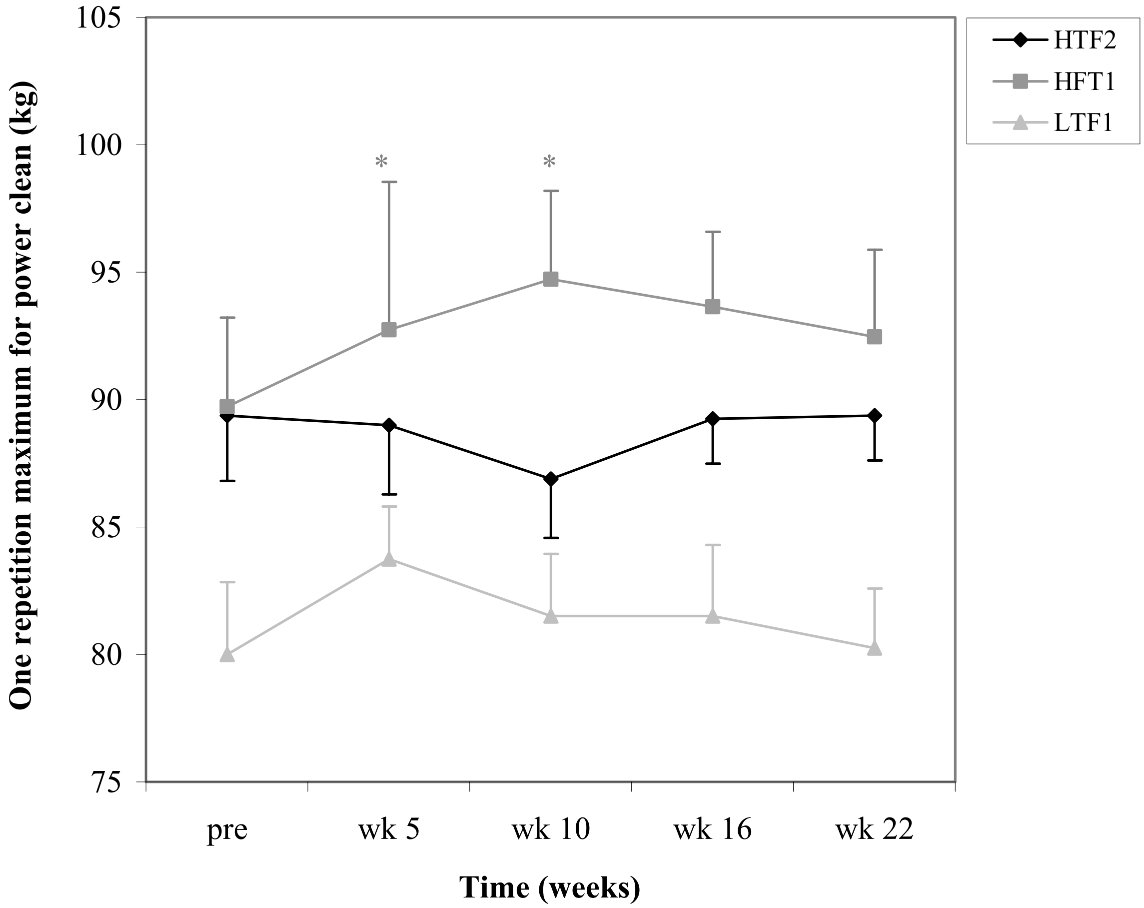


Figure 4.4. One repetition maximum power clean performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group (LTF1) (n=8). Data are means ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significant from corresponding pre-season value).

Table 4.4. In-season speed test variables.

	Group	N	Pre-season mean ± SEM	In-season 1 mean ± SEM	% change	In-season 2 mean ± SEM	% change	In-season 3 mean ± SEM	% change	In-season 4 mean ± SEM	% change	Total % change pre-post
10 m sprint (sec)	HTF2	8#	1.91 ± 0.02	1.94* ± 0.02	-1.6%	1.94 ± 0.02	0.0%	1.95 ± 0.03	-0.5%	1.96* ± 0.03	-1.0%	-2.6%
	HTF1	11	1.94 ± 0.03	1.96* ± 0.02	-1.0%	1.95 ± 0.02	+0.5%	1.94 ± 0.02	+0.5%	1.97* ± 0.02	-1.5%	-1.5%
	LTF1	8	1.88 ± 0.04	1.90 ± 0.04	-1.1%	1.90 ± 0.04	0.0%	1.88 ± 0.04	+1.1%	1.88 ± 0.02	0.0%	0.0%
40 m sprint (sec)	HTF2	8#	5.46 ± 0.06	5.61* ± 0.09	-2.7%	5.60* ± 0.08	-0.1%	5.63* ± 0.08	-0.5%	5.67* ± 0.08	-0.7%	-3.8%
	HTF1	11	5.57 ± 0.02	5.67* ± 0.08	-1.8%	5.64* ± 0.04	+0.5%	5.67* ± 0.04	-0.5%	5.75* ± 0.05	-1.4%	-3.2%
	LTF1	8	5.35 ± 0.04	5.49* ± 0.11	-2.6%	5.49* ± 0.09	0.0%	5.47 ± 0.11	+0.4%	5.48 ± 0.08	-0.2%	-2.4%

The two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group LTF1 (n=8) mean & SEM for pre-season and in-season sprint performances. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value). # injured player at time of off-season testing.

Table 4.4. continued…

	Group	N	Pre-season mean ± SEM	In-season 1 mean ± SEM	% change	In-season 2 mean ± SEM	% change	In-season 3 mean ± SEM	% change	In-season 4 mean ± SEM	% change	Total % change pre-post
Flying 30 m sprint (sec)	HTF2	8[#]	3.53 ± 0.05	3.67* ± 0.08	-4.0%	3.64* ± 0.05	+0.8%	3.67* ± 0.06	-0.8%	3.70* ± 0.05	-0.8%	-4.8%
	HTF1	11	3.62 ± 0.04	3.72* ± 0.06	-2.8%	3.67* ± 0.03	+1.3%	3.72* ± 0.03	-1.3%	3.77* ± 0.04	-1.3%	-4.1%
	LTF1	8	3.45 ± 0.05	3.59* ± 0.08	-4.1%	3.58* ± 0.06	+0.2%	3.58* ± 0.06	0.0%	3.58* ± 0.07	0.0%	-4.1%

The two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group LTF1 (n=8) mean & SEM for pre-season and in-season sprint performances. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value). # injured player at time of off-season testing.

4.2.2. Sprint performances from pre-season to in-season test periods

The largest changes in all three sprint tests for the three groups occurred at week five of the in-season test period. The two high pre-training status groups had a significant decline in 10 m sprint performance from pre-season to week-five in-season ($p<0.05$), with no change in the LTF1 group. However, the performance patterns for the 10 m sprint indicated similar trends in 10 m sprint performance alterations from pre-season to week-10 in-season (Figure 4.5). Furthermore, the performance trends for the 10 m sprint data reveal a similar trend in both the LTF1 and HTF1 groups from pre-season to week-16, with no change in performance by both groups ($p>0.05$). However, HTF1 displayed a significant decrease in 10 m sprint performance from pre-season at week-22 in-season, compared to no alteration by the LTF1 group from week-16 to week-22. Comparatively, the HTF2 group displayed a significant decrease in 10 m sprint performance from week-10 to week-22 ($p<0.05$), resulting in similar significant performance reductions displayed by HTF1 from pre-season to the end of the competition period. All three groups displayed a significant decline in 40 m and flying 30 m sprint performance from pre-season to week-five in-season ($p<0.05$, Figure 4.6 and 4.7, respectively). The significant declines at week-five in-season by all groups are clearly visible in the performance patterns shown in Figures 4.6 and 4.7. Performance patterns for the three groups were similar for the 40 m sprint times from pre-season to week-10 (Figure 4.6).

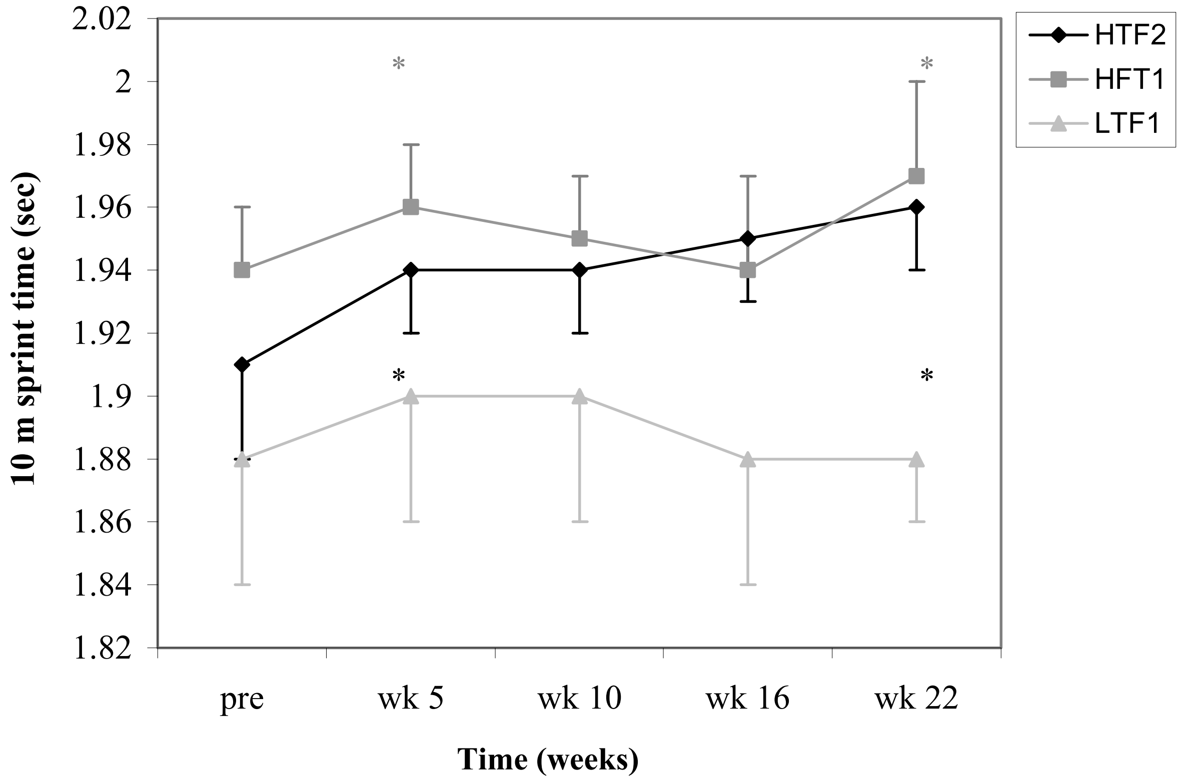


Figure 4.5. 10 m sprint performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk^{-1} high pre-training status group (HTF2) (n=9), one day.wk^{-1} high pre-training status group (HTF1) (n=11), and one day.wk^{-1} low pre-training status group (LTF1) (n=8). Data means are ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value).

