SPECIFICITY IN THE PHYSICAL PREPARATION OF ELITE RUGBY UNION FOOTBALL PLAYERS

A Thesis Submitted for the Degree of Doctor of Philosophy

By

Paul Gamble

School of Sport and Education

Brunel University

May 2005

Specificity in the Physical Preparation of Elite Rugby Union Football Players

11. Appendix – Published Papers

Abstract

The present thesis explored various applications of training specificity with regard to elite-level rugby union football players of various ages. A novel approach to metabolic conditioning employing skill-based conditioning games was investigated with elite-level senior professional players, during the course of a preseason training period. Training responses were assessed using a submaximal intermittent shuttle test performed at weekly intervals. Significant differences post-training ($p<0.01$) were observed for %HRmax reached during the final test stage and recovery of HR from the end of the final stage to the end of the final 1-minute rest period. The second study examined effectiveness of a circuit format for strength training in elite senior professional players during a preseason training period. Following the circuit based strength training, deadlift and bench pull 1-RM strength scores were significantly improved both in comparison to pre-tests ($p<0.01$) and end season scores ($p<0.01$). Bench press scores were also significantly improved following the training period ($p<0.01$), and post-test bench press scores were improved relative to end season scores, albeit to a lesser extent ($p<0.05$). An Olympic lift training intervention was undertaken with junior academy–level rugby union players. The effect of the application of these lifts on mean power output measured using test apparatus that simulated the ruck clean movement featured in rugby union football was examined. The considerably greater increases of the training group on this measure (28% vs 8%) were reflected in greater statistical significance ($p<0.01$) relative to the improvement for the control group ($p<0.05$). A significant interaction effect also indicated the training groups responded significantly differently on the test measure following training. A weighted ballistic push up training mode, incorporating a prototype shoulder harness, was investigated in a group of junior academy-level rugby football players. The training group recorded significant improvements in work output measured using a concentric-only push test ($p<0.05$), whereas countermovement push-up test scores approached significance ($p=0.063$). The final study employed an overweight ball complex training intervention. Following training the elite academy professional players who served as subjects showed significant improvements ($p<0.05$) in right-handed and left-handed mean and peak pass velocities.

List of Figures

3. Metabolic Conditioning

3.2. A Skill-based Conditioning Games Approach to Metabolic Conditioning for Elite Rugby Football Players

4. Strength Training

4.2. Evaluation of a Circuit Strength Training Format for Elite Senior Professional Rugby Union Football Players

5. Power Training

5.2. Application of Olympic Lift Training to Develop Game-Related Power in Junior Academy Rugby Union Football

5.3. A Weighted Ballistic Push Up Training Modality to Develop Upper-body Explosive Muscular Power in Junior Academy Rugby Football Players

5.4. Heavy Ball Complex Training for Development of Pass Velocity in Elite Academy-level Rugby Football Players

List of Tables

3. Metabolic Conditioning

4. Strength Training

5. Power Training

Articles of Relevance to the Thesis

Gamble, P. (2004). A Skill-based Conditioning Games Approach to Metabolic Conditioning for Elite Rugby Football Players. Journal of Strength & Conditioning Research. 18(3): 491-497. *A1*

Gamble, P. (2004). Physical Preparation for Elite-level Rugby Union Football. Strength & Conditioning Journal. 26(4): 10-23. *A2*

Gamble, P. (2005). Strength Training 1 – Why Competitive Athletes have 'Special Needs'. Peak Performance. 209: 4-6. *A3*

Acknowledgements

Above all this is for my dad, Steve Gamble, who has supported me in every sense over the four-and-a-half years it has taken to complete the thesis. I would like to thank Brendan Venter, MD, for initially giving me the opportunity to work with London Irish, and experience being part of what was a genuinely inspiring environment. Many of the ideas that feature in this thesis were borne out of that incredible 2001/2002 season. Likewise, I would like to express my appreciation to Conor O'Shea for the faith shown in me professionally; I hope I have not given you too many regrets thus far, Caesar. Also thanks to the players, coaches and staff at London Irish Rugby Football Club. Special thanks in particular to Toby Booth and Tony Stanger for helping to preserve my sanity. Thanks to Dave Reddin for the use of the Grunt 3000 apparatus and the England gym facility at Twickenham for testing. I would like to recognise the contribution of my supervisor, Prof Alison McConnell. Many thanks also to Prof David Jones for his efforts to secure my PhD place, in collusion with Prof Craig Sharp! Finally, thanks to Dr Lee Romer and Dr Barry Drust for their efforts in examining the thesis.

INTRODUCTION

2.1. Aims of the Thesis

The studies presented in the present thesis evaluate the effects of novel approaches to training for rugby union football. These included methods for metabolic conditioning, strength training, power training and coordination training. Each training mode was designed to incorporate elements of specificity for the sport.

Recent evidence suggests that it is not safe to generalise from data reported from non-athletes with regard to the training responses and optimal training parameters of elite athletes. Training practices that prove to be successful in non-athlete subjects may not necessarily be effective in elite athletes. It is therefore vital that prospective studies are undertaken to gather data directly regarding the specific training responses of elite athletes.

Imposing a control group will always be problematic in the context of professional team sports. Individual athletes typically train in small groups with different coaches so are well used to undertaking different training to their peers. Within a squad of players this is not the case. Unsurprising therefore that there is far more published data from individual event athletes. There is a real lack of published prospective studies assessing training responses of team sports athletes, certainly at elite level.

Three studies in the thesis feature a single experimental group of elite senior and academy professional players. These studies do not presume to provide a definitive answer on the best way of training these players. In the absence of a control training group, there is no basis to conclude the modes of training are superior to conventional training. That said, there is similarly an absence in data regarding responses to conventional training in these athletes. What the studies concerned do is provide data regarding the training responses of elite-level professional players, which does not currently exist. Whether or not these responses were inferior or superior to other forms of training is a topic for future investigations.

This section represents an outline of general principles of specificity in relation to testing and training. Brief examples of the ways in which specificity is manifested are given. A more detailed examination of specificity considerations for metabolic conditioning, strength development and power training will be given in the introductions to the respective sections.

2.2. Principles of Specificity

Training responses are specific to the metabolic, muscular and movement demands of the training activity. Adaptations elicited by training are typically exclusive to the physiological capacities that are directly related to coping with the specific exercise stress (Millet et al, 2002). As a consequence, metabolic and neuromuscular elements that are not directly implicated in the training stimulus are generally unaffected. Physiological adaptations observed following training are accordingly restricted primarily to the muscle groups trained (Kraemer et al, 2002). Likewise upper-body and lower-body strength and power scores are not strongly related in elite team sports athletes with extensive whole body strength and power training experience (Baker & Nance, 1999a).

2.3. Specificity of Testing

Following a period of training the greatest degree of improvement is registered with the test modality that most closely matches the training movement (Morrissey et al, 1995). Isokinetic (constant limb velocity) strength gains following training are found not to be reflected by isoinertial (constant external load) strength tests. Conversely, strength gains following isoinertial training may not be expressed during isokinetic, or indeed isometric strength testing (Abernethy et al, 1995). It follows that testing must be specific to the movement patterns and velocity used in training in order to be sensitive to training-induced changes in muscle function.

Testing must also be specific to functional performance of the athletic activity the athlete is training for (Murphy & Wilson, 1997). Fundamentally, training is aimed at improving functional performance. Tests of muscle function used to evaluate the success of training often bear no relation to changes in functional performance (Murphy & Wilson, 1997). In a study by Murphy and Wilson (1997) isokinetic knee extension tests and dynamic isointertial squat jump scores registered no change despite concurrent improvements in maximum strength and sprint performance. These tests were therefore neither sensitive to the strength training modality or the functional performance it was designed to improve (Murphy & Wilson, 1997). Similarly when tests are used to discriminate between players of different ability, the most game specific test tends to be the one that is given greatest credence. In basketball, the vertical jump test is shown to have the most consistent influence on playing time given to players of any athletic performance test (Hoffman et al, 1996). Specifically, superior performance on this test was positively associated with selection, resulting in greater amount of time on court for better performers. This is a reflection of the specificity and hence relevance to basketball performance of vertical jump testing.

Test specificity also relates to the conditions under which tests of muscle function are measured. Impulse and Rate of Force Development are both highly related to speed-strength performance (Newton & Kraemer, 1994). However, when these factors are measured in static conditions using an isometric testing modality, they show no correlation to dynamic speed-strength performance (vertical jump height and work output) (Baker et al, 1994). This isometric measure of RFD likewise shows no change in response to either ballistic, plyometric, or strength-oriented lower body training, despite concurrent changes in measures of dynamic athletic performance (Wilson et al, 1993). Concentric RFD measured under isoinertial conditions (jump squat) appears to bear more relation to dynamic performance (Wilson et al, 1995). The concentric measure of RFD was shown to be capable of discriminating between good and poor performers on a sprint test, whereas the isometric RFD test was not.

2.4. Specificity of Training

The amount of muscle mass involved and overall exercise intensity dictate whether training responses are limited to peripheral adaptations, or if central cardiovascular changes take place (Millet et al, 2002). Metabolic specificity of training adaptations also applies to the bioenergetics of the training activity. Training adaptations are specific to the energy systems utilised during training. Adaptations following purely anaerobic training are mainly restricted to increased anaerobic enzyme activity. Conversely continuous submaximal aerobic training is reflected in improved oxidative enzymes, whilst the anaerobic enzyme profile remains largely unchanged (Wilmore & Costill, 1999c). Depending on the format, interval training may stress both aerobic and anaerobic systems (Tabata et al 1997). This training format can thus exhibit a combined training response, with adaptations in both aerobic and anaerobic performance measures (Gaiga & Docherty, 1995, Tabata et al, 1996).

Adaptations to endurance training are largely independent of strength and power training responses. The contrasting physiological and endocrine responses to each training stimulus may in fact lead to interference effects with performance of the respective training (Leveritt & Abernethy, 1999). Concurrent specific endurance training can be incompatible with strength- and power-oriented training. A preceding bout of endurance exercise may compromise the ability to perform strength and power training (Leveritt & Abernethy, 1999). These short-term interference effects may result in compromised training responses. Development of anaerobic power appears to be particularly sensitive to interference effects associated with concurrent endurance training (Kraemer et al, 1995).

Exercise-type specificity dictates that greatest improvements in dynamic strength are seen with dynamic training. Conversely, there is a trend towards greater isometric strength improvement in response to isometric rather than dynamic strength training (Morrissey et al, 1995). Strength training effects are similarly specific to muscle contraction type (concentric, eccentric, isometric) (Behm, 1995). Consequently, superior strength adaptations are observed in the particular mode of contraction featured in training (Morrissey et al, 1995).

Biomechanical specificity concerns both joint angles and range of motion (Stone et al, 2000). This is applicable both to dynamic and isometric training, with superior strength gains observed within the range of motion and at the joint angles featured in training (Morrissey et al, 1995). Velocity specificity is exemplified by the tendency for strength gains to be restricted to the velocities at which the muscles were trained (Morrissey et al, 1995). There is some evidence that there is a greater degree of velocity specificity in training responses at higher velocity regions of the force/velocity curve (Morrissey et al, 1995).

Mechanical specificity also extends to structural elements, such as posture and limb position (Baker et al, 1994, Stone et al, 2003b). Open versus closed kinetic chain describes whether the distal portion of a limb is free moving or fixed during the training movement (Potach & Borden, 2000). Open kinetic chain exercises tend to feature single joint articulation, whereas closed kinetic chain training movements are typically multiple joint (Stone et al, 2000). Greatest strength responses are manifested during closed kinetic chain movements following closed kinetic chain training, whereas the opposite applies to open kinetic chain exercises (Stone, 2000).

Mechanical specificity of testing is also evident in the relationship between unilateral and bilateral strength measures. The decisive factor is whether force production during training is unilateral (single limb) or bilateral (both limbs simultaneously) (Newton & Kraemer, 1994). Untrained individuals exhibit bilateral deficit so that maximum force during bilateral contractions is relatively less than the sum of forces for each limb working individually (Enoka, 1997). Differential motor unit activation is exhibited under bilateral and unilateral test conditions for the same test movement following bilateral squat training, which is reflected in greater bilateral force output (Baker et al, 1994). Consequently whether trained subjects exhibit bilateral deficit or facilitation depends on the conditions of force production during training. Specifically, cyclists who alternately exert force with each leg during training and competition exhibit greater overall strength when single-leg press scores are summed in comparison to their bilateral leg press score (Newton & Kraemer, 1994). Conversely, athletes for whom training is bilateral can exhibit bilateral facilitation. Hence, rowers' bilateral leg press scores are greater than the sum of their single leg press scores (Newton & Kraemer, 1994). Fatigue effects also appear to observe similar specificity characteristics in terms of unilateral versus bilateral force production. Subjects are shown to be more resistant to fatigue under bilateral conditions following bilateral training, which is not reflected under unilateral conditions (Enoka, 1997). The inverse applies following unilateral training.

2.5. Transfer of Training Effect

The degree of carry-over of training to competition is described in terms of transfer of training effect. Determining factors are the levels of mechanical and bioenergetic specificity of training in relation to competition. The probability of transfer to athletic performance is highly dependent on the degree to which training replicates athletic performance (Stone et al, 2000).

Conditioning responses observe exercise mode specificity. The running and cycling training completed by elite triathletes are thus unrelated to their swim performance (Millet et al, 2002). This is reinforced by observations that improved performance measured via a swimming test mode following swim training was not reflected in scores on a treadmill test (Magel et al, 1975). In trained non-athletes, cross training (swimming) is likewise shown to be inferior to running training in improving running performance parameters, particularly running velocity at a reference blood lactate (4mM) threshold (Foster et al, 1997).