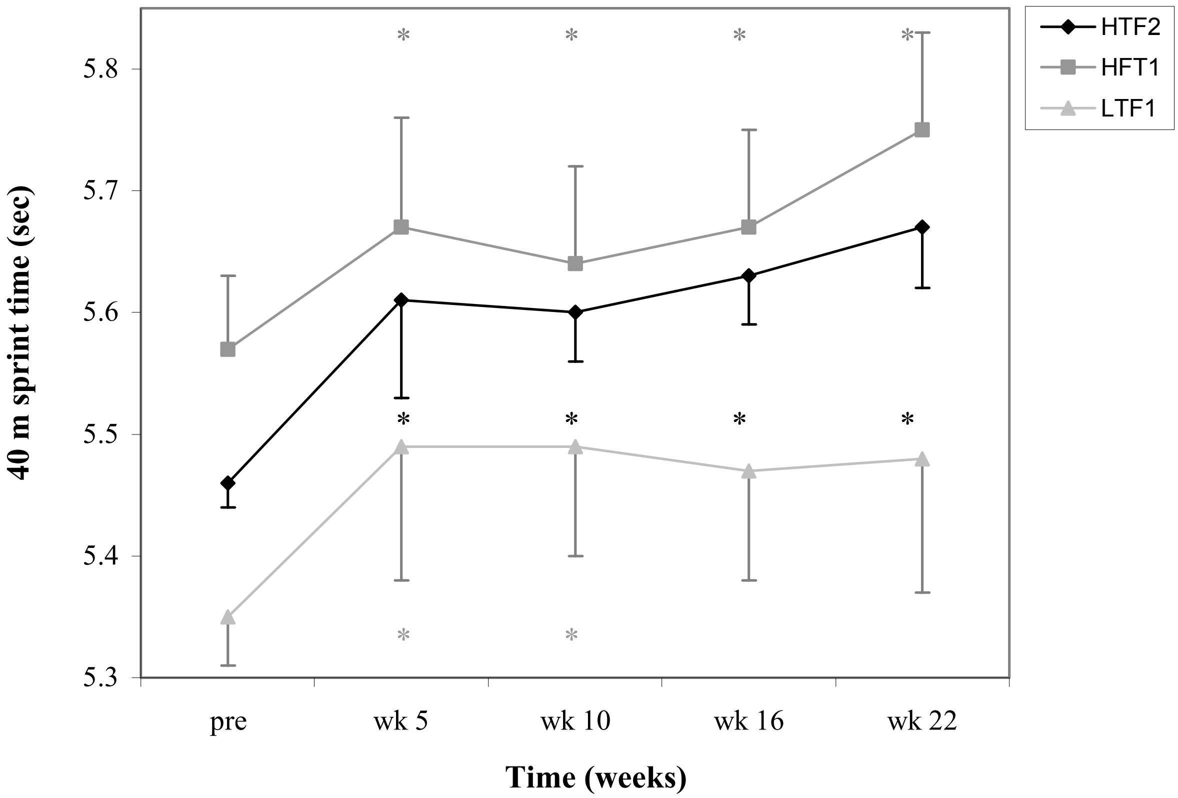


Figure 4.6. 40 m sprint performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group (LTF1) (n=8). Data means are ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at p<0.05 from corresponding pre-season value).

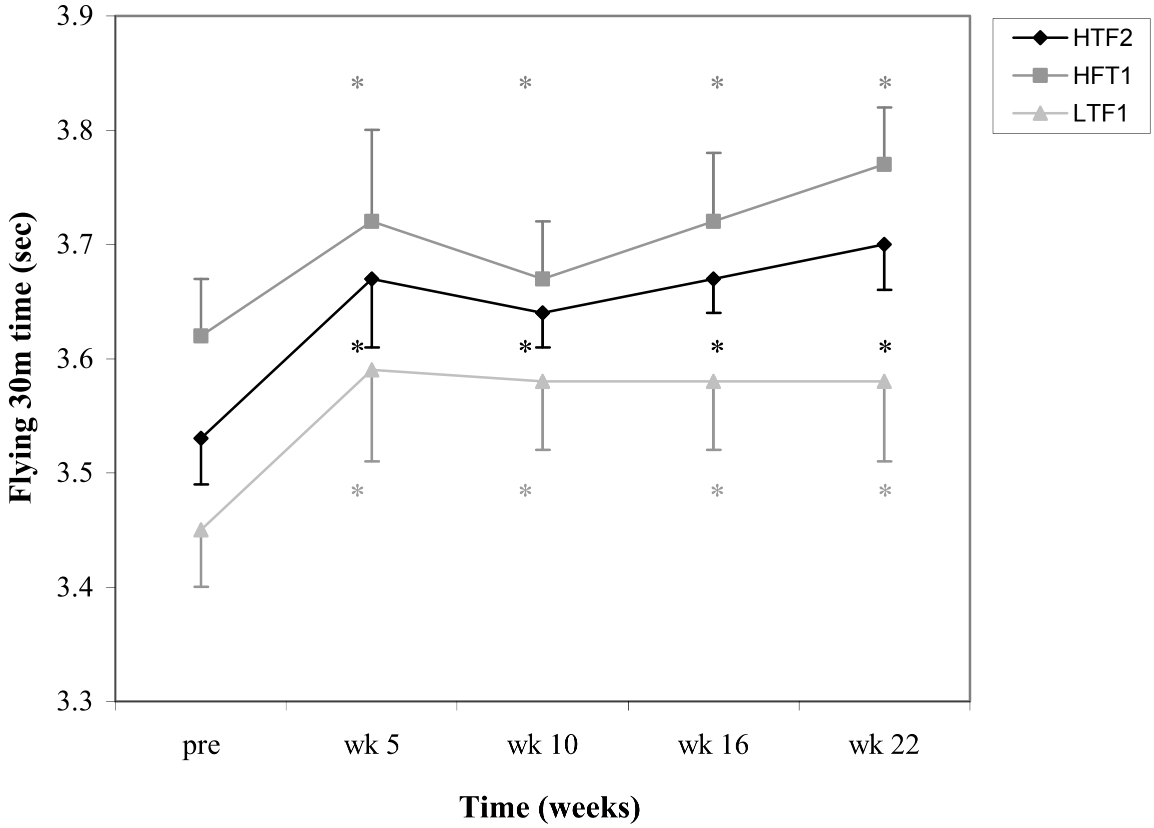


Figure 4.7. Flying 30 m sprint performance for pre-season, weeks-five, 10, 16 and 22 in-season for the two day.wk-1 high pre-training status group (HTF2) (n=9), one day.wk-1 high pre-training status group (HTF1) (n=11), and one day.wk-1 low pre-training status group (LTF1) (n=8). Data means are ± SEM. Significant differences from ANOVA with repeated measures for each group for pre-season and in-season data sets are represented (* significance at $p<0.05$ from corresponding pre-season value).

The 40 m sprint performance trend at week-five displays a significant decline ($p<0.05$), followed by a plateau in performance at week-10 of the in-season period in all three groups (see Figure 4.6). From week-10 to week-22, however, the two high pre-training status groups displayed further statistically significant decreases in 40 m sprint performances ($p<0.05$), whilst the low pre-training status group maintained 40 m sprint performance at the week-10 in-season levels (Figure 4.6). A similar trend in performance patterns was observed for the flying 30 m sprint performances throughout the in-season period (Figure 4.7). Following an initial significant decrease in performances at week-five ($p<0.05$) in all groups, performances in the flying 30 m sprint plateaued at week-10. The high pre-training status groups displayed further significant decreases from week-10 to week-22 ($p<0.05$), whilst the low pre-training status group showed no changes in flying 30 m sprint performance from week-10 onwards (Figure 4.7).

CHAPTER FIVE

DISCUSSION

5.1. Summary

Limited data existed investigating the effect of in-season training frequency on the maintenance of pre-season strength and power levels across a long competition period, and in footballers with different strength pre-training status. The results of the present study suggest in-season strength and power training frequency may have a limited role in determining the success of the in-season strength and power training programme in highly trained footballers. Furthermore, a number of factors other than in-season training frequency may affect in-season strength and power performance and detraining in high strength pre-training status footballers over long competition periods. Detraining still may occur even when an in-season strength and power maintenance programme is an integral part of the weekly practice routine. In contrast, in-season strength and power performance may be maintained at the pre-season level in low pre-training status athletes by training as little as one day.wk^{-1}, as long as the intensity of training is maintained at a high level. The importance of individual in-season programming of strength and power training among athletes within a team is recognised, especially when a range in athlete pre-training status exists.

5.2. In-season strength and power training frequency for rugby league

5.2.1. High strength and power pre-training status

It has been suggested that the frequency of high intensity training may have a considerable role in determining the success of an in-season strength and power training programme (Hakkinen *et al.,* 1985a; Hakkinen, 1993b). The present investigation results propose that in-season strength and power maintenance is influenced by factors other than training frequency. Training frequencies of one and two days a week both resulted in significant detraining in vertical jump, squat and bench press performance, over a 22 week competition period, in footballers with high strength and power pre-training status. Furthermore, the data revealed no differences between the strength and power variables in the two high pre-training status groups at any stage throughout the 22 week competition period. However, detraining performance patterns (Figure 4.1, 4.2, 4.3) of in-season strength and power levels did indicate footballers with a high strength and power pre-training status may benefit from an in-season strength and power training frequency of two days wk^{-1} in order to maintain the highest possible levels of strength and power throughout the competition season.

Although the performance results for the two high pre-training status groups were not significantly different, a trend was evident in the results of the two groups from pre-season to post-season in the performance of strength and power tests. The detraining performance patterns (Figure 4.1, 4.2, and 4.3) indicated an overall trend in the performance decrements of strength and power tasks throughout the in-season period. In particular, alterations in performance by HTF1 at week-10 in the bench press and vertical jump, and at week-16 in the squat, when the HTF2 group performances were unchanged. Up until these periods, strength and power performances in both groups had declined at a steady rate. Data were previously lacking for competition periods longer than 10 weeks, and for footballers with a high strength pre-training status. Previous investigations have used strength training one day.wk^{-1} to maintain strength levels during a 10 week in-season period in footballers with low strength pre-training status (dos Remedios *et al.,* 1995). The present investigation suggests footballers with a high pre-training status suffer similar detraining effects in strength and power performance regardless of in-season training frequency. However, detraining trends (Figure 4.1, 4.2 and 4.3) indicate a more desirable level of strength and power maintenance may be achieved in high pre-training status footballers using a two day.wk^{-1} in-season strength and power training frequency.

A suggestion for the short fall in the hypothesised in-season strength and power performance differences between the two high pre-training status groups may stem from a lack of eccentric loading on the second day of the HTF2 in-season strength and power training programme. It has been suggested that performance of both eccentric and concentric actions maximises the optimal resistance per repetition performed, since the neural adaptations to training are enhanced (Pearson and Costill, 1988; Colliander and Tesch, 1990; Hather *et al.,* 1991). Thus, exercises lacking an eccentric component could compromise the optimal intensity of the training session and the resulting session adaptations (Dudley *et al.,* 1991). One interesting finding from the present study was the result of the power clean performances from pre-season to post-season. In contrast to all other strength and power variables, and speed performance variables, power clean performance was unchanged from pre-season to post-season in both high pre-training status groups. The lack of detraining may have resulted from the minimal eccentric loading associated with the power clean lift. This finding indicates exercise selection on day-two of in-season strength and power training may not have provided the stimulatory effect required to elicit noticeable changes in performance between the two high pre-training status groups. Both HTF1 and HTF2 performed the same strength and power training programme on day-one of each week, using the same exercises, intensity and volume. However, exercise selection for day-two of the HTF2 in-season strength and power training protocol was altered to minimise unwanted muscle soreness that could result from training close to game-day. The HTF2 in-season protocol followed the in-season exercise selection guidelines provided by Bompa (1994) and Baker (1998), suggesting the use of specific power training exercises on day-two of an in-season strength and power programme. Power training exercises such as the power clean, snatch, and jerk, which constituted the majority of the day-two exercise selection in the present investigation, have minimal, if any, eccentric components (Bompa, 1994), reducing the likelihood of delayed onset muscle soreness following the session (Evans, 1987; Ebbing and Clarkson, 1989). It appears that the selection of these exercises may have compromised the overall intensity of training of day-two of the HTF2 in-season strength and power programme, thus, resulting in minimal differences in strength and power performance between the two groups throughout the competition period. Previous research has reported that strength gains resulting from combined eccentric-concentric training decline faster than concentric contraction exercises, such as the power clean, at the cessation or reduction of training, suggesting a fundamental difference in response to detraining between the two contraction types (Colliander and Tesch, 1992). The power clean lift is a multi-joint concentric lift, and is associated with minimal eccentric contraction. In comparison, the bench press and squat exercises are combined concentric-eccentric exercises, providing an explanation of the contrasting results. The present results suggest in-season exercise selection may require special attention when programming for athletes with high strength and power pre-training status.

It may also be suggested that training frequency has little to do with strength maintenance in high pre-training status athletes throughout an in-season period. It has been reported that intensity, not frequency or volume, may be the determining factor in the effectiveness of in-season strength and power training protocols (Morehouse, 1967; Hakkinen *et al.,* 1985a; Hakkinen, 1993a; Schneider *et al.,* 1998). The in-season protocol used by both high pre-training status groups in the present investigation was a 4-week linearly periodised strength and power training programme, with progressions in training intensity from 75 percent to 100 percent from week-one to week-four of the cycle. Moreover, the training programmes were standardised so that differences in strength and power performance at any stage throughout the competition season could be attributed to the different training frequency, not intensity or volume. There were no differences between the two groups at any stage of the competition period. These results suggest in-season strength and power training frequency may have a limited role in determining the success of the in-season strength and power training programme in highly trained footballers.

Schneider *et al.* (1998) have demonstrated significant strength detraining in highly trained footballers using a two day.wk^{-1} training frequency over a 16-week period.

However, in this instance, it appeared that the training intensities used (85% and 60% of maximal intensity) were insufficient in applying a correct stimulus for maintenance training, resulting in strength losses of eight percent in bench press performance over a 16 week competition period. Comparatively, in the present study, the one day.wk^{-1} high pre-training status group displayed a six percent loss in bench press over a longer competition period (22 weeks), performing in-season strength and power training at higher intensities (75 to 100 percent of maximum over a four-week in-season cycle). Furthermore, the two day.wk^{-1} strength and power training frequency group displayed a four percent decrease in bench press performance using the same training intensity and volume over the 22 week in-season period. The outcomes of the two investigations pinpoint the importance of the correct training intensity prescription for in-season strength and power maintenance programmes, above that of training frequency. The frequency of pre-season strength training frequency was reduced from three day.wk^{-1} to either one or two day.wk^{-1} during the in-season period of the present investigation. However, there were no differences between the two groups at any stage throughout the 22 week competition period. Although both groups displayed significant detraining in strength and power performance from pre-season to post-season, it can be concluded that strength training frequency can be reduced considerably during the rugby league competition season, as long as the intensity of strength and power training remains high.

5.2.2. Low strength and power pre-training status

Pre-training status has previously been shown to alter the outcome of strength and power training programmes (Hakkinen, 1989). The results of the present study further reflect the effect of different pre-training status on strength and power training adaptations. Data from off-season and pre-season test periods displayed considerable performance adaptations in strength and power variables for the low pre-training status participants (see Table 3.4). Using the same pre-season strength and power training programmes, the low pre-training status group displayed two to three fold improvement in the strength and power test variables compared to the two high pre-training status groups, although results were not statistically proven. Hakkinen (1989) has previously shown varying athlete pre-training status results in a marked difference in the magnitude of strength and power adaptations using the same training protocol, favouring the adaptations of a low pre-training status individual. However, data are lacking comparing the effect of different strength and power pre-training status on in-season strength and power detraining. The results from the present study demonstrate rugby league players with low strength and power pre-training status can maintain pre-season strength and power performance levels over a 22 week competition period by using a high intensity one day.wk^{-1} strength and power training programme.

The contrasting results between the one day.wk^{-1} low and high pre-training status groups in the present study suggest pre-training status has a considerable effect on the prescription of in-season strength and power training. In comparison to the significant strength and power detraining reported in the high pre-training status group, the low pre-training status group displayed no changes in strength and power performance over the 22 week competition period using the same in-season strength and power training protocol. An explanation for the altered results in athletes with different strength training backgrounds may stem from the contribution of endogenous hormones to muscular adaptations once neuromuscular training adaptations reach a ceiling point (Hakkinen *et al.,* 1985c; Hakkinen, 1989). In strength athletes with a high pre-training status, the role of endogenous hormone balance may have increasing importance for strength development. During the most stressful prolonged periods of strength training, which is the pre-season for footballers, the level of biologically active unbound testosterone, as well as the balance between androgenic-anabolic activity and the catabolising effect of glucocorticoids, effects the optimal training adaptations (Hakkinen *et al.,* 1985c; Hakkinen, 1989). During periods of reduced strength training stress in high strength pre-training status athletes, such as the competition period, the balance is upset, resulting in a detraining effect that may not be experienced to the same degree by a low strength pre-training status athlete (Hakkinen, 1989). This may explain the significant detraining observed in the present study by two high pre-training status groups, compared to no detraining of pre-season strength and power by the low pre-training status group over the 22 week competition period. In a similar fashion to the present study, one day.wk^{-1} high intensity in-season strength training protocols have been sufficient in retaining strength during periods of up to 12 weeks in low pre-training status footballers (dos Remedios *et al.*, 1995), and in pubescent and previously sedentary people (Graves *et al.,* 1988; DeRenne *et al.,* 1996). In addition, in-season strength and power training two day.wk^{-1} successfully maintained pre-season levels in male basketball players whom had only previously completed six months of pre-season strength training (Hoffman *et al.,* 1991b). However, in a similar fashion to the present investigation, a group of female volleyball players with varying strength pre-training status differed in their adaptations to in-season strength and power training. Hakkinen (1993b) reported those athletes with greater levels of strength at the start of the competition period, compared with other team members, experienced the largest individual reductions in strength and power performances throughout a 20 week competition period (Hakkinen, 1993b). The results of the present investigation, in conjunction with these previous research findings, suggest the success of in-season strength and power training programmes may be limited in athletes of high strength pre-training status, as the involvement of endogenous hormones takes a greater role in the training adaptations of high pre-training status athletes compared to those with low strength pre-training status.

The present data have important practical applications for athletes participating in a strength training programme. When training frequency must be reduced, as is the case in competition periods, muscular strength may be maintained in low pre-training status athletes by training as little as one day.wk^{-1}, provided the intensity of training is maintained at a high level. In addition, it appears that there is a different requirement for rugby league players with a high strength and power pre-training status. The maintenance of muscular strength in highly trained individuals may require a considerably different training stimulus. The results of the present study suggest a number of factors other than training frequency may affect in-season strength and power performance and detraining in high strength pre-training status footballers over long competition periods, such as the role of endogenous hormones. It is important to recognise that detraining still might occur even when an in-season strength and power maintenance programme is an integral part of the weekly practice routine. Nevertheless, there is a need for individual programming of strength training among athletes within a team, especially when a wide range of athlete pre-training levels exist.

5.2.3. In-season explosive power training frequency

Explosive power training (plyometrics) was combined with the strength and power training sessions one or two days a week for the entire 22 week competition period. Explosive power performance, as measured by vertical jump, showed no difference between the two highly trained groups at any stage throughout the in-season period. However, the one $day.wk^{-1}$ high pre-training status group displayed a significant decrease in vertical jump performance at all in-season test periods (week five, 10, 16 and 22), where the group training two $day.wk^{-1}$ displayed a significant decrease only at week-22 in-season. Decreases in explosive power performance from pre-season have been reported in footballers and other athletes resulting from an overall reduced volume and intensity in-season plyometrics programme (Hakkinen, 1988, 1993b; Schneider *et al.,* 1998). In a similar fashion to in-season strength training intensity, in-season explosive power training intensity must be of high intensity to be effective in maintaining pre-season levels (Hakkinen, 1988, 1993b). The selection of explosive power exercises requires those that provide a high neuromuscular stress, such as depth jumps, bounding, and single leg hops. However, data were lacking in the correct prescription of in-season explosive power training frequency in high pre-training status athletes.