Strength training adaptations similarly exhibit mechanical specificity. These considerations include direction and range of movement, type of muscle contraction, dynamics of the movement in terms of velocity and acceleration profiles, and the rate and duration of force development (Stone et al, 2000). In terms of structural characteristics, closed kinetic chain exercises transfer more readily to athletic performance measures as they typically feature multi-joint movements. Closed kinetic chain free weights exercises also incorporate force transmission from the ground upwards, which again more closely resembles what occurs during athletic movements (Stone et al, 2000).

Theoretically, from a kinetic and kinematic specificity viewpoint, the most functional form of training is to perform the actual movement(s) of the sport (Siff, 2002). However, this neglects the requisite element of overload to elicit a training response and ultimately improve performance. The solution would appear to be training modes that replicate the movement patterns of the sport to account for biomechanical specificity – but also incorporate the element of overload.

2.6. Specificity of Psychological Aspects During Training

Functional training describes the practice of imposing the requirements and constraints of performance during training to enhance transfer, in accordance with the principles of training specificity (Ives & Shelley, 2003). Physiological capabilities are manifested in a sports setting as part of co-ordinated and skilled movements during competition. A key consideration therefore is the context in which physiological training is performed (Siff, 2002). It follows that strength, power, and metabolic conditioning should therefore be trained in a manner that replicates not only sports movements but also psychological aspects of performance conditions. By extension of the functional training construct, cognitive and perceptual elements of performance conditions should also be accounted for in training (Ives & Shelley, 2003). In doing so, it is hypothesised that transfer of training effects may be enhanced.

The principles of specificity therefore also apply to psychological aspects. Three crucial interrelated components that are identified as influencing training responses are mental effort, attention and intention (Ives & Shelley, 2003). There is preliminary evidence that incorporating practice-related cognitive strategies to account for these elements in physiological training leads to greater carry over of training effects to sports performance (Ives & Shelley, 2003).

It has been shown that directed mental effort has the potential to directly affect the magnitude of training response. Conscious effort to exert maximal force has been found to significantly influence gains in strength and power. Greater gains in strength are manifested when subjects are specifically instructed to focus on maximally accelerating the barbell for every repetition, in comparison to when subjects are left to lift without specific instruction (Jones et al, 1999).

For athletes in team sports in particular, physical and mental capabilities are irrevocably linked. Attention is a key factor in perception-action coupling and superior decision-making of elite performers. Elite athletes attend to relevant cues from the competition environment and process them better as the basis for their movement responses (Ives & Shelley, 2003). During training and practices attention is also crucial to anticipatory responses and associated postural and motor control. The athlete's locus of attention, in terms of whether it is externally or internally focussed, similarly impacts upon motor learning and performance (Ives & Shelley, 2003).

Intent is integral to neural factors associated with adaptations in high-velocity strength and rate of force development (Behm & Sale, 1993). Ballistic contractions are part pre-programmed by higher motor control centres, which includes a pre-movement silent period in agonist motor units in preparation for maximal recruitment (Behm, 1995). As a result, motor unit recruitment and firing patterns associated with ballistic training are in part dictated by what is anticipated prior to the movement (Behm, 1995). Resulting physiological adaptations are therefore specific to and partially determined by the intention and corresponding neuromuscular patterns during training (Ives & Shelley, 2003). Improvements in rate of force development typically associated with ballistic training can thus be manifested under static training conditions if the subject's intent during training is to lift the static resistance explosively (Behm & Sale, 1993).

Functional training therefore not only aims to account for mechanical and metabolic specificity, but also create a training environment that features sufficient sport-specific constraints to appropriately shape training movement responses. It is suggested this approach may encourage more adaptive learning and likewise develop decision making (Ives & Shelley, 2003). Conversely, excessively restricting training either by mechanically fixing the planes and range of movement or through overtly prescriptive coaching intervention will tend to discourage development of directed mental effort, task specific attention, and sport-specific intent (Handford et al, 1997). Conducting physiological training in isolation of the athletic performance the athlete is training for may similarly hinder transfer of training effects (Ives & Shelley, 2003).

2.7. Specificity of Training in Relation to Training Experience and Athletic Status

The extent to which specificity principles apply appears to vary according to the initial training status and degree of training experience of the individual. In untrained individuals, training specificity does not exert the same degree of influence. This is illustrated by the lack of training mode specificity in untrained subjects' endurance training responses (Millet et al, 2002). Untrained and recreationally trained individuals show transfer of endurance training responses to other exercise modes that do not occur in elite athletes. What limited cross training effects have been observed in athletes fall far short of the performance improvement elicited by mode-specific training (Millet et al, 2002).

Similarly in the field of strength training, almost any training represents a novel stimulus to the untrained neuromuscular system. In untrained individuals an array of training effects are demonstrable, regardless of the nature of the training (Newton & Kraemer, 1994). As a consequence, a variety of training interventions will produce favourable adaptations in a given aspect of neuromuscular performance with untrained individuals (Newton et al, 1999, Kraemer et al, 2002). This again is not the case in advanced lifters and elite athletes.

It is recognised that skill level and training experience influence the training parameters that will be effective in developing athletic performance (Cronin et al, 2001). With increased training experience and progression in training status, exercise selection must be increasingly specific to elicit the desired response to train a particular property of the neuromuscular system (Newton & Kraemer, 1994, Stone et al, 2003a).

There is increasing evidence that the dose-response relationships with regard to volume, frequency and intensity of strength training are specific to the level of training experience and athletic status of the individual (Rhea et al, 2003, Paterson et al, 2004). The optimal strength training prescriptions identified from meta-analyses of the respective strength training studies employing untrained, recreationally trained and athletic subjects differ markedly on all three of these training variables (Paterson et al, 2004). The trends in each training parameter between groups appear to form a continuum of optimal levels of volume, frequency, and intensity with progression in training experience and athletic status.

In conclusion, specificity principles appear to have greatest relevance and application to elite athletes. The implications of this is that there is a corresponding need to gather data pertaining to the specific training responses of athletes on the basis that they do appear to be a special population. It is recognised that some compromise with regard to experimental design may be necessary to achieve this aim.

METABOLIC CONDITIONING

3.1. Overview

The metabolic conditioning and resulting physical performance capacity of a team sports player serves a crucial role in defining and ultimately limiting their contribution to the game (Helgerud et al, 2001). It is reported that measures of fitness in team sports players are significantly related to distance covered in a game and the number of high-intensity efforts they attempt (Reilly, 1994). Level of fitness is also a critical factor in determining a player's ability to fulfil the specific demands imposed by the playing position. The capacity of players to retain their ability to perform bursts of high-intensity exertion is often crucial in deciding the result of a match (Reilly, 1997, Drust et el, 1998).

It is acknowledged that sport-specific conditioning modes that replicate and overload physiological and kinematic conditions encountered during athletic performance are most effective for preparing athletes for competition (Deutsch et al, 1998). To satisfy training specificity, the format of conditioning for team sports players should aim to impose proportionate stresses on metabolic and physiological systems corresponding to those typically experienced during match-play (Taylor, 2004).

3.1.1. Metabolic Conditioning for Multiple Sprint Sports

Characteristically, physical exertion during team sports is of an intermittent nature, comprising sprints or phases of high-intensity effort. These bouts of intense activity are interspersed with periods of variable duration engaged in lower intensity locomotion, during which active recovery can take place. Metabolic demands thus alternate between energy provision for bouts of high-intensity work, and replenishing energy sources and restoring homeostasis during the intervals in between (Balsom et al, 1992).

A study examining rugby has previously identified five hundred and sixty discrete activities during a seventy-minute age-grade match, affirming the intermittent nature of match play activity in rugby union football (Deutsch et al, 1998). Intermittent running performed under controlled conditions on a treadmill is associated with greater physiological strain (reflected in higher ratings of perceived exertion and ventilatory responses) than exercise of the same average intensity performed continuously (Drust et al, 2000). This would necessitate a greater relative contribution of anaerobic metabolism to energy provision.

A key aspect of metabolic conditioning is developing 'anaerobic capacity'. Developing this parameter of athletic performance is a primary objective of conditioning for team sports in order to ensure players are able to sustain power output and sprint performance for the duration of playing time. The ability to perform intermittent maximal intensity efforts is largely dependent on the relative capacity to recover from the prior work bouts (Balsom et al, 1992). Peripheral adaptations that support this include lactate handling, acid/base buffering, and high-energy phosphate (phosphocreatine and ATP) resynthesis (Balsom et al, 1992, Bell et al, 1997).

Anaerobic capacity can be functionally assessed by the player's ability to sustain repeated high intensity bouts of exertion with given rest intervals. A 'fatigue index' score is generally used to measure this parameter, expressed as percentage drop-off in sprint times or power output with progression of a fixed number of intervals (Quarrie et al, 1995). Despite the importance of this capability, it has been highlighted recently that there is a lack of data pertaining to this capacity in team sports players in general and rugby football players in particular, especially at elite level (Duthie et al, 2003).

It has been shown that a conditioning stimulus needs to exceed a threshold intensity in order to have a measurable effect on anaerobic capacity, despite marked concurrent improvements in measures of aerobic performance (Tabata et al, 1996). This is most often achieved via an intermittent or interval framework, whereby high-intensity phases are interspersed with active or passive rest periods.

It has been suggested previously for rugby union football that the role of aerobic metabolism is limited to rest periods during stoppages between periods of activity. Some authors have inferred that aerobic fitness is of lesser relative importance based upon the comparatively lower aerobic power scores reported for rugby union players (Duthie et al, 2003). However, repeated sprint exercise features a significant aerobic contribution to energy production. Aerobic sources contribute a major portion of the energy during subsequent sets following the first sprint, increasing from 31% in the first 30-s sprint in a set to almost 50% in the second, even with four minutes recovery between sprints (Bogdanis et al, 1996). This appears to offset losses in power output resulting from reduced capacity for anaerobic energy production. A relationship has been identified between oxidative capacity of muscle and ability to resynthesise phosphocreatine (PCr), which is the key energy source for brief maximal efforts (Bogdanis et al, 1996). This is reinforced by the observation a measure of aerobic endurance, specifically running velocity at a reference lactate threshold value (typically 4mM blood lactate), shows strong relationships to PCr resynthesis. This in turn is manifested in recovery of power output during the early portion of consecutive sprints observed in recreationally trained subjects. Accordingly, PCr resynthesis capabilities can be improved by endurance training (Bogdanis et al, 1996).

3.1.2. Format of Metabolic Conditioning for Repeated Sprint Performance

Investigations of interval (multiple sprint) training protocols have found aerobic and anaerobic systems are taxed to a different relative extent depending on the length of sprint and recovery phases employed (Tabata et al, 1997). Appropriate recovery interval length is that which provides sufficient physiological stimulus to develop aerobic-anaerobic endurance whilst avoiding accumulation of excessive lactate and compromised work output (Vuorimaa & Karvonen, 1988). Training of this type elevates the relative exercise intensity the athlete is able to sustain for extended periods. This parameter is typically measured in terms of running velocity at a reference threshold value of blood lactate (Jones & Carter, 2000). Training can develop this component independently of changes in aerobic power (VO_2 max). These specific adaptations are attributed to peripheral adaptations associated with improvements in lactate handling (Jones & Carter, 2000). In addition, continuous or intermittent exercise at threshold intensity is shown to be similarly effective in developing this measure of endurance fitness (Jones & Carter, 2000). The relative work output an athlete can sustain may be more relevant to endurance for intermittent team sports such as rugby football than absolute aerobic power, which may explain the relatively modest VO_2max scores of rugby football players. Indeed VO_2max was shown to be unrelated to metabolic recovery measures during an intermittent exercise bout in endurance trained athletes (Bell et al, 1997).

It has been identified that an appropriately structured intermittent high-intensity exercise protocol may have the potential to simultaneously stress both aerobic and anaerobic systems almost maximally (Tabata et al 1997). Accordingly high-intensity interval exercise has been shown to elicit significant concurrent improvement in both aerobic power (VO_2max) and a selection of anaerobic capacity and intermittent exercise performance measures (Gaiga & Docherty, 1995, Tabata et al, 1996).

Exercise economy is identified as a key component of endurance fitness (Jones & Carter, 2000). Improvements in the efficiency of locomotion and movement during athletic performance can therefore influence endurance levels during competition conditions. Neuromuscular control and motor patterns used in training are therefore of crucial importance. This may partly account for the exercise mode-specific effects observed with endurance training. In runners improvements in exercise economy are observed to be greatest at the running velocity at which the athlete habitually trains (Jones & Carter, 2000). It follows that metabolic conditioning for team sports athletes should similarly replicate patterns of locomotion and movements encountered during matches to develop this exercise economy component of endurance. Improvements in movement efficiency are particularly key for the unorthodox forms of locomotion performed during games (Reilly, 1994).

Accordingly, high-intensity intermittent training is shown to improve cardiorespiratory fitness parameters and measures of performance in team sports athletes. (Helgerud et al, 2001). Increases in aerobic power, lactate threshold and running economy observed in junior elite soccer players following training were manifested in concurrent improvements in performance measures. Significant increases were observed in distance covered in a match, average work intensity in both halves of play, number of sprints and frequency of involvement in play (Helgerud et al, 2001).

3.1.3. Special Endurance Approach to Metabolic Conditioning

The 'special endurance' training format models training upon workloads and activity profiles observed during competition (Plisk & Gambetta, 1997, Plisk, 2000). These methods give recognition to the interrelationship between energy systems during competition. Energy systems are thus trained in combination, according to the bioenergetics of competition. In the case of intermittent activity sports, the effort distribution upon which conditioning is modelled is defined in terms of work:rest ratios observed from match play (Plisk, 2000). This has been termed 'tactical modelling' (Plisk & Gambetta, 1997).