The results of this investigation highlight the effect of reducing in-season explosive power training to one day.wk^{-1} in athletes with high strength and power pre-training status. Although there was no difference between the two groups at any in-season test period, a detraining trend was evident, resulting in a 4.3 cm decrease in vertical jump performance from pre-season to post-season in the one day.wk^{-1} group, compared to a decrease of 1.8 cm in the two day.wk^{-1} group. Furthermore, there was a tendency in the vertical jump performance pattern for the HTF1 group to further decrease vertical jump performance from week-10 to week-16, when the HTF2 group maintained performance (see Figure 4.1). It could be suggested that explosive power training one day.wk^{-1} was insufficient in maintaining vertical jump performance for even small competition periods of five to 10 weeks in high pre-training status athletes. In comparison, explosive power training two day.wk^{-1} maintained vertical jump performance up to week-16 in-season, before a significant decrease was observed from pre-season levels during the last in-season test period (week 16 to week 22). If explosive power performance is to be maintained in rugby league players with high pre-training status during a competition period, a training frequency of two day.wk^{-1} appears to be the preferred option. In contrast to the one day.wk^{-1} high pre-training status group, an in-season explosive power training frequency of one day.wk^{-1} successfully maintained explosive power performance in the low pre-training status group over the 22 week competition period. In order to maintain the level of explosive power capacity in footballers the magnitude of the explosive power training stimuli should be given individual attention during the entire course of the competition period. Also, prescription of an in-season explosive power training programme must consider the pre-training status of individual athletes.

5.2.4. Strength and power performances during a rugby league competition season

The effect of a competition period on strength and power performance has previously been investigated in terms of strength changes from pre-season to post-season (dos Remedios *et al.,* 1995; Schneider *et al.,* 1998; Legg and Burnham, 1999). It was hypothesised that the largest decreases in strength and power performance would occur at the start of the competition period when players are required to overcome the added stress of weekly competition matches, combined with the usual training activities. The results from the present study have demonstrated the negative effect the start of the competition period has on dynamic physical performance variables. Strength and power performances measured by the bench press, vertical jump, and the sprint variables, all showed similar performance trends, with the largest decreases in performances observed at week-five in-season, with smaller non-significant changes in performance from week-five until the end of the competition period (see Figures 4.1, 4.2, 4.5, 4.6 and 4.7). Fleck (1994) has stated that strength and power losses can be expected in athletes following an intense training programme that achieved peak levels prior to the start of competition. Furthermore, it was hypothesised that once an adaptation to the initial stress of the combined competition and training schedule was achieved, the resulting performance decrements may plateau, with possible dynamic performance increases following this initial decline. The results of the present study have shown the negative impact the start of the competition period has on performance of dynamic test activities. Similar trends in strength and power performance decrements due to the start of a competition period have been demonstrated in sports other than football. Hoffman *et al.*

(1991a) reported significant decreases in performance of vertical jump, squat and 27 m sprint at mid-season of a 20 week basketball competition period, with subsequent increases in performances, to near pre-season levels, observed at post-season testing.

The high intensity contact nature of rugby league places extremely high physical demands on player fitness during the in-season period, which may hamper the ability of players to train and recover following the weekly competition game. It may be possible to associate the initial large dynamic performance decrements during the early competition period to fatigue from the introduction of high-speed collisions to the physical stress of the footballer, with the effect diminishing as the players adapt to the new stress. The ability to recover may have greater emphasis in the prescription of in-season strength and power training in contact sports, especially at the start of the competition period, compared to non-contact sports. It has been reported that either making or receiving a tackle is the most fatiguing part of rugby league (Docherty *et al.,* 1985). Interestingly, the contact nature of the sport is given minimal time in training, as the intensity of such training affects the performance in other training activities. Therefore, the intensity and volume of body contacts during the 80 minute game is far beyond that experienced in training. This may have adverse affects on the ability of the players to adapt to the new stress of competition, combined with the in-season training schedule.

Fleck and Kraemer (1997) suggest a competitive sport season taxes sport-specific musculature and produces strength performance decrements. It may be explained that the amount of training and competition activity undertaken had produced fatigue or impairment of strength performance during the competition season (Fleck and Kraemer, 1997). However, at the cessation of training, recovery from the competition stress occurs, returning strength performance to initial pre-season levels. In line with this theory, Campbell (1967) reported the largest decreases in strength performance during the last week of a competition period, with an increase in performance to pre-season levels resulting at the cessation of training (post-season). In the present investigation, the last test period was at week-22, during the final competition week. Subsequently, the data collected during this period may have been affected by competition fatigue. This limitation could have been alleviated if post-season data collection for the test variables used in the present investigation were performed at the cessation of the competition period. Hakkinen *et al.* (1991) state that maximal strength performance in highly trained strength athletes may be brought to peak level not necessarily during normal strength training but more likely after some period of time with a reduced volume of training. It may have been beneficial to collect post-season data in the present study at the cessation of training and competition, when participants fatigue levels were reduced, in order to observe the effect of recovery on strength and power performances once the competition stress was removed.

It appears that the start of the competition period affects the performance of the test variables with large speed and power components. In the three groups, vertical jump performance patterns improved from week-five to week-10 in-season following a significant decline from pre-season to week-five (see Figure 4.1). In conjunction, the sprint performance patterns at week-10 either plateaued, or improved, following a significant decrease at week-five in-season (see Figure 4.5, 4.6 and 4.7). It has been previously stated that speed is one of the first elements to be affected by detraining, as the breakdown of protein, and the deterioration of motor units causes a reduction in nerve impulses, reduces contraction rates, and thereby, decreases the power capabilities of muscle contraction (Edgerton, 1976; Hainaut and Duchateau, 1991; Houmard, 1991). However, it is difficult to conclude if detraining resulted in the losses in speed and vertical jump performances in the present study, as performances in these variables plateaued following the initial decline in performance at week-five. Furthermore, there were no changes in the body composition variables at any stage through the competition period to suggest a breakdown of lean muscle mass usually associated with detraining (Hainaut and Duchateau, 1991). Alternatively, the initial decreases in speed performance from pre-season to week-five in-season may have resulted from neural fatigue associated with the initially large stress of weekly competition games combined with the ordinary training load. This combination may have resulted in a short-term over-reaching period, where the athlete must overcome and adapt to a new high intensity stimulus (Stone *et al.,* 1981). This is even more plausible when considering that there were no further significant changes in sprint performances until week-22 in-season.

The findings of the present study have implications towards in-season strength and power training practices for rugby league, at the start of the competition period. It may be necessary to alter in-season training programmes to account for the initial stress encountered at the start of the rugby league competition period. Larger decreases in the training load than those used in the present study may be necessary to assist in the adaptation process at this critical period. However, it cannot be guaranteed that further reductions in training load during the initial competition period will alter the effect on dynamic performance variables. It may be that performance variables during the early in-season period are compromised by competition schedules. A longitudinal study that investigates the effect of the start of the competition period in a larger population of athletes, across a number of sports, is required to confirm the findings of the present study.

5.2.5. Contribution of strength and power to performance outcomes

Any decrease in performance that might occur in individual athletes during the competitive season could have serious implications for overall team performance (Schneider *et al.,* 1998). This becomes even more critical in football, where the success of each play depends on the collective performance of all players (Schneider *et al.,* 1998). One of the elements of strength and power training for athletes that remains uncertain is an indicator of a desired level of strength and power for performance in specific sporting activities, and the contribution to the performance outcome. This becomes more plausible in team sports, in which an outcome in performance can be affected by numerous external factors.

The results from the present study have shown that the performance decrements in the sprints had no relationship with the strength and power detraining observed from pre-season to post-season in any group. The three groups displayed significant decreases in the flying 30 m sprint performances from pre-season to week-22 in-season, with no relationship to the decreases observed in any strength and power variable. The positive relationship between explosive strength and sprint performance in athletes has previously been displayed (Pryor *et al.,* 1994; Young 1995a). Thus, a decrease in explosive strength performance, in turn, would affect the performance in speed tasks, especially the 10 m sprint. There was no relationship between the changes in performance of the 10 m sprint and vertical jump for either group from pre-season to post-season in the present study. Therefore, the significant changes experienced in vertical jump performance from pre-season to post-season for the two highly trained groups had no effect on the performance of the sprint variables in this study. These findings raise further questions as to the desired level of strength and power required for rugby league performance. The game of rugby league is played over 80 minutes, with players involved in intermittent passages that last from five to 90 seconds (Meir *et al.,* 1993). Subsequently, passages of play would ordinarily be at a sub-maximal intensity due to the duration and frequency of the intense exercise bouts. A number of other dynamic performance variables may have assisted in discussing the results of the present investigation. Strength, power, and speed tests that measure performance decrements over repeated repetitions may have provided greater insights into the relationship between detraining and performance of dynamic tests during the competition period. Future in-season investigations should take this into consideration.

5.3. Implications for rugby league in-season strength and power training prescription

According to the current data, the intensity of training, not frequency, appears to be the determining factor in the effectiveness of in-season strength and power training protocols, agreeing with previous findings (Morehouse, 1967; Hakkinen *et al.,* 1985a; Hakkinen, 1993a; Schneider *et al.,* 1998). The results of the present study suggest a number of factors other than in-season training frequency may affect in-season strength and power performance and detraining in high strength pre-training status footballers over long competition periods. These factors include increased fatigue levels resulting from the high amount of body contact experienced in rugby league, and the role endogenous hormones play in strength training adaptations of athletes with varying pre-training status. Furthermore, detraining still might occur even when an in-season strength and power maintenance programme is an integral part of the rugby league weekly practice routine.

In-season strength and power training frequency can be reduced from pre-season with minimal strength and power detraining over a 22 week rugby league competition period in high pre-training status footballers, providing the intensity remains elevated (75-100 percent of maximum). However, a more desirable level of strength and power maintenance may be achieved through a two day.wk^{-1} in-season frequency in high pre-training status footballers. A high intensity in-season strength and power training frequency of one day.wk^{-1} will successfully maintain pre-season strength and power levels in low pre-training status footballers throughout a 22 week competition period.

In-season explosive power training prescription is similar, with low pre-training status athletes requiring one day.wk^{-1} of explosive power training, with a more desirable result in high pre-training athletes expected by using a two day.wk^{-1} frequency. In-season strength and power training volume, although not directly investigated in the current study, can be reduced from pre-season levels. However, the results of the present investigation, and other recommendations (Kraemer, 1997a), have indicated a multi-set system, where a number of sets per exercise are performed in a session, as opposed to the single-set system, is the preferred method of in-season strength and power training volume prescription. In-season strength and power exercise selection also needs consideration. Eccentric/concentric exercises should be combined with concentric exercises in each training session to alleviate a decrease in neuromuscular stimulus, which may arise when eccentric contractions are removed.

A competitive sport season taxes sport-specific musculature and produces strength performance decrements. The amount of training and competition activity undertaken produces fatigue or impairment of strength performance during the competition season. The start of the football competition period needs special consideration when designing an in-season strength and power training protocol. The combined stress of competition and the weekly training activities requires the alteration of training load and overall training volume to allow physical adaptation, especially in the first five weeks of the rugby league competition period.

5.3.1. Rugby league in-season strength and power training model

A number of in-season strength and power training models have been developed to maintain strength and power levels throughout the competition period (Matveyev, 1981; Stone *et al.,* 1981; Bompa, 1994; Wathen, 1994). These models have been developed for individual sports, or for sports with relatively short competition phases. Limited data has been published comparing existing in-season strength and power training models, or the effectiveness of these models in maintaining strength and power levels throughout a competition season. In addition, most existing in-season strength and power training models have limited application to training prescription for athletes with differing strength and power pre-training status. Furthermore, the start of the competition period and its effects on the performance of dynamic athletic activities needs special consideration, especially with the demanding physical body-contact nature of rugby league. Making generic prescriptions across sports and training situations in such papers or texts is exceedingly difficult, yet the models cited above may not greatly enlighten strength and conditioning coaches about the specifics of implementing an efficient method of overload across a football season (Baker, 1998). The current recommendations for in-season strength and power training are clearly limited, especially in the validation of existing models. The data from the current investigation provides the greatest insights to date for the in-season strength and power training requirements of rugby league players over a long competition period.

This rugby league in-season strength and power model is a combination of the current recommendations for in-season strength and power training, merged with the present data (see Table 5.1). The findings from the present study have assisted the development of the rugby league in-season strength and power training model through; identification of training frequency requirements for athletes with varying pre-training status; the effect the start of the competition period has on dynamic athletic performance; and an understanding that frequency of in-season strength and power training may have a limited role in determining the success of a specified programme. Furthermore, the inclusion and resulting prescription of in-season explosive power training in the current model stems from the results of vertical jump performance trends over the 22-week competition period.

The suggested in-season strength and power protocol is a four-week periodised linear intensification model, based on the concept of training periodisation (Matveyev, 1981). The Australian rugby league competition season runs for a 26-week period. The proposed in-season strength and power training programme is repeated six times throughout the Australian rugby league in-season period, with a one week active rest period at the completion of each two-cycle period (eight weeks) (see Figure 5.1). The four-week structure has a large initial volume at a moderate intensity, with progressive increases in intensity whilst working toward a peaking of intensity, and a reduction in total volume (Baker *et al.,* 1994). The early high volume period emphasises the hypertrophic adaptations, while the later intensity periods stress the neural responses, thus, providing a more efficient training structure for strength gain in footballers (Stone *et al.,* 1981). From a biological point of view, the cycling of training appears to be advantageous when training for long periods (Hakkinen, 1985), such as those

Table 5.1. Four week rugby league in-season strength and power training programme.

Training Week	1	2	3	4
Session Intensity (% 1 RM)	80% 1RM	85% 1RM	90% 1RM	95-100% 1RM
Session Volume (sets x reps)	90-95	60-70	45-55	20-30
Core strength	3x8	3x5	3x3	2x2,1x1
Core power	3x5	3x4	3x3	2x2,1x1
Assistant strength	2x10	2x8	2x6	2x5
Assistant power	2x6	2x5	2x5	2x4
Plyometrics	6x12	6x10	8x6	8x4

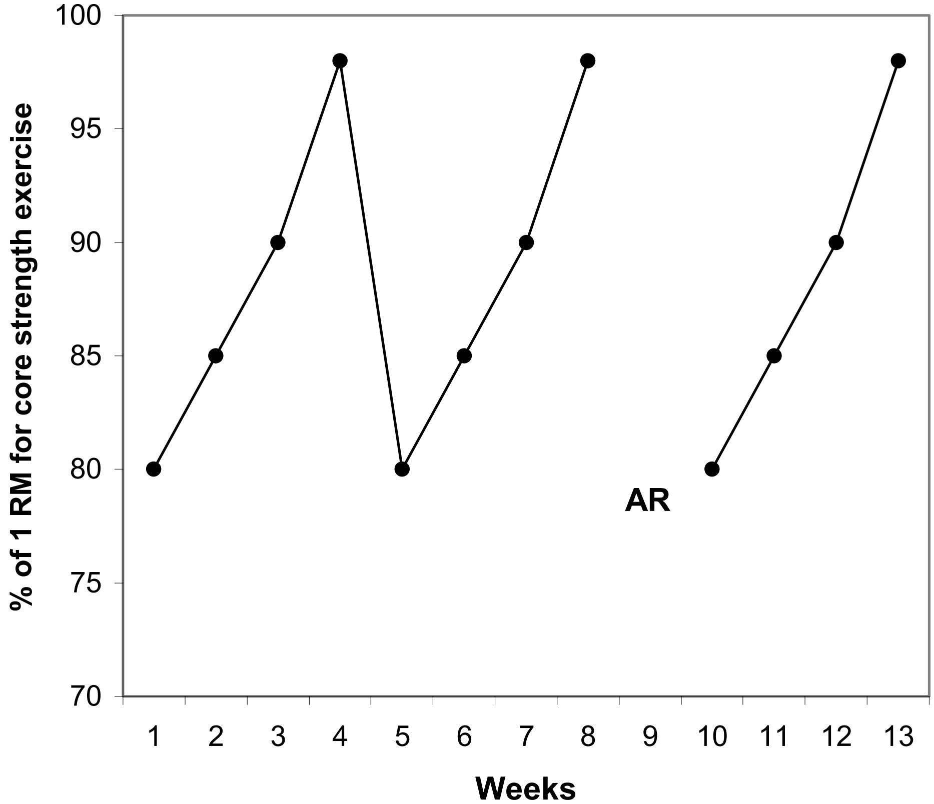


Figure 5.1. Undulating periodised progression of core in-season strength training intensity (% of 1 RM) for the first 13-weeks of the rugby league in-season strength and power training model based on the training progressions in Table 5.1. AR denotes the active recovery week at competition-week nine, where no strength and power training is performed.

encountered during a long rugby league competition season. Variability in the training stimulus becomes a major issue in the strength and power development in strength and power trained athletes, as demonstrated by Hakkinen and Komi (1981).

The repeated nature of the four-week cycle ultimately becomes a variation of the undulating periodised programme promoted by Poliquin (1988, see Figure 5.1). This method of strength and power periodisation has been shown to offer a better alternative to the periodised linear intensification model (Stone *et al.*, 1981; Stowers *et al.*, 1983). Prolonged linear intensification can lead to neural fatigue and staleness, leading to limitations in strength gains (Komi, 1986; Bompa, 1990). These problems can be avoided with variation and cycling of training intensities, which is especially useful over long competition periods. Thus, by combining high intensity training with intermittent periods of high volume/low intensity training, optimal strength gains result (Baker *et al.*, 1994; Stone *et al.*, 1981; Stone *et al.*, 1999a, 1999b). High intensity strength training is unable to maintain LMM levels over extended periods of time once training intensities rise above the desirable level for muscle fiber hypertrophy (Hakkinen *et al.*, 1985a; Utter *et al.,* 1999). Therefore, a degree of strength training aimed at hypertrophy is required in sports where athletes require a higher degree of LMM, such as rugby league forwards.

The frequency of training for the rugby league in-season strength and power training model is variable at certain stages of the competition period, and for players with different levels of pre-training status. A training frequency of one day.wk^{-1} is recommended for the first four-week in-season cycle. This period of reduced in-season strength and power training frequency is supposed to allow greater recovery and rest from the initial stress players experience at the start of the competition period, by alleviating the extra fatigue that may be brought on by extra strength and power training in this early competition period. Following this initial four-week period, an in-season strength and power training frequency of two $day.wk^{-1}$ is recommended for high pre-training status athletes, which is also the frequency for the combined explosive power training exercises (plyometrics and ballistics exercises). An in-season frequency of one $day.wk^{-1}$ is sufficient for maintaining pre-season strength and power levels in athletes with low pre-training status. However, a training frequency of two $day.wk^{-1}$ can also be used in these low pre-training status athletes, if conformity to team training schedules is required.

The strength and power training exercises used in the in-season period must specifically target the dominant abilities of rugby league, whilst conditioning the muscles for increased performance. Exercises in this programme have been distinguished between strength and power exercises. Further differentiation within each category of exercises for the purposes of core and assistant exercises is necessary. Plyometrics and ballistics exercises (explosive power) are included in each rugby league in-season strength and power session, with an emphasis on developing functional football power. Each in-season training session consists of both strength and power exercises, with explosive power exercises combined with core strength and power exercises (see Table 5.2). It is the strength coach's role to assign exercise selection depending on the ability of each athlete. Furthermore, the recommended percentage 1 RM is only an intensity guideline for the coach to select loads to be lifted by each athlete. However, the success of the model will be measured on the strength coach's ability to make alterations according to the training state of the players and the objectives of the training week. Further investigation should be carried out to determine the success of the proposed model of in-season strength and power training for rugby league.

Table 5.2. Example of the exercises used in a rugby league in-season strength and power training week.

Day 1	Day 2
Back Squat (CS)	Dead Lift (CS)
Multiple Jumps (EP)	Power Snatch (CP)
Shoulder Press (CS)	Standing Long Jump (EP)
Medicine Ball Squat Throws (EP)	Power Jerk (CP)
Power Cleans (CP)	Double Clap Push Ups (EP)
Chin Ups (AS)	Dips (AS)

Notes

CS = core strength

CP = core power

AS = assistant strength

EP = explosive power

CHAPTER SIX

CONCLUSIONS, LIMITATIONS & RECOMMENDATIONS

6.1. Conclusions

The results of the present study suggest in-season strength and power training frequency may have a limited role in determining the success of the in-season strength and power training programme in highly trained footballers. It was hypothesised that strength and power performances would be maintained significantly longer in high pre-training status footballers using a two day.wk^{-1} in-season strength and power frequency, compared to a one day.wk^{-1} frequency. However, high pre-training status footballers in this study suffered similar detraining effects in strength and power performance regardless of in-season training frequency. The in-season strength training frequency was reduced to one or two days.wk^{-1} from the pre-season training frequency of three days.wk^{-1} in the present investigation. However, there were no differences between the two groups at any stage throughout the 22 week competition period. In contrast, the low pre-training status footballers displayed no change from pre-season strength and power performance following 22 weeks of a competition period, incorporating a one day.wk^{-1} in-season strength and power training frequency.