Proposed advantages of this conditioning format include greater time efficiency, as skill practice is incorporated into metabolic conditioning (Plisk & Gambetta, 1997). This is favourable from a coaching point of view in the sense that game-related skills are executed in simulated game conditions. The game-oriented nature of this is also postulated to be advantageous in that it is likely to engender greater motivation and enhanced training compliance among athletes (Plisk & Gambetta, 1997).

The special conditioning approach for team sports was originally developed in American football. This sport is highly structured with the ball only being live for brief periods until the player in possession of the ball is tackled or the ball goes out of play, at which time there are extended stoppages until play restarts. Application of this format to more continuous team sports featuring more variable patterns of activity, such as rugby football, may be more problematic.

3.1.4. Physiological Characteristics of Team Sports Athletes

Evaluation of physiological profiles of elite athletes has become an established area of study as a means to infer the physiological demands that are characteristic of the particular sport. Scores on batteries of anthropometric, physiological, and performance tests have been used to detail physical performance characteristics of match-play, notably in soccer (Bangsbo, 1998, Reilly et al, 2000) and indeed rugby union (Quarrie et al, 1995, Quarrie et al, 1996). The rationale for this approach is that players must possess certain physical capacities to compete at elite level. This practice similarly works on the assumption that athletes will have undergone specific adaptations in response to the rigours and physiological stimuli provided by match-play, and these will be manifested particularly in elite level players. However, it has been shown that typical physiological performance test measures give little indication of capacity to perform repetitive sprint exercise (a key aspect of match-play) in an endurance trained population (Bell et al, 1997). Anthropometric and physiological test profiling can thus offer only limited insight into the energetic demands associated with competition; mainly highlighting trends associated with player position groupings (within large inter-individual variation) and differences between playing levels on particular parameters.

One key effect highlighted by these studies is the greater insight offered by more game-specific (generally field-based) tests. This is evidenced by the observation that the relative performance of individual positional groups in teams sports can differ as a consequence of the protocol used, which in turn is influenced by whether the test is conducted on a treadmill or in the field. For example, in a report of professional soccer players in Denmark (Bangsbo, 1998), central defenders exhibited significantly better performance than strikers in an intermittent field test incorporating game activities (utility movements, turns, accelerations and decelerations). The direct opposite outcome was observed when the same groups undertook a continuous treadmill test at a fixed blood lactate concentration, with the central defenders scoring significantly worse than the strikers (Bangsbo, 1998). This effect emphasises the importance of specificity of testing when assessing performance capacity in team sports players. However, as stated by Bangsbo (1998) and Reilly et al (2000), the multifactorial requirements entailed by match-play in team sports such as soccer and rugby football means that no single measure gives an accurate representation of physical performance demands associated with competition.

Simulations of match-play activities performed in series are similarly limited in terms of the insight they can offer. As with all physiological performance tests, there is inevitably a trade-off between imposing controlled test conditions and accurately replicating exertion levels and activity profiles performed in competition. Treadmill simulations have been devised for intermittent team sports such as soccer (Drust et al, 2000). However, protocols of this type necessarily exclude 'utility' locomotive movements (lateral and backwards running) and game-related activities, both of which are key elements of match play. Similar restrictions imposed by the test apparatus preclude such tests from replicating the frequency of transitions between discrete activities observed during competition. These again represent a fundamental aspect of match-play exertion. Such omissions limit the insight offered by such studies into performance conditions encountered during competitive matches (Drust et al, 2000).

Field tests incorporating game activities may provide a means to measure the specific ability of players in different positions in the team or different playing standards to perform match-specific fitness drills. However, they do not offer any quantitative insight into the physiological demands of competition per se.

3.1.5. Evaluating Bioenergetics of Team Sports during Competition

Attempts to quantify demands of team sports as a basis upon which to model sport-specific conditioning practices frequently feature time-motion based analysis of players' movements during match play. Distance covered during the course of a match is commonly used as a global measure of energy expenditure and physiological demand (Reilly, 1994). However, it is notoriously difficult to evaluate physiological stresses associated with intermittent sports by such indirect estimation.

Time-motion analysis does provide a means to document the types of activity players engage in during a match (Duthie et al, 2003). However, intermittent sports have been shown to have energetic demands far in excess of those that would be predicted from covering the same distance continuously (Drust et al

2000). The frequent changes in direction and velocity of movement that are characteristic of intermittent sports require inertia to be repeatedly overcome. These repeated accelerations and decelerations represent added metabolic demands placed on the player (Wilkins et al, 1991). Effectively, the patterns of transitions between movement phases are of similar importance to the individual component activities themselves.

Time-motion studies show that unorthodox (sideways and backwards) modes of locomotion feature prominently in team sports, with certain playing positions having a particular emphasis on these modes of locomotion (Reilly, 1994, Rienzi et al, 1999, Duthie et al, 2003). These movements involve energy demands in excess of conventional running (Reilly, 1997). This added physiological cost rises disproportionately with increases in speed of movement (Reilly, 1994). Game-related activities similarly impose considerably higher energy expenditure than running (Reilly, 1994, Reilly, 1997). Both of these factors compound the underestimation of physiological cost of match play for team sports from indirect observation and time-motion analysis.

It follows that accurate assessment of exertion levels requires players to be directly monitored during game-play. Estimations based on individual component activities in isolation will significantly underestimate physiological stresses imposed on players, and thereby give a false indication of the metabolic pathways implicated in real game situations.

The consensus is that assessment of energetic demands in team sports must feature sampling of markers of physiological stress under performance conditions (Reilly, 1994, Reilly, 1997, Duthie et al, 2003). There have been numerous attempts to analyse activity patterns by some form of direct monitoring in a range of team sports, including basketball (McInnes et al, 1995), field hockey (Boyle et al, 1994), ice hockey (Green et al, 1976), football (Ali & Farrally, 1991, Bangsbo et al, 1991), and netball (Woolford & Angove, 1991). As a consequence of the methodological issues and impracticality of sampling expired air to assess energy expenditure directly studies typically use heart rate (HR) or blood lactate concentration [BLa] as the physiological marker (Reilly, 1994). Despite technological advances, gas analysis apparatus will inevitably restrict players' movements and interfere with match play, and certainly would not be safe for contact sports such as rugby football.

McInnes et al (1995) examined physiological responses during match-play in basketball, observed through continuous recording of heart rate and discrete sampling of blood lactate. This was accompanied by time-motion analysis of video recordings to discern players' movement patterns. A large number of discrete movements were identified, typically lasting less than three seconds. Elevated HR and [BLa] values were observed, despite the fact that only 15% of total 'live time' was spent in activities classified as 'high-intensity'. This emphasises the additional physiological cost demanded by changes in velocity and direction of movement involved in transitions between activities and phases of game-play.

Studies of this type have reported significant differences in relative time spent in different modes of activity and work-rate patterns between different positions in a team. This has been identified as being the case in sports as diverse as ice hockey (Green et al, 1976), soccer (Ali & Farrally, 1991, Bangsbo et al, 1991) and netball (Woolford & Angove, 1991). Monitoring HR has also allowed investigators to cross-reference patterns of training intensities with exertion profiles obtained from game situations in a variety of team sports. Recent studies of this type have often concluded that team conditioning sessions should take more account of the observed differences in positional demands. Hence, it has frequently been recommended that the structure of metabolic conditioning should allocate different emphasis appropriate to each player position grouping (Defence/Midfield/Attack). In effect, this consideration is merely a logical extension of sport specific conditioning, and the replication (and overload) of 'physiological performance conditions' (Deutsch et al, 1998) for each player.

The validity of the use of blood lactate [BLa] as the physiological indicator of exertion levels in intermittent team sports has been questioned by Bangsbo (1991) in his studies investigating top-level soccer in Scandinavia. Like rugby football, soccer is a team game of an intermittent nature, featuring a vast range of discrete game-related movements, and regular transitions between these activity phases. The main argument against [BLa] as an index of exertion levels during competitive matches, as stated by Bangsbo (1991), is the dynamic nature of lactate as a metabolite. Blood lactate levels are essentially determined by relative rates of production, release, uptake and removal. A consequence of this is that single blood samples merely give a snap-shot of the type of activity performed in the interval immediately prior to when the sample was taken. Concentrations of blood lactate are commonly used to indicate contribution of anaerobic glycolysis to energy production (Coutts et al, 2003). However, beyond establishing the role of anaerobic metabolism in match-play exertion, sporadic determination of BLa is of little value in profiling activity or intensity patterns across an entire match. Theoretically, serial measurements may better reflect shifts in intensity of exertion throughout a game, but the frequency of sampling required would be unfeasible during a competitive match.

In addition to the methodological issues outlined, the relevance of absolute BLa concentrations must be questioned. The highest workload that can be sustained without accumulation of [BLa] is termed Maximal Lactate Steady State (MLSS) (Billat et al, 2003). Classically, this has been taken to correspond to a lactate value of 4 $mmol.l^{-1}$. This 4 $mmol.l^{-1}$ concentration of BLa has traditionally been widely used to denote the onset of blood lactate accumulation (OBLA) (Wilmore & Costill, 1999). However, recently it has been documented that the actual concentration of BLa that corresponds to this MLSS workload varies widely between individuals, falling between a broad range of values between 2 $mmol.l^{-1}$ and 8 $mmol.l^{-1}$ (Billat et al, 2003). This 4 $mmol.l^{-1}$ OBLA value is thus an arbitrary figure, which bears little resemblance to the actual MLSS value of [BLa] for many individuals. Comparisons of absolute values of [BLa] sampled within and between studies would also appear spurious without the appropriate reference MLSS [BLa] values for subjects.

Assessments of the demands of game-play have thus tended to favour HR monitoring as the most reliable and practical indicator of physiological strain or energy expenditure (Boyle et al, 1994). This has frequently been coupled with notational analysis of accompanying match footage. The consensus in the literature is that the influence on match play HR of psychological stress is largely nullified under the conditions of moderate-high intensity activity employing large muscle mass experienced during intermittent team sports, such as rugby football (Bangsbo, 1994, McInnes et al, 1995). HR profiling is well established as an objective measure of physiological stress. Furthermore, relative HR has been used to indicate proportionate stresses on metabolic systems; threshold percentage HRmax or HR Reserve (deficit between HRmax and resting HR) (%HRR) values have been used as correlates for transitions between metabolic systems mobilised with increments in intensity level. Specifically, 75% HRmax has been taken to correspond to athletes' 'Lactate Threshold' (the point at which anaerobic glycolysis begins to make a significant contribution to energy provision), and 'Individual Anaerobic Threshold' (the point at which anaerobic metabolism becomes the dominant source of energy production) has been identified as occurring around 85%-92%HRmax (Woolford & Angove, 1991).

From these investigations it appears that intermittent team sports have certain energetic requirements in common. The unorthodox forms of locomotion, frequent transitions in direction, velocity and mode of movement, and demands involved in performing game-related activities lead to energetic requirements in excess of those associated with more orthodox running-type exertion covering the same amount of ground. Consequently, intermittent team sports players are required to operate at a high percentage of their HRmax for extended periods. Similarly, studies of field team sports tend to characterise 'off the ball' activity (representing the majority of game time) as being in the main aerobic, emphasising the importance of a strong aerobic base. Conversely, the more critical moments, which ultimately decide the outcome of the match, that involve bursts of pace to allow players to be available to cover or defend scoring opportunities and phases when directly involved in play, tend to be predominantly anaerobic (Reilly et al, 2000).

3.1.6. Quantifying Physiological Demands of Match Play in Rugby Football

The contact nature of the sport of rugby football has tended to preclude direct measurement of physiological responses during game play (Duthie et al, 2003). A consequence of this failure to objectively define the specific demands of match play in rugby union is that training specificity has frequently been neglected in the design of conditioning regimes for players at all levels.

Of the few studies focusing directly on the sport of rugby union, the dominant contemporary research has focused mainly on time-motion analysis from video footage, anthropometric assessment of players, and sporadic blood lactate measurement. The majority of the documented research on demands and characteristics of the top-level rugby union in the Northern Hemisphere predates the recent advent of professionalism in 1996 (Reid & Williams, 1974, Morton, 1978), which has brought widely reported changes in styles of play (Duthie et al, 2003). As a consequence of this progression there will likely have been significant changes in terms of associated demands on specific fitness components. This in turn limits the relevance of previous data and underlines the need for contemporary analysis of rugby union at elite level (Duthie et al, 2003).

Of these earlier studies, possibly one the major developments in terms of scientific study of rugby union have been the use of 'Work:Rest' ratios to express patterns of game intensities (McLean, 1992). McLean's time-motion analysis of edited footage from the 1988-89 Five Nations' tournament reported the majority of Work:Rest ratios as being between 1:1 and 1:1.9, of which 63% of the time rest intervals following periods of exertion were of longer duration than the work phase. The protocol used did not discriminate between playing position, or even individual players – the study merely monitored the activity of any player central to the action in the videotape footage at any given time. Consequently, as the author acknowledged, the findings presented may tend to misrepresent (specifically, overestimate) activity patterns for certain playing positions in the group sampled.

Another early study identified differences in type, intensity and relative frequency of match-play activities between two positional groupings within a rugby team. Docherty et al (1988) examined only two positions – Prop and Centre, chosen because of the obvious differences between their respective roles. Briefly, the prop's primary function is to compete for possession in set-pieces and at each tackle. The centre, on the other hand, is primarily concerned with defending the 'gain-line' in midfield and carrying the ball forward when his team are in possession. Accordingly, Docherty et al found that the props they assessed spent relatively more time in non-running (predominantly upper-body) exertion, whereas the centres were found to engage in more intense running. It should be reiterated however, that styles of play have changed considerably in the intervening decade, with a greater overlap in duties across forward and back positions. That said, more recent match analyses assessing age-grade players have reported that the forward positions still typically engage in significantly more (upper-body intensive) rucks and mauls than the backs positions they followed (Deutsch et al, 1998). This suggestion of differences in mode and intensity of activity between playing positions has potentially crucial consequences for team conditioning.

Both these earlier studies also reported blood lactate concentrations. McLean (1992) sampled blood lactates during extended stoppages in play in Scottish First Division matches, from which peak values of 5.8-9.8 $mmol.l^{-1}$ were recorded. This finding is at odds with the significantly lower levels of BLa (mean values 2.8 $mmol.l^{-1}$) taken from players competing in first division and representative matches by Docherty et al (1988). However, crucially there were significant differences in sampling procedures – specifically the times at which the samples were taken. McLean's blood lactate measurements were taken during matches, whereas Docherty et al merely collected samples 5-10 minutes after the end of matches. Hence, the figures reported by McLean (1992) would appear to reflect better the conditions experienced during competitive matches.

In recent years there have been renewed attempts to assess physiological demands of game-play in both codes of rugby. Brewer and Davis (1995) summarised the major findings of research into physiological demands in rugby league. These included a breakdown, by time-motion analysis, of mean distances covered and relative time spent in specific match play activities of four key positions on the team (Prop, Hooker, Half-back, and Wing) in matches between premier Australian rugby league sides. Also examined were modes of locomotion players engaged in during certain phases of the game, such as receiving a pass, making a tackle, taking a tackle. The authors identified that high-intensity upper and lower body exertion involved in sprinting and collision phases places significant demands on anaerobic metabolism, in addition to the more constant aerobic activity featured in the game. This is in broad agreement with findings from other field team sports. The authors concluded further research into the specific demands of match play was required, with particular reference to playing position (Brewer & Davis, 1995). It was noted that a fundamental rule change in 1994, requiring the defending side (with the exception of two 'markers') to retire ten metres from after each tackle is completed, represents a substantial demand in excess of the values reported in this review. However, the conclusion of the authors that the objective of conditioning should be to stress both aerobic and anaerobic endurance capacities whilst incorporating match play activities still has merit.

Coutts et al (2003) examined physiological responses in semi professional rugby league players after the advent of the 'ten metre defensive rule'. During a competitive match HR was sampled continuously and BLa samples taken. Energy expenditure was calculated from HR recorded, based on HR-VO_2 relationships determined from players' maximal treadmill test. There was no corresponding analysis of activity profiles of the players sampled. On the basis of average HR recorded and proportion of time spent in moderate and high-intensity HR zones, combined with the elevated [BLa] values sampled, the authors concluded that contemporary rugby league at semi professional level imposes significant demands on both aerobic and anaerobic metabolism. Elevated BLa concentrations were recorded, however samples were taken during stoppages in play following scores by either team. This was acknowledged to be a factor in the level of activity immediately preceding the sample, which could influence the result and hence may not be totally representative of general play. The HR data reported indicated greater time spent in high-intensity HR zones in comparison to those recorded previously for junior elite level players. This suggests that higher exercise intensity is encountered at higher levels of competition in rugby league. The high estimated energy expenditure observed in the study indicated greater metabolic demand in comparison to other field sports This was attributed to the larger body mass, combined with the added element of physical contact and associated upper body exertion featured in rugby league. Summarising their findings, the authors identified that the main objectives of conditioning for rugby league players should be enhancing endurance fitness and lactate tolerance.

There is, albeit limited, contemporary research in rugby union which has assessed both the seven-a-side and full fifteen-a-side game. Quarrie et al (1995, 1996) profiled anthropometric characteristics and physical performance test scores in 'senior A' club players in New Zealand. Significant differences were reported for height, weight and somatotype, as well as selected physical performance measures between the combined 'Forwards' and 'Backs' positions. Differences were also observed on certain measures between positional categories within these broad groups. However, as mentioned previously, observational studies of this type offer very little direct information about physiological demands of competition, particularly as comparisons were often made between combinations of positional groupings, to boost statistical significance. In a broadly similar study examining the seven-a-side game, Rienzi et al (1999) presented an analysis of anthropometric characteristics, this time coupled with time-motion data, assessing players competing in an international rugby 'Sevens' tournament. The authors went on to examine whether there was any correlation between players' scores and results in matches. Nothing approaching significance level was found.

A major recent advance was the collection of physiological responses and kinematic data in elite Australian 'Colts' (Under-19) rugby union matches by Deustch et al (1998). This was the first study of its kind to record heart rates of rugby union players during competitive matches and relate physiological responses to time-motion analysis. This work was facilitated by advances in monitoring technology, also aided by the growing trend in the use of under-kit protective padding. Considerable time was reported in the higher intensity %HRmax zones, which would appear to corroborate the significant contribution of anaerobic metabolism to match-play exertion. The times spent in moderate and high-intensity HR zones were broadly similar to those reported for semi-professional rugby league players (Coutts et al, 2003). Recorded blood lactate [BLa] values sampled periodically during extended stoppages in play were also comparable to those for rugby league (Coutts et al, 2003), and were similarly elevated to those reported by McLean (1992). This appears to verify that rugby union match-play exertion does indeed include a significant contribution from anaerobic glycolysis. The data also suggests that the low values of [BLa] reported by Docherty et al (1988) were indeed an artefact of the manner in which they were sampled (5-10 min post-match).

Importantly, Deutsch et al (1998) also differentiated by playing position in their analysis of players' data. The authors divided the forward positions into 'Front row' (Props and Locks) and 'Back-row' (Flankers and Number 8) categories, and backs into 'Inside backs' (Fly-half and Centres) and 'Outside backs' (Full-back and Wings). The breakdown by positional group highlighted the significant variation in frequency of high-intensity exertion across positions, expressed both in terms of relative time spent in higher intensity %HRmax zones and Work:Rest ratios derived from the respective position's activity profiles. Specifically, the time spent in the 'high-intensity' zone (85-95% HRmax) by the forward positions was significantly greater (Props & Locks 58.4%; Back-row 56.2%) than the corresponding values for the backs groupings (Inside backs 40.5%; Outside backs 33.9%). This suggests that forwards were required to work more continuously than the back positions in the matches recorded. Work:Rest ratios reported for the combined forwards (1:1.4) categories were significantly higher than that reported for the backs groupings (1:2.7). The magnitude of this difference was greater still when 'Back-row' and 'Outside backs' were compared (1:1.2 vs. 1:3.6). The other major positional difference identified was the greater time spent in utility (sideways and backwards) locomotion by the back positions.

The significant differences between positional categories suggest a need for more comprehensive, position-specific examination of patterns of exertion in match-play. Investigation coupling heart rate profiles recorded from players with notational analysis of accompanying game footage has the potential to elucidate the specific metabolic demands for different playing positions competing in contemporary rugby at elite level.

3.1.7. Attempts to Quantify Bioenergetic Demands Imposed Upon Elite Players

Pilot trials were undertaken for the present thesis in an attempt to evaluate physiological and kinematic demands employing a combination of heart rate telemetry and video analysis. A software program was written for the purpose. This logged the player and mode of activity, categorised as standing, walking, jogging, striding, sprinting, utility (sideways or backwards locomotion), upper body static and upper-body dynamic activity. Elapsed time engaged in activity could thereby be recorded alongside HR values for the period, taken from the player's HR trace. Pilot trials were undertaken for Under-21 matches and two senior preseason warm-up matches, sampling players in a variety of playing positions.

Ultimately these attempts proved to be undermined by methodological constraints, and the inherently variable nature of rugby union match play. Even given the technological advance allowing the HR telemetry apparatus to be integrated within a sensor strap, players remained reluctant to wear the monitoring equipment during competitive matches. Of those that did, some did so without any complaint but others found the kit uncomfortable and distracting. There were also reports of abrasions and bruising when they took contact around the sternum area where the sensor strap was worn, despite players wearing padding. Furthermore, the early data was so variable that it became apparent that it would take a massive number of games to be sampled for players in a range of positions to draw any definitive conclusions regarding specific demands of match play and how they vary according to playing position. On this basis this area of study was abandoned for the present thesis.

There are a myriad of factors that influence the pattern of play and hence nature, frequency, duration and density (with respect to time) of activities players are required to perform (Duthie et al, 2003). The strength and style of play of the opposition will inevitably be a major influence, both in terms of the opposition's game plan when in possession and the tactics employed against them. For example, if they favour a kicking game, the time during which the ball is in play will be less and passages of play in defence will be shorter than against a team who keeps possession and looks to keep the ball in play. These considerations will similarly be affected by the officiating styles and environmental conditions (Duthie et al, 2003). As a consequence of the highly technical nature of rugby union, the referee has a major bearing on the format the game takes in terms of number of stoppages and duration of phases of play. Similarly, environmental conditions will influence tactics and the errors committed by both sides, which will in turn influence the pattern and mode of activity players will be engaged in. Thus, there is significant variation not only within a match but also between consecutive games (Duthie et al, 2003).

Notwithstanding the difficulties outlined in gathering data pertaining to the global demands of match play as they relate to a team, individual roles of particular playing positions within a team are also quite diverse (Duthie et al, 2003). In addition, as rugby union teams become more structured in terms of the game plan they employ, individual positions are given more defined roles for each aspect of attacking and defensive play. Precise roles of the respective playing positions therefore vary between teams, depending on their particular structured game plan, and associated roles allocated to players in different positions.

A significant volume of data would therefore appear to be required to overcome the inherent variability within and between games to establish an accurate assessment of demands during competition that are representative for a particular team. This demand is multiplied several fold if the aim is to gather a complete picture of the associated demands for individual playing positions within that team. In the absence of such data, alternative methods of sport-specific conditioning for rugby union football must be explored.

3.1.8. A Novel Conditioning Format for Elite-level Rugby Union Football

As outlined there are significant methodological issues that compound the inherent difficulty in collecting data upon which to quantify demands of elite-level rugby union. The complexities and inherent variability of the sport renders efforts to design conditioning drills to simulate match conditions all the more difficult (Gabbett, 2002). Aside from these considerations, Dave Reddin (English Rugby Football Union Strength & Conditioning Head Coach) expressed his position that it would not be sufficient to simulate match play demands (personal communication). Rather, to improve metabolic conditioning levels of players, overload would be required in terms of intensity, frequency, duration and density of specific activities demanded in match play.

An effective alternative conditioning format would provide appropriate overload by operating at the extremes of frequency, duration and intensity of activity levels a player could expect to experience during a competitive match. A possible solution is the skill-based conditioning games approach. This training format has been used to simulate the various game-related movements and intermittent nature of rugby league with some success (Gabbett, 2002). In addition, this form of metabolic conditioning is associated with lower injury incidence rates, in comparison to other forms of training. The reduced injury rates reported when engaged in skill-based conditioning games was in contrast to traditional conditioning without any skill element, which featured by the far the highest incidence of injury (Gabbett, 2002). The application of this approach to metabolic conditioning is to be determined for elite level rugby union football.

A Skill-based Conditioning Games Approach to Metabolic Conditioning for Elite Rugby Football Players

3.2.1. Introduction

Over the past twenty years, sport scientists have reached consensus that the most effective mode of training to prepare an athlete for competition is that which most closely replicates competitive performance conditions (Daniels, 2001, Durstine & Davis, 2001, Wilmore & Costill, 1999). Sport-specific conditioning methods that incorporate skills and movements specific to the sport are increasingly implemented, with the aim of simulating the movement patterns and metabolic conditions encountered during competition (Lawson, 2001, Meir et al, 2001). An extension of this is the Tactical Metabolic Training (TMT) format, which comprises performing set plays modelled upon match-play scenarios, coupled with work:rest ratios derived from tactical evaluation of real or 'ideal' match sequences (Plisk & Gambetta, 1997, Plisk, 2000). This is a corollary of the race-event training strategies employed in athletics, whereby series of target training paces are set, based on desired or achieved competition performance.

The TMT approach has typically only been applied to relatively structured team sports, notably American football (Plisk & Gambetta, 1997). Aside from the practical difficulties of implementing this approach in the more variable and continuous sport of rugby football, there is an absence of requisite data from elite-level competition. A further challenge for strength and conditioning coaches working with rugby football players is providing metabolic conditioning in the limited time allowed by the concurrent high volumes of team practices and other forms of training, particularly resistance training, players are required to complete.

A novel approach that encompasses both movement and context specificity and is highly time-efficient involves the use of skill-based conditioning games. These comprise purpose-designed games featuring modified playing areas and rules, which allow training intensity to be manipulated (Hoff et al, 2002, Jeffreys, 2004). Skill-based conditioning games are by definition less structured and conducted in a more open and random setting than the discrete drills, or simulated plays used under the tactical metabolic conditioning format. The skill and competition elements that are the key features of skill-based conditioning games are suggested to promote enhanced effort and greater compliance, which will in turn be manifested in increased training intensity (Gabbett, 2002, Jeffreys, 2004).

Training using such an inherently unstructured format as conditioning games requires some objective marker to evaluate the work rates of individual players. Heart rate (HR) monitoring is extensively used as the most effective and practical means to objectively monitor intensity during a training session (Potteiger & Evans, 1995), and quantify training loads in the athlete's weekly training log (Gilman & Wells, 1993). HR monitoring therefore would appear a crucial adjunct to the skill-based conditioning games approach, as a tool to quantify intensity in the conditioning game setting. In addition, HR monitoring offers a basis to assess cardiorespiratory fitness, via measurement of cardiorespiratory responses during and immediately following a standardised work bout (McConnell, 2001, Wilmore & Costill, 1999). Crucially, the use of HR to monitor exercise intensity has also been validated against direct measurement of ventilatory responses during small-sided conditioning games in soccer players (Hoff et al, 2002).