The present data have important practical applications for athletes participating in a strength and power training programme. When training frequency must be reduced, as is the case in competition periods, muscular strength may be maintained in low pre-training status athletes by training as little as one day.wk^{-1}, as long as the intensity of training is maintained at a high level. In addition, it appears that there is a different requirement for rugby league players with a high strength and power pre-training status. The maintenance of muscular strength in highly trained individuals may require a considerably different training stimulus. The results of the present study suggest a number of factors other than in-season training frequency may affect in-season strength and power performance and detraining in high strength pre-training status footballers over long competition periods, such as the role endogenous hormones play once neuromuscular training adaptations reach a ceiling point. It is important to recognise that detraining still might occur, even when an in-season strength and power maintenance programme is an integral part of the weekly practice routine. Nevertheless, there is a need for individual programming of strength and power training among athletes within a team, especially when a wide range of athlete pre-training levels exist.

It was hypothesised that performance of explosive power training one day.wk-1 would be sufficient to maintain pre-season levels of explosive power in all three groups. The results from the present investigation highlights an in-season training frequency of two day.wk^{-1} appears to be the preferred option for explosive power maintenance in rugby league players with high pre-training status during long competition periods. However, an in-season explosive power training frequency of one day.wk^{-1} is sufficient in maintaining explosive power performance in the low pre-training status group over the 22 week rugby league competition period. In order to maintain the level of explosive power capacity in footballers, the magnitude of the explosive power training stimuli should be given individual attention during the entire course of the competition period.

The start of the rugby league competition season has negative effects on dynamic athletic performance, especially in sprint performance. This negative effect was hypothesised to occur, regardless of pre-training status, until the adaptation to competition stress was achieved at week-10 in-season, which the present data represents. It may be necessary to initially alter in-season training programmes to account for the initial stress encountered at the start of the rugby league competition period, with a return to normal in-season training loads once adaptation to this stress is achieved. Decreases in the training load may need to be larger than those used in the present study to assist in the adaptation process at this critical period. However, it cannot be guaranteed that further reductions in training load during the initial competition period will alter the effect on dynamic performance variables. It may be that performance variables during the early in-season period are compromised by competition schedules. A longitudinal study that investigates the effect of the start of the competition period in a larger population of athletes, across a number of sports, is required to confirm the findings of the present study.

In-season exercise selection may require special attention when programming for athletes with high strength and power pre-training status. The absence of eccentric loading with power training exercises, such as the power clean and power snatch, could compromise the optimal intensity of the training session and the resulting session adaptations. Therefore, exercise selection on day two of in-season strength and power training necessitates a combination of eccentric and concentric contractions to provide the stimulatory effect required to elicit noticeable changes in performance, as opposed to the protocol used on day two of the present investigation.

6.2. Limitations

The results of this research are not without limitation. As with most longitudinal investigations, external factors, such as injuries, influence drop-out rates of a sample. This can limit the power of statistical analyses, especially of a repeated measures nature. Moreover, a larger sample would have provided greater statistical power, which may in turn, provide more conclusive results for this investigation. Furthermore, larger sample sizes increase the ability to generalise the results.

Strength and power measurement equipment that is more sensitive to changes in performance may have provided greater insights into changes resulting from the rugby league competition period and different in-season strength and power training frequencies. However, the CYBEX II isokinetic dynamometer and force plates, commonly used in research of this nature, are expensive and inaccessible to most football clubs. Thus, the elimination of such equipment restricted the collection of other neuromuscular performance variables, such as rate of force development and reaction time measurements, which may have been useful for this investigation. It is recommended that future investigations use force platforms to gain insights into the effect of a competition period on the neural components of force and speed production. Furthermore, strength, power, and speed tests that measure performance decrements over repeated repetitions may have provided greater insights into the relationship between detraining and performance of dynamic tests during the competition period. Future in-season investigations should take this into consideration.

A further limitation of the present investigation was the collection of the last data set. The last test period was at week-22, during the final competition week. Subsequently, the data collected during this period may have been affected by competition fatigue. This limitation could have been alleviated if post-season data collection was performed at the cessation of the competition period. A competitive sport season taxes sport-specific musculature and produces strength performance decrements. The amount of training and competition activity undertaken produces fatigue or impairment of strength performance during the competition season. However, at the cessation of training, recovery from the competition stress occurs, returning strength performance to initial pre-season levels. It is recommended that future in-season investigations collect data both in-season and post-season to identify if post-season performances are effected by competition recovery.

6.3. Recommendations

Based on the findings of the present investigation a number of recommendations for future investigation are given to further substantiate and expand on the current results. These recommendations include;

1. Further investigation into the effect of the start of the competition period on dynamic athletic performance in both contact and non-contact sports. These investigations should be performed at both the elite and non-elite competition levels.

2. Future investigation manipulating the training load at the start of the competition period in order to assess the effect of training load on dynamic athletic performance at the start of the rugby league competition period.

3. Examination of the existing models of in-season strength and power training (Matveyev, 1981; Stone *et al.,* 1981; Bompa, 1994; Wathen, 1994) versus the recommended model, from the current investigation, of in-season strength and power training for rugby league.

4. Future investigations should utilise more sensitive measurement instruments for strength and power data collection, with an inclusion rate of force development and reaction time variables to further identify the effect of competition on the neural mechanisms of force and speed development.

5. Future repeated measures investigations to collect data at in-season and post-season periods to identify and eliminate the effect of competition fatigue on performance of strength and power variables.

6. Investigations into the contribution of strength and power levels to the outcome of sports performance. Future investigations need to identify the importance of strength and power in the overall performance of a sport, taking into consideration

other sport specific components, such as skill level and external competition components.

REFERENCE LIST

Ackland, T., Dawson, B. & Roberts, C. (1985). Pre-season fitness profiles of Australian football players and umpires. *Sports Coach, 8*(4), p.43-48.

Alen, M., Reinila, M. & Vihko, R. (1984). Response of serum hormones to androgen administration in power athletes. *Medicine and Science in Sports and Exercise, 17*, p.354-359.

Alexander, M.J. (1989). The relationship between muscle strength and sprint kinematics in elite sprinters. *Canadian Journal of Sports Science, 14*(3), p.148-157.

Allen, G.D. (1989). Physiological and metabolic changes with six weeks detraining. *The Australian Journal of Science and Medicine in Sport, 21*(1), p.4-9.

Appell, H.J. (1990). Muscle atrophy following immobilization: a review. *Sports Medicine, 10*(1), p.42-58.

Baker, D. (1998). Applying the in-season periodisation of strength and power training to football. *Strength and Conditioning Journal, 20*(2), p.18-24.

Baker, D. & Nance, S. (1999a). The relation between strength and power in professional rugby league players. *Journal of Strength and Conditioning Research, 13*(3), p.224-229.

Baker, D. & Nance, S. (1999b). The relation between running speed and measures of strength and power in professional rugby league players. *Journal of Strength and Conditioning Research, 13*(3), p.230-235.

Baker, D., Wilson, G. & Carylon, R. (1994). Periodisation: the effect of manipulating volume and intensity. *Journal of Strength and Conditioning Research, 8*(4), p.235-242.

Bauer, T., Thayer, R.E. & Baras, G. (1990). Comparison of training modalities for power development in the lower extremity. *Journal of Applied Sport Science Research, 4*(4), p.115-121.

Bell, G., Petersen, S., Quinney, H. & Wenger, H. (1988). Sequencing of endurance and high-velocity strength training. *Canadian Journal of Sort Science, 13*, p.214-219.

Bell, G., Petersen, S., Wessel, J., Bagnall, K. & Quinney, H. (1991). Adaptations to endurance and low-velocity resistance training performed in sequence. *Canadian Journal of Sport Science, 16*, p.186-192.

Bell, G.J., Syrotuik, D.G., Attwood, K. & Quinney, H.A. (1993). Maintenance of strength gains while performing endurance training in oarswomen. *Canadian Journal of Applied Physiology, 18*(1), p.104-115.

Bell, W., Cobner, D., Cooper, S. & Phillips, S.J. (1993). Anaerobic performance and body composition of international rugby union players. In, T. Reilly, J. Clarys & A. Stibble (Eds), *Science and Football II.* E & F Spon: London.

Blakey, J.B. & Southard, D. (1987). The combined effects of weight training and plyometrics on dynamic leg strength and leg power. *Journal of Applied Sport Science Research, 1*(1), p.14-16.

Bompa T.O. (1990). Periodisation of strength: The most effective methodology of strength training. *National Strength and Conditioning Association Journal, 12*(5), p.49-52.

Bompa**,** T.O. (1993). *Periodization of strength: the new wave in strength training.* Veritas Publishing: Toronto.

Bompa, T.O. (1994). *Theory and Methodology of Training.* Dubuque, IO: Kendall/Hunt.

Brewer, J., Davis, J.A. & Kear, J. (1994). A comparison of the physiological characteristics of rugby league forwards and backs (abstract). *Journal of Sport Science, 12*(2), p. 158.

Caiozzo, V.J., Perrine, J.J. & Edgerton, V.R. (1981). Training-induced alterations of the in vivo force velocity relationships of human muscle. *Journal of Applied Physiology, 51*(3), p.750-754.

Campbell, D.E. (1967). Maintenance of strength during a season of sports participation. *American Corrective Therapy Journal, 21*(6), p.343-348.

Colliander, E.B. & Tesch, P.A. (1990). Effects of eccentric and concentric muscle actions in resistance training. *Acta Physiologica Scandinavica, 140*, p.31-39.

Colliander, E.B. & Tesch, P.A. (1992). Effects of detraining following short term resistance training on eccentric and concentric muscle strength. *Acta Physiologica Scandinavica, 144*(1), p.23-29.

Davis, J.A., Brewer, J. & Atkin, D. (1992). Pre-season physiological characteristics of English first and second division soccer players. *Journal of Sport Sciences, 10*(6), p. 541-547.