The latter study by Hoff et al (2002) concluded that small-sided games fulfilled the criteria to be an effective means of interval training for soccer players, on the basis of HR and respiratory responses directly recorded during training. However, to date no study has examined chronic cardiorespiratory adaptations associated with skill-based conditioning games. There are also no published data recording training responses of elite-level rugby union football players.

To assess the efficacy of skill-based conditioning methods in this group, the preseason metabolic conditioning for an elite-level professional rugby union team was undertaken exclusively in the form of continuous skill-based conditioning games. HR was recorded in all conditioning sessions for all players. Likewise, cardiorespiratory fitness was monitored via HR responses to a standardised interval work bout, assessed at weekly intervals throughout the nine weeks of preseason training.

3.2.2. Methods

Experimental Design

All subjects were part of a single experimental group. Dependent variables were percentage of HRmax elicited by a constant submaximal workload and percentage recovery score. These are both established markers used to track progressions in training status. The study design is based on the assumption that changes observed in dependent variables were due to the conditioning games intervention. This was deemed valid on the basis that this was the only form of metabolic conditioning undertaken and no matches were played in the period.

Subjects

Senior professional male rugby union players (n=35). All subjects represented the same English Premier league team, and included current and former international players from England and South Africa. Subject characteristics are presented in Table 3.2.1. All players were familiar with all conditioning games and testing procedures.

Table 3.2.1 – Subject Characteristics and Heart Rate Parameters

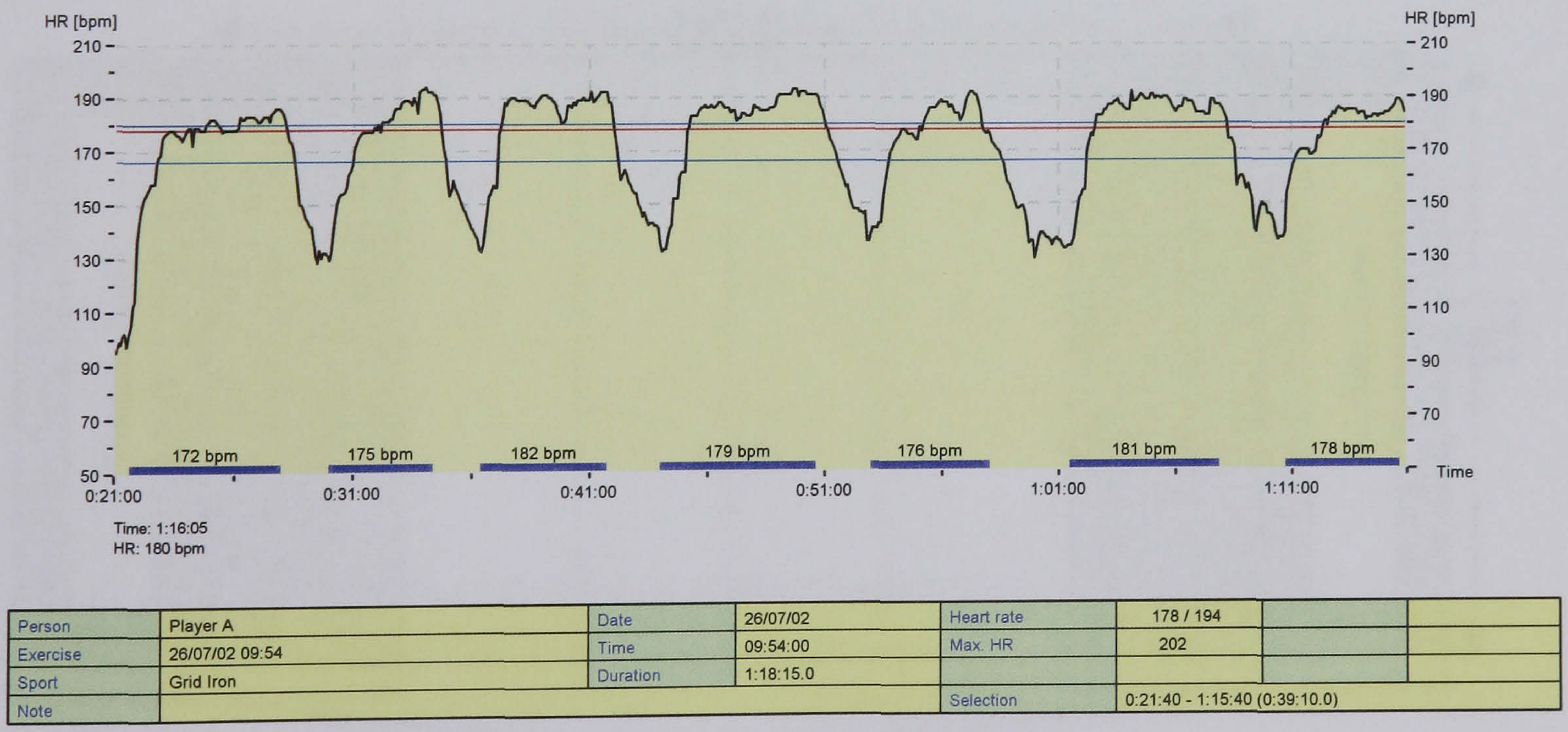
Variable	Mean	SD	Range
Age	27.6	4.2	20.4-36.2
Height	185.4	7.3	170-202
Body Mass	98.6	13.7	80-121
HRmax	190	9.6	174-212
Resting HR	50	6.4	40-65

Determination of HR Parameters

The majority of players (30 of the 35) had a database of HR files from the previous twelve months training. HRmax was taken as the highest HR recorded during any session in this period and the duration of the study in these players. New players' HRmax was taken as their individual peak HR registered in the nine weeks of preseason training. For determination of resting HR, monitors were fitted before the team meeting on conditioning days, and the minimum value from the resulting HR trace was noted. In this way resting HR was updated on a continual basis, on the occasion that a new minimum HR was recorded for a given player. From these parameters, heart rate reserve (HRR) for each player was calculated, as the deficit between the athlete's individual HRmax and resting HR (Holly & Shaffrath, 2001). From these, each player was assigned his individualised training zone (75-85% HRR), which was updated as necessary on an ongoing basis.

Monitoring Apparatus

The implementation of skill-based conditioning games was underpinned by the use of HR monitoring technology (Polar Team HR Monitoring System, Polar Electro, Kempele, Finland). This is a fully integrated one-piece model that can be used independently of a watch device, with HR files being stored and downloaded directly from the sensor strap. The HR trace for each conditioning session was downloaded, and the quality of the session was assessed based on the degree to which the player maintained his HR in his specific target zone (Figure 3.2.1). Printouts of each player's HR trace, with their individual HR parameters superimposed, were handed out in the following day's team meeting. Any additional feedback was given individually by the Head Coach, as required.



Person	Player A	Date	26/07/02	Heart rate	178 / 194		
Exercise	26/07/02 09:54	Time	09:54:00	Max. HR	202		
Sport	Grid Iron	Duration	1:18:15.0				
Note				Selection	0:21:40 - 1:15:40 (0:39:10.0)		

Figure 3.2.1. – Individual Player's Conditioning Game HR Trace

Conditioning Game Design

Conditioning games were derived from elements of Gridiron, netball, and soccer (playing area for the grid iron conditioning game is depicted in Figure 3.2.2). Penalties were imposed if players were not keeping up with play (i.e. within a designated area in the vicinity of the scoring zone when a score was made). Penalties included disallowing the score if the penalised player was on the scoring side, or awarding double scores if committed by opposition players. Alternatively, offending players were made to do conditioning drills or sprints, before rejoining play. Likewise, all players were punished with 'down-and-ups' (dropping to a prone position on the ground before rapidly returning to an upright stance to resume play) when unforced errors were committed. Periodically conditioning games were also filmed, and video analysis was undertaken for the session to generate performance stats for each player, specifically, the number of times each player touched the ball in each period of the conditioning game and errors made. In this way, the coaches were able to objectively evaluate each player's involvement and error count. This practice was adopted to guard against players staying on the periphery and doing the minimum necessary to keep up with play and avoid being penalised, without getting directly involved in play.

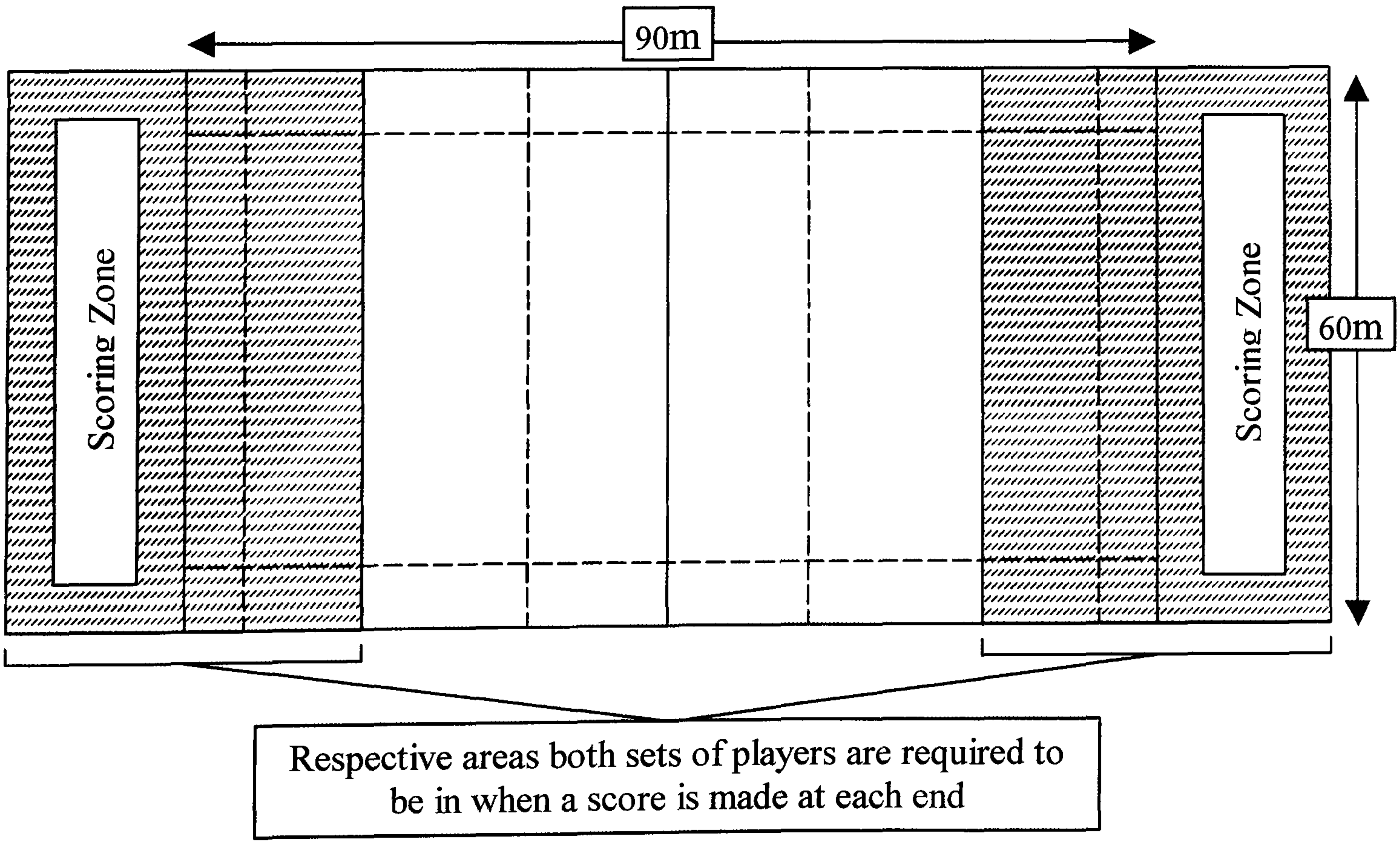


Figure 3.2.2. – Skill-based Conditioning Game Playing Area

Testing

Cardiorespiratory fitness and, indirectly, autonomic nervous system (ANS) functioning, was assessed at the beginning of each week of preseason, with the exception of Week 8, when players were away for a training camp. These assessments were based on HR responses to a standardised interval work bout. The test consists of four two-minute stages, interspersed with one minute (passive) rest periods, during which subjects remained standing and assumed standardised stationary postures (static stretches) (Sports Science Institute, Cape Town, South Africa). The 'beep' cadence (hence shuttle velocity) within each 2-minute bout was constant, but the pace increased with each successive stage. The first stage is an easy jog, equating to Level One of the Multistage Shuttle 'Bleep' Test (Leger et al, 1988). This progresses to rapid striding (analogous to Bleep Test Level Eight) in the final stage. The intervening two stages approximated to Level Three and Level Six of the Bleep Test, respectively, and essentially serve to progressively prime the cardiorespiratory system (VO2-'on' response) in readiness for the final stage.

High intraclass correlations have been reported for 20-m multi-stage shuttle run test (Leger et al, 1988, Ramsbottom et al, 1988, Leger & Gadoury, 1989), from which the test protocol is derived. The effects of psychological arousal on HR are reported to be nullified during high-intensity exercise involving large muscle groups (McInnes et al, 1995, Bangsbo, 1994). Even at the end of the training period, the HR in the final stage was 88.5±3.6%HRmax, which was deemed to be of a sufficiently high intensity to offset any interference effects of psychological arousal.

The test provided two indices of training status. The first was the HR, expressed as a percentage of the player's individual HRmax, reached at the end of the final stage. A well-established marker of progression in endurance training is that a given absolute power output elicits a lower percentage of VO2max, hence lower percentage of HRmax (Franklin & Roitman, 2001, Wilmore & Costill, 1999). The second index of training status was a percentage recovery score. This was derived from the decline in HR from the end of the final stage to the end of the final 1-

minute rest period, expressed as a percentage of the player's individual HRR. HR recovery after a standardised work bout reflects autonomic nerve system function (Imai et al, 1994, Savin et al, 1982). This index has likewise been shown to be sensitive to training status; with endurance-trained subjects exhibiting a more rapid recovery of HR following maximal and submaximal work bouts (Darr et al, 1988, Imai et al, 1994, Wilmore & Costill, 1999, Yamamoto et al, 2001).

Statitistical Analysis

Group data were analysed using one-way analysis of variance (ANOVA) with repeated measures. Simple and repeated within-subjects contrasts were undertaken in the case of significant differences. Comparisons of data for new versus existing players in the squad were undertaken via independent t-tests. Statistical significance was set at $p<0.05$. Data analysis was completed with SPSS software (SPSS for Windows, version 10, SPSS Inc).

3.2.3. Results

Repeated measures ANOVA revealed significant differences in %HRmax at the end of the final stage of the test pre- and post-training, displayed in Figure 3.2.3. The %Recovery score ($p<0.01$) was also significantly lower ($p<0.01$) at the end of preseason training (see Figure 3.2.4). However, repeated within-subject contrasts showed a significant difference in both test measures from Week 1 to Week 2 ($p<0.01$, see Table 3.2.2). In view of this, repeated measures ANOVA were re-run for both data sets using Week 2 as baseline. Simple within-subject contrasts with Week 2 as the reference revealed %HRmax at the end of the final stage was significantly improved at Weeks 4, 5, and 7 ($p<0.05$) and Week 9 ($p<0.01$). Similarly, %Recovery was shown to be significantly lower at Week 7 ($p<0.05$) and Week 9 ($p<0.01$), relative to Week 2.

Table 3.2.2 – Repeated Within-Subject Contrasts

Weeks	**%HRmax**	**%HR Recovery Score**
	***p* value**	
Week 1 vs. Week 2	**<0.01**	**<0.01**
Week 2 vs. Week 3	>0.05	>0.05
Week 3 vs. Week 4	>0.05	=0.078
Week 4 vs. Week 5	>0.05	>0.05
Week 5 vs. Week 6	**<0.01**	=0.76
Week 6 vs. Week 7	**<0.01**	**<0.01**
Week 7 vs Week 9	>0.05	>0.05

Week 5 was selected as the baseline to evaluate changes from mid-preseason to the end of the training period. Reductions %HRmax reached in the final test stage from mid-preseason (Week 5) became significant at Week 9 ($p<0.05$), shown in Figure 3.2.4. Significantly higher % Recovery scores were observed in Week 8 ($p<0.01$) and Week 9 ($p=0.012$), and this persisted into the first week of the playing season ($p<0.01$, see Figure 3.2.3).

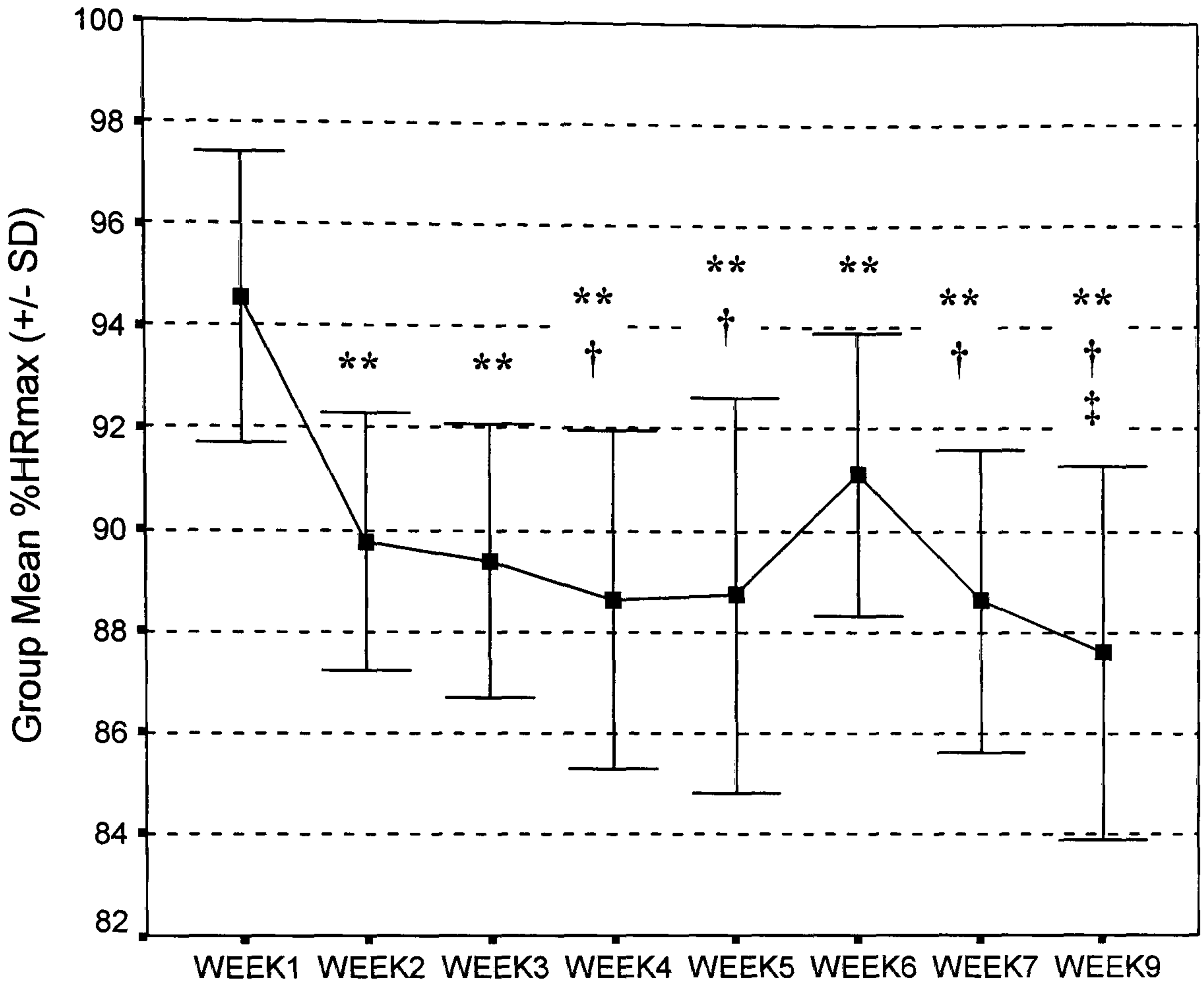


Figure 3.2.3 – Group Final Test Stage Percentage of Maximum Heart Rate

** Significantly lower than Week 1 ($p<0.01$)

† Significantly lower than Week 2 ($p<0.05$). †† Significantly lower than Week 2 ($p<0.01$)

‡ Significantly lower than Week 5 ($p<0.05$)

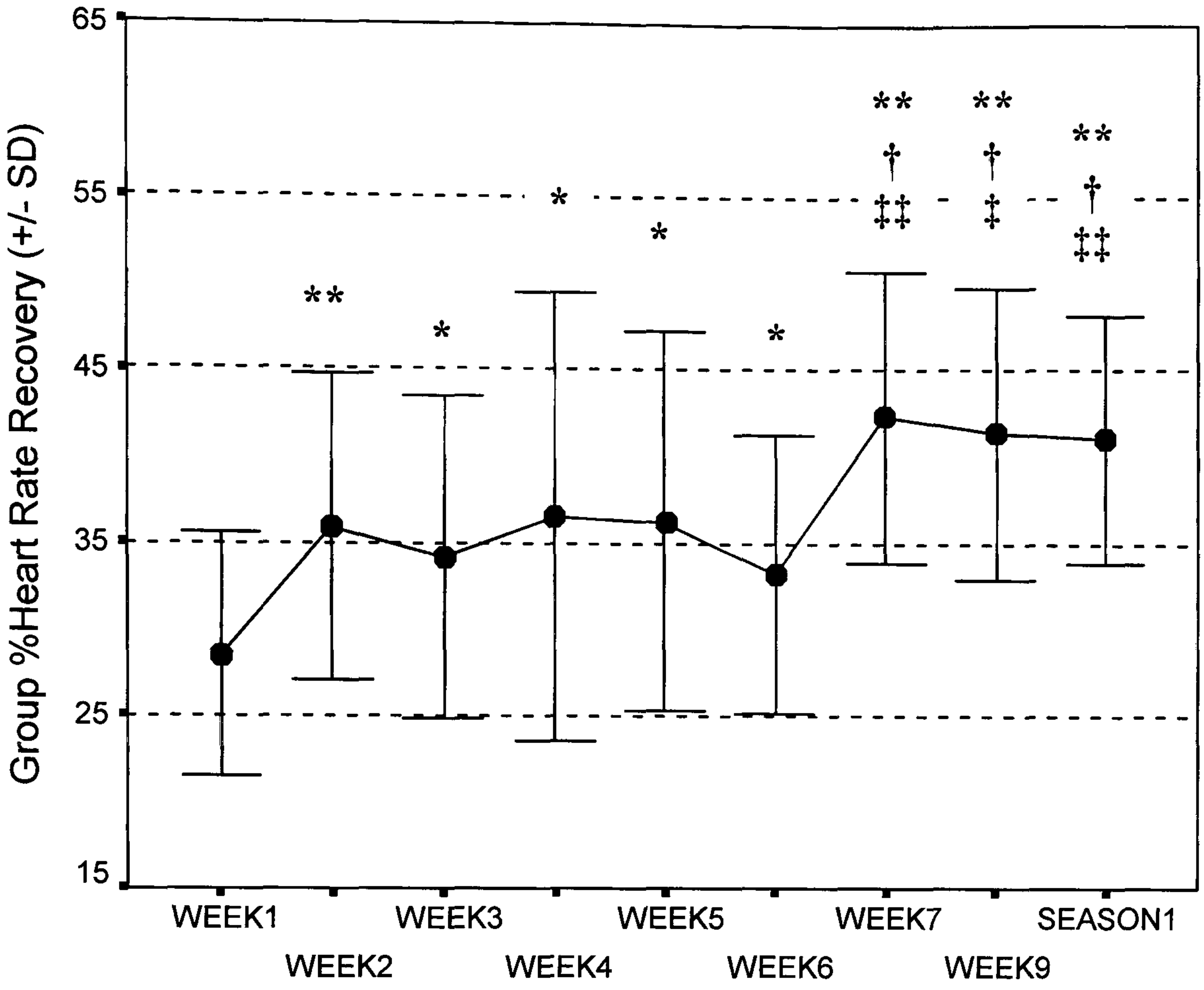


Figure 3.2.4 – Group Percentage Heart Rate Recovery Scores

* Significantly higher than Week 1 (p<0.05). ** Significantly higher than Week 1 (p<0.01)

† Significantly higher than Week 2 (p<0.05). †† Significantly higher than Week 2 (p<0.01)

‡ Significantly higher than Week 5 (p<0.05). ‡‡ Significantly higher than Week 5 (p<0.01)

During Week 6 there was a significant elevation in end stage %HRmax and depression in %HR Recovery scores (Figures 3.2.3 and 3.2.4). This was reflected in the repeated within-subject contrasts Week 6 versus Week 7 (p<0.01) for %Recovery Scores (Table 3.2.2), and was likewise apparent for %HRmax, both Week 5 versus Week 6 (p<0.01) and Week 6 versus Week 7 (p<0.01).

Scores for positional categories are presented in Figures 3.2.5 and 3.2.6. There was some indication of differences in rate and magnitude of improvement between different playing positions. However, there were insufficient numbers in each positional group to allow post hoc tests to assess any position effect. Any differences were negated when playing positions were merged into broader groupings.