Dawson, B. (1985). Physical and physiological characteristics of eight league footballers. *Sports Coach, 9*(2), p. 33-36.

DeRenne, C., Hetzler, R.K., Buxton, B.P. and Ho, K.W. (1996). Effects of training frequency on strength maintenance in pubescent baseball players. *Journal of Strength and Conditioning Research, 10*(1), p.8-14.

Docherty, D., Wenger, H.A. & Neary, P. (1985). Time-motion analysis related to the physiological demands of rugby. *Journal of Human Movement Studies, 14*, p.269-277.

Doggart, L., Keane, S., Reilly, T. & Stanhope, J. (1993). A task analysis of Gaelic football, In T. Reilly, J. Clarys & A. Stibble (Eds.) *Science and Football II* (pp.186-189). E & FN Spon; London.

dos Remedios, K.A, dos Remedios, R.L., Loy, S.F., Holland, G.J., Vincent, W.J., Conley, L.M. and Heng, M. (1995). Physiological and field test performance changes of community football players over a season. *Journal of Strength and Conditioning Research, 9*(4), p.211-215.

Douge, B. (1988). Football: the common threads between the games, In T. Reilly, A. Lees, K. Davids, & W.J. Murphy (Eds.), *Science and Football* (pp. 3-19). E and F Spon; London.

Duchateau, J. Hainaut, K. (1991). Effects of immobilization on electromyogram power spectrum changes during fatigue. *European Journal of Applied Physiology, 63*(6), p.458-462.

Dudley, G.A. & Djamil**,** R. (1985). Incompatibility of endurance- and strength-training modes of exercise. *Journal of Applied Physiology, 59*(5), p.1446-1451.

Dudley, G.A., Tesch, P.A., Miller, M.A. & Buchanan, P. (1991). Importance of eccentric actions in performance adaptations to resistance training. *Aviation, Space and Environmental Medicine, 62,* p.543-550.

Ebbing, C. & Clarkson, P. (1989). Exercise-induced muscle damage and adaptation. *Sport Medicine, 7*, p.207-234.

Edgerton, V.R. (1976). Neuromuscular adaptation to power and endurance work. *Canadian Journal of Applied Sport Sciences, 1*(1), p.49-58

Evans, W.J. (1987). Exercise induced skeletal muscle damage. *The physician and Sport Medicine, 15*(1), p.89-100.

Faulkner, J.A., Clafin, D.R. & McCully, K.K. (1987). Muscle function in the cold. In, J.R. Suttton, C.S. Houston & G. Coates (Eds.), *Hypoxia and Cold* (pp. 429-437). New York: Praeger.

Fleck, S.J. (1994). Detraining: Its effects on endurance and strength. *Strength and Conditioning, 16*(1), p.22-28.

Fleck, S.J. & Kraemer, W.J. (1997). *Designing Resistance Training Programs (2nd ed.).* Human Kinetics: Champaign, IL.

Fry, A.C., Kraemer, W.J., Weseman, C.A., Conroy, B.P., Gordon, S.E., Hoffman, J.R. & Maresh, C.M. (1991). The effects of an off-season strength and conditioning program on starters and non-starters in women's collegiate volleyball. *Journal of Applied Sport Science Research, 5*(4), p.174-181.

Garhammer, J. & Gregor, R. (1992). Propulsion forces as a function of intensity for weightlifting and vertical jumping. *Journal of Applied Sport Science Research, 6*(3), p.129-134.

Gillam, G.M. (1981). Effects of frequency of weight training on muscle strength enhancement. *Journal of Sports Medicine and Physical Fitness, 21*(4), p.432-436.

Gleim, G.W. (1984). The profiling of professional football players. *Clinics in Sports Medicine, 3*(1), p.185-197.

Gonyea, W.D., Sale, D. & Dixon, J.A. (1983). Increase in muscle number in response to weight-lifting exercise (Abstract). *Medicine and Science in Sport and Exercise, 15*(2), p.135

Graves, J.E., Pollock, M.L., Leggett, S.H., Braith, R.W., Carpenter, D.M. & Bishop, L.E. (1988). Effects of reduced training frequency on muscular strength. *International Journal of Sport Medicine, 9*(5), p.316-319.

Green, S. (1992). Anthropometric and physiological characteristics of South Australian soccer players. *The Australian Journal of Science and Medicine in Sport, 24*(1), p. 3-7.

Hainaut, K. & Duchatteau, J. (1989). Muscle fatigue: Effects of training and disuse. *Muscle and Nerve, 12*, p.660-669.

Hakkinen, K. (1985). Factors influencing trainability of muscular strength during short term and prolonged training. *National Strength and Conditioning Association Journal, 7*(2), p. 32-37.

Hakkinen, K. (1988). Effects of the competitive season on physical-fitness profile in elite basketball players. *Journal of Human Movement Studies, 15*(3), p.119-128.

Hakkinen, K. (1989). Neuromuscular and hormonal adaptations during strength and power training. *Journal of Sports Medicine and Physical Fitness, 29*(1), p.9-26.

Hakkinen, K. (1993a). Changes in physical fitness profile in female basketball players during the competitive season including explosive type strength training. *Journal of Sports Medicine and Physical Fitness, 31*(1), p. 19-26.

Hakkinen, K. (1993b). Changes in physical fitness profile in female volleyball players during the competitive season. *Journal of Sports Medicine and Physical Fitness, 31*(3), p. 223-232.

Hakkinen, K. & Alen**,** M. (1986). Physiological performance, serum hormones, enzymes and lipids of an elite power athlete during training with and without androgens and during prolonged detraining. *Journal of Sports Medicine and Physical Fitness, 26*(1), p.92-100

Hakkinen, K. & Komi, P.V. (1981). Specificity of training induced changes in strength performance considering the integrative functions of the neuromuscular system. *World Weightliting, 3,* p.44-46.

Hakkinen, K. & Komi, P.V. (1983). Changes in neuromuscular performance in voluntary and reflex contraction during strength training in man. *International Journal of Sports Medicine, 4*(4), p.282-288.

Hakkinen, K., Komi, P.V. & Alen, M. (1985a). Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiologica Scandinavica, 125, p.573-585.*

Hakkinen, K., Komi, P.V. & Alen, M. (1985b). Effect of explosive type strength training on isometric force and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiologica Scandinavica, 125,* p.587-600.

Hakkinen, K., Kallinen, M., Komi, P.V. & Kauhanen, H. (1991). Neuromuscular adaptations during short-term normal and reduced training periods in strength athletes. *Electromyography and Clinical Neurophysiology, 31*, p.35-42.

Hakkinen, K., Keskinen, K.L., Alen, M., Komi, P.V. & Kauhanen, H. (1989). Serum hormone concentrations during prolonged training in elite endurance-trained and strength-trained athletes. *European Journal of Applied Physiology and Occupational Physiology, 59*(3), p.233-238.

Hakkinen, K., Komi, P.V., Tesch, P.A. (1981). Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fibre and metabolic characteristics of long extensor muscles. *Scandinavian Journal of Sports Sciences 3*(2), p.50-58.

Hakkinen, K., Pakarinen, A., Alen, M., Komi, P.V. (1985c). Serum hormones during prolonged training of neuromuscular performance. *European Journal of Applied Physiology and Occupational Physiology, 53*(4), p.287-293.

Hakkinen, K., Pakarinen, A., Alen, M., Kauhanen, H. & Komi, P.V. (1987). Relationship between training volume, physical performance capacity, and serum hormones concentrations during prolonged training in elite weightlifters. *International Journal of Sports Medicine, 8*(Suppl 1), p.S61-S65.

Hakkinen, K. & Sinnemaki, P. (1991). Changes in physical profile during the competitive season in elite bandy players. *Journal of Sports Medicine and Physical Fitness, 31*(1), p. 37-43.

Hakkinen, K., Viitsalo, J.T. & Komi, P.V. (1980). Effect of different combinations of concentric and eccentric muscular activity on strength and time characteristics of leg extensors. *Leitungssport, 10*(5), p.374-381.

Harris, G.R., Stone, M.H., O'Bryant, H.S., Proulx, C.M. & Johnson, R.L. (2000). Short-term performance effects of high power, high force, or combined weight-training methods. *Journal of Strength and Conditioning Research, 14*(1), p.14-20.

Hather, B.M., Tesch, P.A., Buchanan, P. & Dudley, G.A. (1991). Influence of eccentric actions on skeletal muscle adaptations to resistance training. *Acta Physiologica Scandinavica, 143*(2), p.177-185.

Hayes, K.C. (1978). A theory of the mechanism of muscular strength development based upon EMG evidence of motor unit synchronization. In F. Landry & W. Orban (Eds.) *Biomechanics of sport and kinanthropometry.* Symposium Specialists: Miami.

Hickson, R. (1980). Interference of strength development by simultaneously training for strength and endurance. *European Journal of Applied Physiology, 45,* p.255-263.

Hoffman, J.R., Fry, A.C., Howard, R., & Maresh, C.M. (1991a). Strength, speed and endurance changes during the course of a division I basketball season. *Journal of Applied Sport Science Research, 5*(3), p.14-149.

Hoffman, J.R., Maresh, C.M., Armstrong, L.E. & Kraemer, W.J. (1991b). Effects of off-season and in-season resistance training programs on a collegiate male basketball team. *Journal of Human Muscle Performance, 1*(2), p.48-55.

Hortobagyi, T., Houmard, J.A., Stevenson, J.R., Fraser, D.D., Johns, R.A. & Isreal, R.G. (1993). The effects of detraining on power athletes. *Medicine and Science in Sport and Exercise, 25*(8), p.929-935.

Hortobagyi, T., Katch, F.I. & LaChance, P.F. (1989). Interrelationships between various measures of upper body strength assessed by different contraction modes. *European Journal of Appied Physiology, 58*, p.749-755.

Hortobagyi, T., Katch, F.I. & Lachance, P.F. (1991). Effects of simultaneous training for strength and endurance on upper and lower body strength and running performance. *Journal of Sports Medicine and Physical Fitness, 31*(1), p.20-30.

Houmard, J.A. (1991). Impact of reduced training on performance in endurance athletes. *Sports Medicine, 12*(6), p.380-393.

Hunter, G., Demnent, R. & Miller, D. (1987). Development of strength and maximal oxygen uptake during simultaneous training for strength and endurance. *International Journal of Sports medicine and Physical Fitness, 27,* p.269-275.