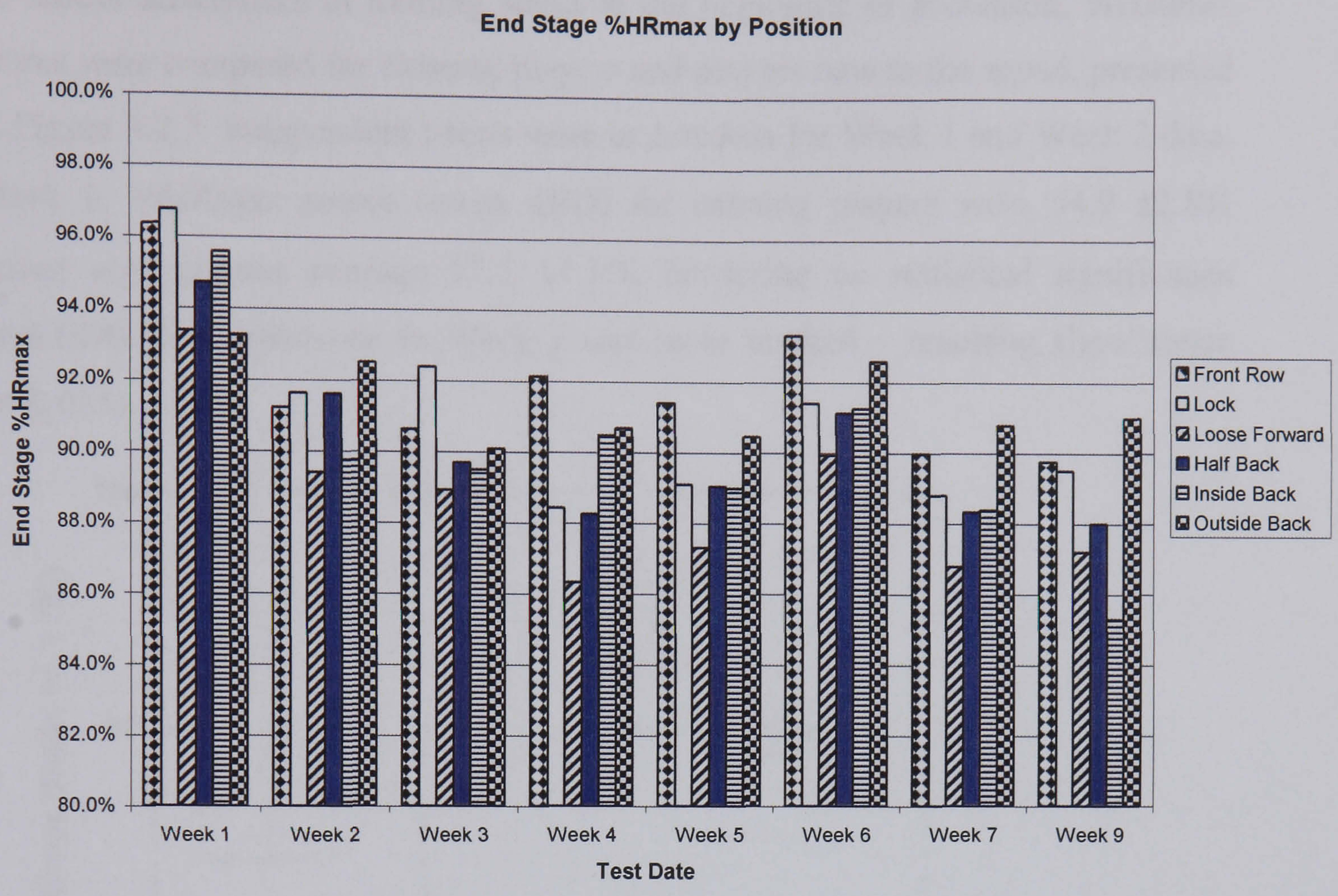


Figure 3.2.5 – Final Test Stage Percentage Heart Rate by Position

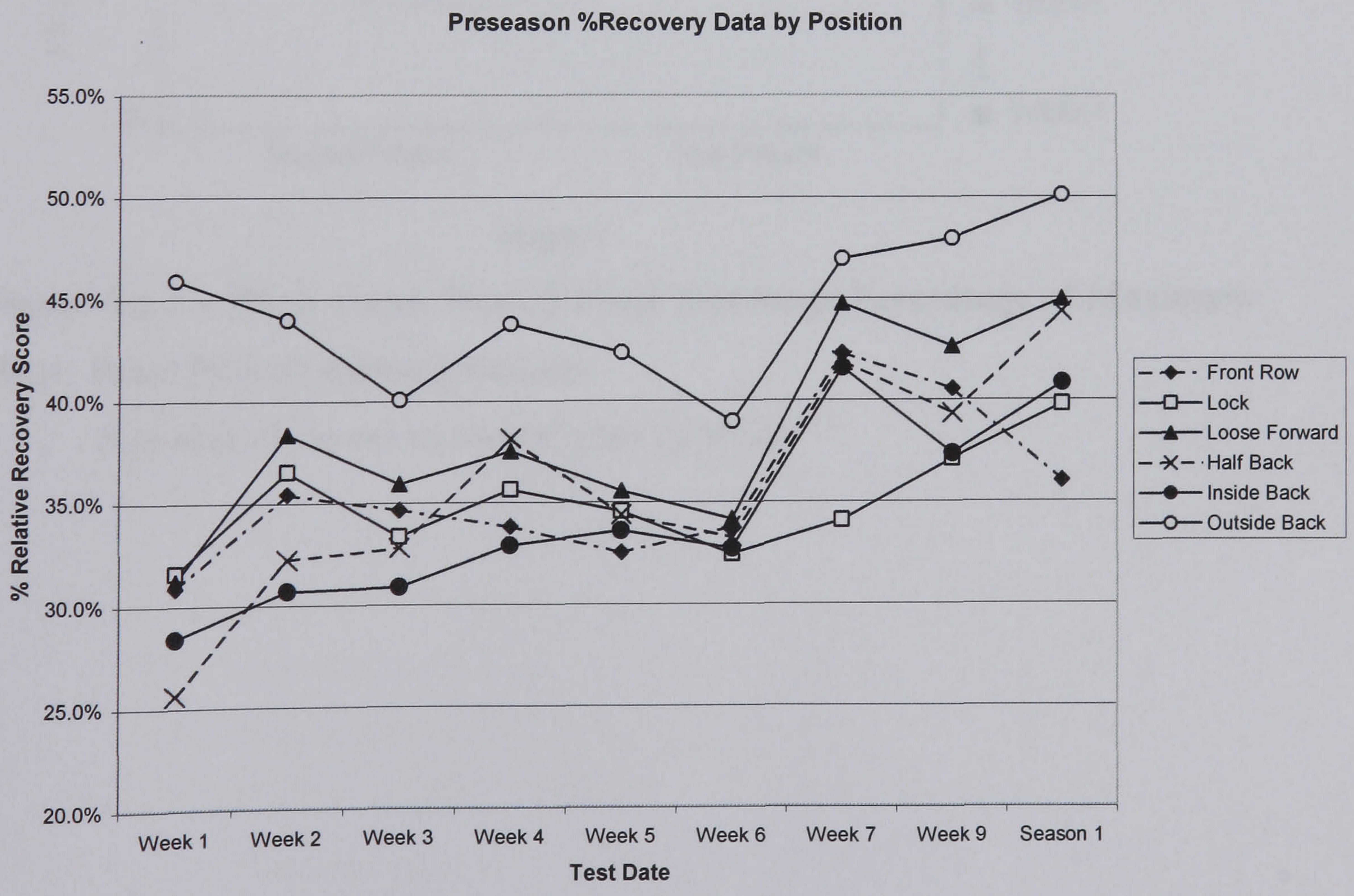


Figure 3.2.6 – Recovery Scores by Position

To assess differences in training status at the beginning of preseason, %HRmax scores were compared for existing players and players new to the squad, presented in Figure 3.2.7. Independent t-tests were undertaken for Week 1 and Week 2 data. Week 1, %HRmax scores (mean ±SD) for existing players were 94.9 ±2.8% versus new players average 97.5 ±1.1%, bordering on statistical significance (p=0.078). The difference in Week 2 was more marked – reaching significance (p=0.015).

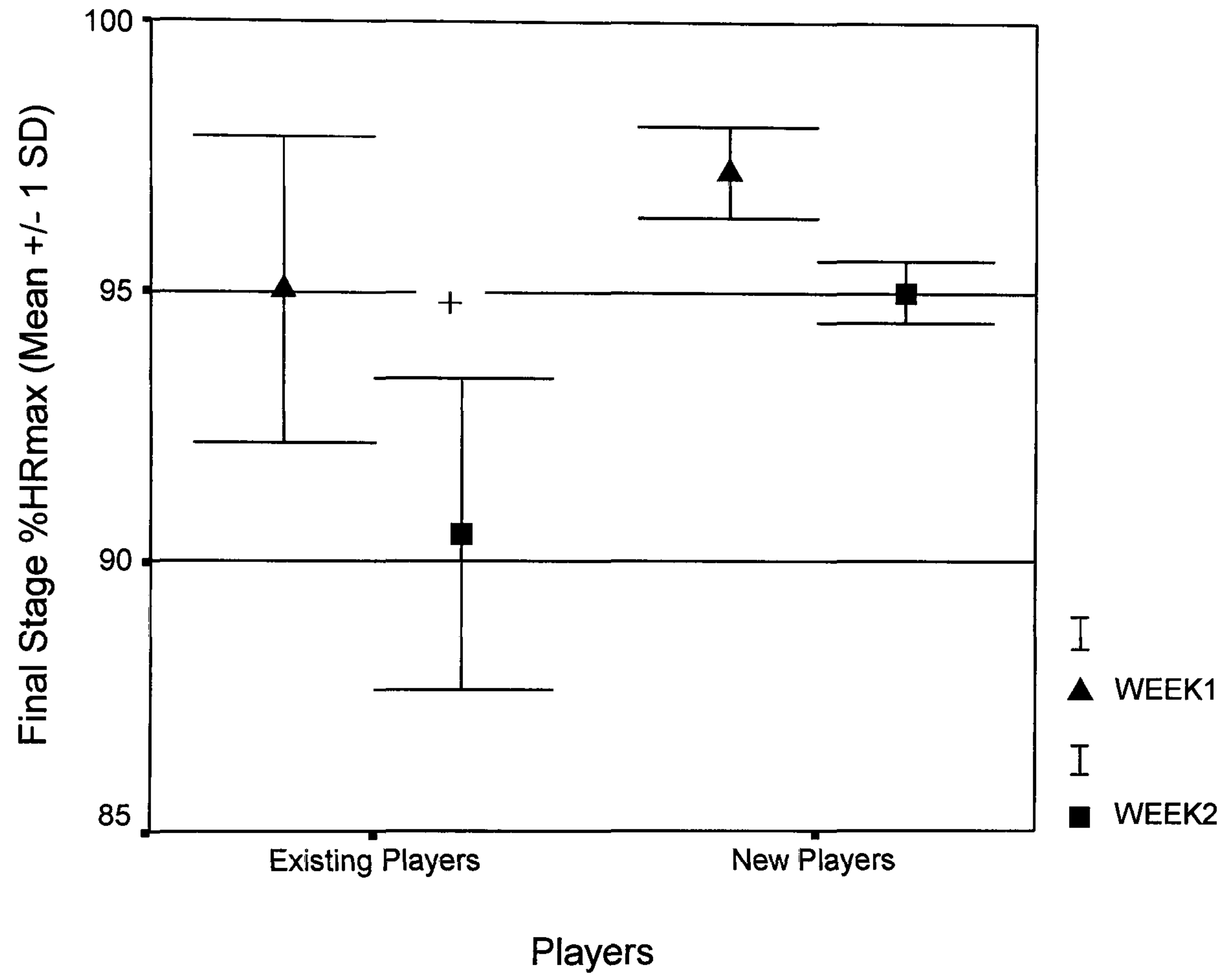


Figure 3.2.7 – Week 1 and Week 2 Final Test Stage Percentage of Maximum Heart Rate: New vs Existing Players

\+ Significantly lower vs New Players ($p<0.05$)

3.2.4. Discussion

The results of the current study support the efficacy of skill-based conditioning games to develop cardiorespiratory fitness in elite-level professional rugby union football players. Both HR recovery and %HRmax for the final stage showed the expected trends indicative of advances in training status. Significant improvement was seen post-training for both of these markers of endurance fitness. These significant effects persisted when Week 2 was substituted as baseline, to correct for possible effects on submaximal HR of hypervolaemia (increase in blood plasma volume) occurring early in the training period (Jones & Carter, 2000). Furthermore, continued improvements were also observed between the midpoint of the preseason phase and the end of the training period.

It should be stated these gains were elicited in already fit players, the majority of whom had been trained using conditioning games for the previous twelve months, and were coming off the back of the most successful season in the club's history. The scope for physiological adaptation is finite, and the superior early preseason fitness of existing players in the squad suggests these players had already fulfilled a good portion of their window of adaptation for cardiorespiratory fitness. This being the case, these players would be at a stage of physical development whereby diminishing returns would be expected (Holly & Shaffrath, 2001), rendering the fact gains were made throughout preseason training all the more notable.

To the author's knowledge this is the first published study to quantify changes in cardiorespiratory fitness in response to a preseason training program in elite rugby union players. The lack of studies thus makes comparison of the current findings to existing data impossible. Given this, and from an overall scientific perspective, the ideal would therefore have been to match subjects for playing position and randomly assign players to a matched control group. However, the reality is that it would be untenable to disrupt the preparation of a professional team to this extent in view of the financial rewards and consequences of failure (i.e. relegation) contingent on the team's performance in the subsequent season. Likewise, players would be opposed to having their chances of selection jeopardised on the basis they may have been assigned to the 'wrong' experimental group, and their physical preparation was not to the same standard as other players in their position as a result. Conceivably, such factors may have contributed to the lack of published studies in rugby union football since the advent of professionalism in 1995.

The study thus rests on the assumption that the observed improvement in markers of cardiorespiratory fitness resulted from the skill-based conditioning games training intervention. The only other mode of training undertaken in the period that could conceivably have had a metabolic conditioning effect is team tactical practices. However, HR traces from these sessions revealed the average work intensity to be considerably lower than that elicited by conditioning games (unpublished findings). Similarly, due to their nature, these practice sessions were not continuous, featuring frequent and often extended pauses for fault correction and coaching input. Further, the tactical practice sessions were introduced in the latter stages of the preseason training period, by which time significant gains in cardiorespiratory fitness were already evident.

Rugby union is very much an intermittent sport, in the sense that patterns of activity during match play are highly variable, being dictated by a multitude of factors, including the game plan of the opposition and refereeing calls. As a consequence, practically it is very difficult to design drills to simulate the continuum of intensities and movement patterns encountered during match play. The solution described that circumvents the need for structured conditioning drills is skill-based conditioning games. The conditioning games are continuous and require players to operate in the upper range of Work:Relief ratios encountered during match play and evoke exercise intensities in the range required (~90-100% VO2max) for optimal gains in cardiorespiratory fitness (Plisk & Gambetta, 1997, Plisk, 2000, Wenger & Bell, 1986). Skill-based conditioning games were found to offer far greater intrinsic motivation as a consequence of the game-play element, in agreement with the findings of other authors (Jeffreys, 2004). It requires significant motivation to reproduce these high work rates on a consistent basis to obtain continued improvements. Previously it has been identified that the majority of team sports players are more likely to work at these higher intensities when conditioning is perceived as game-related than when engaged in more traditional conditioning (running laps or intervals) with no skill or competition element (Plisk & Gambetta, 1997, Jeffreys, 2004).