Kirgan, B. & Reilly, T. (1993). A Fitness evaluation of Gaelic football club players, In T. Reilly, J. Clarys & A. Stibble (Eds.) *Science and Football II* (pp.59-61). E & FN Spon; London.

Komi**,** P.V. (1986) Training of muscle strength power: interaction of neuromotoric, hypertrophic, and mechanical factors. *International Journal of Sports Medicine, 7*(Suppl 1), p.10-15

Komi, P.V. & Bosco, C. (1978). Utilisation of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sport, 10*(4), p.261-265.

Koutedakis, Y., Boreham, C., Kabitsis, C. & Sharp, .C. (1992). Seasonal deterioration of selected physiological variables in elite male skiers. *International Journal of Sports Medicine, 13(*7), p.548-551.

Kraemer, W.J. (1997a). A series of studies- the physiological basis for strength training in American football: fact over philosophy. *Journal of Strength and Conditioning Research, 11*(3), p.131-142.

Kraemer, W.J. (1997b). Results of an in-season resistance program for American football on 1-RM lifts, In S.J. Fleck & W.J. Kraemer, *Designing Resistance Training Programs (2nd ed.),* p.175-176, Champaign, IL: Human Kinetics.

Kristensen, J. (1979). Overtrianed: the problematic effect of overtraining. *International Olympic Lifter, 4,* p.8-26.

Kuipers, H. & Keizel, H.A. (1988). Overtraining in elite athletes: review and directions for the future. *Sports Medicine, 6*(2), p.79-92.

Larder, P. (1992). *The Rugby League Coaching Manual (ed. 2).* Kingswood Press: London.

Legg, D. & Burnham, R. (1999). In-season shoulder abduction strength changes in football players. *Journal of Strength and Conditioning Researh, 13*(4), p.381-383.

Lyttle, A.D., Wilson, G.J. & Ostrowski, K.J. (1996). Enhancing performance: maximal power versus combined weights and plyometrics training. *Journal of strength and conditioning research, 10*(3), p.173-179.

Matveyev, L. (1981). *Fundamentals of Sports Training.* Progress Publishers: Moscow.

Maud, P.J. (1983). Physiological and anthropometric parameters that describe a rugby union team. *British Journal of Sports Medicine, 17*(1), p.16-23.

Mayhew, S.R. & Wenger, H.A. (1985). Time-motion analysis of professional soccer. *Journal of Human Movement Studies, 11*(1), p.49-52.

McDonach, M.J.N. & Davies, C.T.M. (1984). Adaptative response of mammalian skeletal muscle to exercise with high loads. *European Journal of Applied Physiology, 52*, p.139-155.

McMorris, R.O. & Elkins, E.C. (1954). A study of production and evaluation of muscular hypertrophy. *Archives of Physical Medicine and Rehabilitation, 35*, p.420-426.

Meir, R. (1993). Evaluating player fitness in professional rugby league: Reducing subjectivity. *Strength and Conditioning Coach, 1*(4), p. 11-17.

Meir, R. (1994). Seasonal changes in estimates of body composition in professional rugby league players. *Sport Health, 11*(4), p.27-31.

Meir, R., Arthur, D. & Forrest, M. (1993). Time and motion analysis of professional rugby league: A case study. *Strength and Conditioning Coach.* 1(3), p.24-29.

Mero, A., Luhtanen, P., Viitasalo, J.T. & Komi, P. (1981). Relationships between the maximal running velocity, muscle fiber characteristics, force production and force relaxation of sprinters. *Scandinavian Journal of Sport Science, 3*(1), p.16-22.

Morehouse, C. (1967). Development and maintenance of isometric strength of subjects with diverse initial strengths. *Research Quarterly, 38*, p.449-456.

Moritani, T. & DeVries, H. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. *American Journal of Physical Medicine, 58*(3), p.115-130.

Moss, B.M., Refnes, P.E., Abildgaard, A., Nicolayson, K. & Jensen, J. (1997). Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *European Journal of Applied Physiology and Occupational Physiology, 75*, p.193-199.

Neuffer, P.D., Costill, D.L., Fielding, R.A., Flynn, M.G. & Kirwan, J.P. (1987). Effect of reduced training on muscular strength and endurance in competitive swimmers. *Medicine and Science in Sports and Exercise, 19*(5), p.486-490.

O'Bryant, H.S., Byrd, R. & Stone, M.H. (1988). Cycle ergometer performance and maximal leg and hip strength adaptations to two different methods of weight training. *Journal of Applied Sports Science Research, 2*(2), p.27-30.

O'Connor, D. (1996). Physiological characteristics of professional rugby league players. *Strength and Conditioning Coach, 4*(1), p.21-26.

Pearson, D.R. & Costill, D.L. (1988). The effect of constant external resistance exercise and isokinetic exercise training on work-induced hypertrophy. *Journal of Applied Sport Science Research, 2*(3), p.39-41.

Poliquin, C. (1988). Five ways to increase the effectiveness of your strength training program. *National Strength and Conditioning Association Journal, 10*(3), p.34-39.

Poliquin, C. & Patterson, P. (1989). Classification of strength qualities. *National Strength and Conditioning Association Journal, 11*(6), p.48-50.

Pryor, J.F., Wilson, G.J. & Murphy, A.J. (1994). The effectiveness of eccentric, concentric and isometric rate of force development tests. *Journal of Human Movement Studies, 27*, p.153-172.

Rasch, P. (1971). Isometric exercise and gains of muscular strength. In R. Shephard (Ed.) *Frontiers of Fitness,* p.98-111. Springfield, IL: Charles C. Thomas.

Rasch, P. & Morehouse, L (1957). Effect of static and dynamic exercises on muscular strength and hypertrophy. *Journal of Applied Physiology, 11*, p.29-34.

Ross, W.D., Marfell-Jones, M.J., Bailey, D.A., Carter, J.E., Clavys, J.P., Day, J.A., Drinkwater, D.T., Leahy, R.M., Martin, A.D., Milward, R.L., Stirling, D.R., Vajda-Janyk, A.S. and Ward, R. in *Physiological Testing of the Elite Athlete,* Macdougal, J.D., Wenger, H. A. & Green, H.J. (1982). New York: Movement Publications.

Sale, D.G., MacDougall, J.D., Upton, A.R. & McComas, A.J. (1983a). Effects of strength training upon motoneuron excitability in man. *Medicine and Science and Sport and Exercise, 15* (1)*,* p.57-62.

Sale, D.G., MacDougall, J.D., Always, S.E. & Sutton, J.R. (1983b). Muscle cross-sectional area, fiber distribution and voluntary strength in humans (Abstract). *Canadian Journal of Applied Sport Sciences, 221.*

Schmidtbleicher, D. (1992). Training for power events, In P.V. Komi (Ed), Strength and Power in Sport, p.381-395. Blackwell Science: Oxford, London.

Schneider, V., Arnold, B., Martin, K., Bell, D. & Crocker, P. (1998). Detraining effects in college football players during the competitive season. *Journal of Strength and Conditioning Research, 12*(1), p. 42-45.

Staron, R.S., Hagerman, F.C. & Hikida, R.S. (1981). Effects of detraining on an elite power lifter. a case study. *Journal of Neurological Sciences, 51*(2), p.247-257.

Stone, M.H., O'Bryant, H. & Garhammer, J. (1981). A hypothetical model of strength training. *Journal of Sports Medicine, 21*(4), p.56-62.

Stone, M.H., O'Bryant, H.S., Schilling, B.K., Johnson, R.L., Peirce, K.C., Haff, G.G., Kock, A.J. & Stone, M. (1999a). Periodization: Effects of manipulating volume and intensity. Part 1. *National Strength and Conditioning Association, 21*(2), p.56-62.

Stone, M.H., O'Bryant, H.S., Schilling, B.K., Johnson, R.L., Peirce, K.C., Haff, G.G., Kock, A.J. & Stone, M. (1999b). Periodization: Effects of manipulating volume and intensity. Part 1. *National Strength and Conditioning Association, 21*(3), p.54-60.

Stowers, T., McMillan, J., Scala, D., Davis, V., Wilson, D. & Stone, M. (1983). The short- term effects of three different strength-power training methods. *National Strength and Conditioning Association Journal, 5*(3), p.24-27.

Thorstensson, A., Larsson, L., Tesch, P. & Karlsson, J. (1977). Muscle strength and fiber composition in athletes and sedentary men. *Medicine and Science in sports and Exercise, 9*(1), p.26-30.

Tosh, M. (1982). Applying physiological principles to rugby league training. Unpublished Dissertation. University of Sydney.

Tschiene, P. (1979). The distinction of training structure in different stages of athlete's preparation. Paper presented at the International Congress of Sport Sciences, Edmonton, Alberta, Canada, July 25-29.

Utter, A., Stone, M., O'Bryant, H., Summinski, R. & Ward, B. (1998). Sport seasonal changes in body composition, strength, and power of college wrestlers. *Journal of Strength and Conditioning Research, 12*(4), p. 266-271.

Waldman. R. & Stull, G. (1969). Effects of various periods of inactivity on retention of newly acquired levels of muscular endurance. *Research Quarterly, 40*, p.393-401.

Wathen, D. (1994). Periodization: Concepts and applications, *In: Essentials of Strength and Conditioning.* T. Baechle (Ed.), Champaign, IL: Human Kinetics.

Willoughby, D.S. (1992). A comparison of three selected weight training programs on the upper- and lower-body strength of trained males. *Annual Journal of Applied Research in Coaching and Athletics, March,* p.124-146.

Willoughby, D.S. (1993). The effects of mesocycle-length weight training programs involving periodisation of partially equated volumes of upper and lower body strength. *Journal of Strength and Conditioning Research, 7*(1), p.2-8.

Wilson, G.J., Newton, R.U., Murphy, A.J. & Humphries, B.J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sports and Exercise, 25*(11), p.1279-1286.

Young, W. (1995a). Strength qualities and what they mean to the coach. *Strength and Conditioning Coach 3*(4), p.13-16.

Young, W. (1995b). Laboratory strength assessment of athletes. *New Studies in Athletics, 10*(1), p.89-96.

Young, W.B. & Bilby, G.E. (1993). The effect of voluntary effort to influence speed of contraction on strength, muscular power, and hypertrophy development. *Journal of Strength and Conditioning Research, 7*(3), p.172-178.

Young, W., McLean, B. & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. Journal of Sports Medicine and Physical Fitness, 35(1), p.13-19.