Indirect evidence for the superiority of conditioning games as a training mode for athletes in rugby union is alluded to by the deficit in early preseason test scores of new players in the squad, compared to the existing players' average scores (Figure 3.2.7). Differences in training status are indicated from the fact new players required a greater percentage of their individual HRmax in completing the final test stage. This would suggest the conditioning they were exposed to at previous clubs was less effective, certainly from the point of view of maintaining endurance in-season.

The skill-based conditioning games approach accounts for movement specificity to a greater extent than traditional conditioning methods. This is significant, as the more specific an activity is to the training mode in which endurance gains were made, the greater the degree to which these gains are expressed (Durstine & Davis, 2001, Millet et al, 2002). The games format requires players to react to the movement of both team-mates and opponents, as well as following the ball. In this way, the conditioning games mode of training incorporates the changes in direction and velocity, and 'utility' movements (lateral and backwards locomotion) that feature in match play. A key parameter contributing to endurance performance is exercise economy (Jones & Carter, 2000). Running efficiency has been identified as the major avenue for advancing performance in highly-trained endurance athletes (Daniels, 2001). Exercise economy is postulated to be closely related to patterns of motor unit recruitment, and as such improvements are highly specific to the speeds and power outputs at which athletes habitually train (Jones & Carter, 2000). It follows that the skill-based conditioning games training format should similarly enhance economy for the range of sport-specific modes of locomotion and continuum of velocities that feature in match-play. Indeed conditioning games may be the optimal training mode available to promote these adaptations. This sport-specific movement efficiency factor is likely to be underestimated from the 20m-shuttle test format, which requires only straight-line running and 180-degree turns.

Regardless of the apparent effectiveness of the conditioning games training mode, it is unlikely that coaches would be receptive to skill-based conditioning games without being able to substantiate that each player in the squad is working sufficiently hard in the conditioning game setting for consistent gains in cardiorespiratory fitness. In view of this, HR monitoring technology is a critical element in the skill-based conditioning games approach. HR as a physiological marker of cardiorespiratory intensity is proven to be more accurate an index of exercise intensity during an acute exercise bout than perceptual cues, such as central or peripheral ratings of perceived exertion (Potteiger & Evans, 1995). Likewise, HR provides a basis to prescribe intensity that is sensitive to environmental conditions (heat and humidity) and changes in training status. This offers an objective means to verify players are working at or above their individually determined threshold to ensure a training effect, enabling the coaching staff to take appropriate steps if a player is found to not be working at the required intensity. Similarly, on a longitudinal basis, HR records of training sessions allow training load and volume to be logged far more reliably, as compared to self reports of intensity for daily training sessions (Gilman & Wells, 1993). In this way, HR offers a basis for training loads to be manipulated with a greater degree of accuracy as part of the players' long-term periodised training plan.

There are characteristic changes observed in cardiac ANS modulation with advances in endurance training status. Reduced resting sympathetic input and greater vagal (parasympathetic) tonic activity is reflected in relative bradycardia (lowered heart rate) at rest following a period of endurance training (Imai et al, 1994). Recovery of HR immediately post-exercise is likewise sensitive to endurance training status, with endurance trained individuals exhibiting accelerated return to resting levels following termination of exercise (Darr et al, 1988, Imai et al, 1994, Yamamoto et al, 2001). This is attributed predominantly to enhanced vagal (parasympathetic) reactivation. Practically, it is difficult to separate psychological factors to get a true resting HR measure on a consistent basis. Measurement of resting HR is therefore too unreliable to be used as the primary marker to track changes in cardiac ANS modulation. In contrast, HR recovery assessed using the intermittent shuttle test proved to be an easily implemented and time efficient test that could be conducted with large numbers of athletes.

HR recovery after a standardised work bout can thus provides insight into ANS functioning. This is significant, as it is the disruption of ANS function that is the primary characteristic of acute over-reaching and the chronic state of overtraining (Kraemer, 2000). Any marked decrease in a player's recovery score may indicate sleep disturbance, acute fatigue due to alterations in training (acute 'over-reaching'), residual fatigue from the previous week's training, or other daily stressors. These precursors of overtraining, if not addressed, can render the player susceptible to the chronically overtrained state. Interestingly, this was evident late in preseason, whereby there was a depression in recovery scores evident in some playing positions in Week 5, which became particularly marked for the group as a whole in Week 6. Paradoxically, this appeared to be provoked by a decrease in training volume. Preceding the Week 5 and Week 6 tests, players were given the Friday off training, which entailed three days away from training, as opposed to the two-day weekend rest they were accustomed to. Many players reported the following Monday that they were feeling tired, corroborated by the decline in recovery test scores. It appears the active rest provided by the Friday training session may have served to enhance sleep quality and recovery. Accordingly, when the squad reverted back to the normal weekly training plan (i.e. with Friday training session) recovery scores rebounded back to continue their previous upward trend, which persisted into the first week of the playing season.

With the high volumes of team practices and other training required in rugby football there is a necessity for metabolic conditioning to be as time-efficient as possible to maximize gains in the limited training time allowed. Skill-based conditioning games enable players to simultaneously develop awareness of space, execute game skills and decision-making under pressure, and practice effective communication with team-mates in a simulated competitive environment. Collectively these elements have been termed 'game sense' in rugby league coaching circles (Den Duyn, 1997, Den Duyn, 1996). As skill-based conditioning games offer development of game skills and communication, coaches are able to continue metabolic conditioning even late in preseason when the training emphasis shifts to skills practice and game strategy sessions. There was a noticeable plateau in endurance performance measures towards the end of the training period concurrent with the shift in emphasis to greater strategy and tactical work, and correspondingly less time engaged in metabolic conditioning. If undertaking metabolic conditioning using less game-related conditioning activities this shift away from metabolic conditioning work would likely occur earlier. In this case, reduced total conditioning time would likely elicit lesser net gains in cardiorespiratory fitness at the end of the preseason training period. Anecdotally, the skill element likewise encourages coaches to continue to implement conditioning games during the playing season, allowing cardiorespiratory endurance to be maintained to a far greater extent in-season.

The skill-based games approach to metabolic conditioning may offer an ancillary benefit of lower injury incidence rates, as compared to traditional conditioning activities without a ball. In a study by Gabbett (2002) injury rates were adjusted for time engaged in a particular mode of training for the duration of a rugby league season. The majority of injuries were sustained during traditional conditioning work without a ball or skill element, in contrast to the low incidence of injury when participating in skill-based conditioning games (Gabbett, 2002). The underlying reasons for the apparent decreased occurrence of injury associated with conditioning games remains to be clarified. There are indications that skill sports athletes exhibit enhanced agility when holding the implement of their sport (Kraemer & Gomez, 2001). Improved neuromuscular control is identified as helping guard against 'non-contact' injuries (Pettitt & Bryson, 2002). It is conceivable therefore that improved motor control may be an underlying factor in the decreased injury when performing sports movements, as opposed to running without a ball. Whatever the mechanism, the benefits of less time away from the training pitch due to injury will be readily apparent to the coach and athlete.

3.2.5. Practical Applications

This study provides the first quantitative data to support the efficacy of skill-based conditioning games as the primary mode of metabolic conditioning for elite-level rugby union players. This supports the proposed benefits of conditioning games, with regard to specificity of training. These results, taken with the findings of a previous investigation indicating lower injury incidence rates associated with skill-based conditioning games, suggest the conditioning games approach may offer a credible alternative to traditional conditioning activities for rugby football players. To directly assess the relative merits of each training mode, further research quantifying changes in cardiorespiratory fitness for a preseason period employing traditional conditioning methods in a similar group of athletes is needed to allow direct comparison with the present results.

HR monitoring was demonstrated to be a practical means of quantifying training intensity in the conditioning games format, providing an objective basis to validate this mode of training. Coaches can thus implement conditioning games in their team's metabolic conditioning, in the knowledge that they can verify each player's work-rate in any given training session, and in doing so gain insight into the work ethic of individuals in their playing squad. The study further indicates the HR recovery index described has potential use as an index for coaching staff to identify players exhibiting disruption of ANS function indicative of acute fatigue that may be precursors of overtraining.

These findings have most relevance for coaches in rugby union and rugby league. However, this approach to metabolic conditioning may also be applied to other team sports of an intermittent nature.

STRENGTH TRAINING

4.1.1. Components of Strength

Strength is defined in terms of the greatest amount of force or torque an individual can generate during maximum voluntary contraction under a defined set of conditions (Abernethy et al, 1995). Individual testable qualities that comprise the global term strength can be isolated (Newton, 2002). In accordance with the force-velocity relationship, there is a distinction between force-generating capacities (i.e. strength) at faster movement velocities and slow velocity or zero velocity. High-velocity strength or speed-strength comprises force-generating capacities at fast contraction velocities (Newton, 2002). There is a further distinction between slow velocity maximum strength and isometric strength. Slow velocity strength is defined as the maximum weight that can be lifted in a dynamic fashion, typically measured using an isoinertial lift (squat, deadlift, bench press etc). Isometric strength is quantified as the maximum force that can be applied under static conditions. At negative movement velocities maximal torques are described in terms of eccentric strength. Eccentric strength has the greatest magnitude of force of all strength components. The combination of eccentric and concentric strength yields a further component, termed 'reactive strength'. This final quality is typically assessed via measures such as depth jump height, in which the subject must overcome significant momentum in a negative direction before reversing the movement to overcome inertia (Newton, 2002).

When athletes are required to perform movements repeatedly, other capabilities are implicated that relate to the strength qualities described. Strength-endurance, speed-endurance, and power-endurance are identified as discrete elements and should be considered independently, as opposed to merely derivatives of strength, speed and power (Yessis, 1994). Neuromuscular coordination is implicated in speed-endurance and power-endurance, as movement efficiency plays a key role in both. Two key adaptations identified as underlying strength-endurance are acid-base buffering (Kraemer, 1997) and neural mechanisms that make the athlete better able to more fully activate fatigued motor units (Behm, 1995).

4.1.2. Strength Training Methods and Modes

Particular modes of strength training have greater transfer of training effect for a particular capacity than others, based upon the mechanics and kinetic profile of a training exercise (Stone et al, 2000). The method of applying resistance will dictate the degree of neuromuscular control and coordination required, which influences its relative effectiveness in developing a given neuromuscular property. For the majority of multi-joint training movements, free weight application of resistance is considered most functional as the lifter is required to stabilise their own body and the external resistance, whilst controlling and directing the movement (Stone et al, 2000). As a consequence, free weights exercises develop intra- and inter-muscular coordination to a greater degree. This is reflected in superior transfer to athletic and ergonomic performance measures relative to machine-based resistance training (Stone et al, 2000). Similarly, free weights strength training is consistently shown to produce greater strength gains in comparison to resistance machines. For these reasons it is typically recommended that advanced strength training should emphasise free weights exercises, with resistance machine exercises having an auxiliary role (Kraemer et al, 2002).

The biomechanics and kinetic profile of a particular strength training exercise dictates its relative effectiveness in developing a particular strength property. Structural, mechanical, and neural elements of the lift will impact on training velocity and rate of force development. This in turn determines the nature of the training adaptation, such as slow velocity strength versus speed strength (Baker & Nance, 1999). Multiple-joint free weights exercises are recommended when training to develop explosive muscular power (Kraemer et al, 2002). Closed kinetic chain free weights exercises typically comprise multi-joint movements and feature transmission from the ground upwards, which favours transfer to athletic activities (Stone et al, 2000).

The quantity of muscle mass involved in the training exercise, as well as frequency and volume load (repetitions multiplied by mass lifted) of training will influence adaptations in body composition (Stone et al, 2000). Free weight exercises that recruit a large amount of muscle mass have greater metabolic demand and hormonal responses, which tends to favour alterations in body composition. Similar considerations underpin recommendations for multiple-joint free weights exercises recruiting large muscle mass to develop local muscular endurance and strength endurance (Kraemer et al, 2002).

4.1.3. Foundations of Strength Training

The first foundation of any strength training program is 'overload'. Essentially, overload dictates that the athlete needs to be loaded beyond what he is accustomed to in order to produce any adaptation (Baechle et al, 2000). The muscles and motor control systems require a novel stimulus in order to elicit a training response. When these conditions are met the body is prompted to initiate adaptations in the nervous system, muscles and connective tissues to be able to better deal with this new movement and loading in the future. Even the best designed program will not produce significant gains without taking the neuromuscular system beyond what it is accustomed to in terms of movement patterns being executed, the intensity, volume load, and the rest allowed between exercises and workouts.

The second foundation leads on from overload; this is 'progression'. This concerns the need for progressive increases in training stress applied as training advances to achieve continued adaptation (Newton et al, 2002). The most simple illustration of the need for progression is that as the athlete gains strength, a load that would previously have been challenging no longer offers the element of overload due to the athlete's enhanced capabilities (Rhea et al, 2003). Progression can also be achieved by manipulating repetitions performed, training volume (number of sets and exercises in the workout) and/or training frequency (weekly number of sessions per muscle group) (Kraemer et al, 2002). Finally, selection of exercises can be used to progress a player's training, moving towards more technical lifts as their lifting abilities develop. Progression therefore is a continual process of marrying the program variables to the level of adaptation that has already taken place. For a lifter with limited training experience almost any systematic strength training program represents a novel training stimulus for the neuromuscular system. With increasing training experience and as training status advances, more challenging training regimes and more sophisticated manipulation of training parameters are required to elicit a training response (Newton & Kraemer, 1994, Kraemer et al, 2002).

The final foundation of strength training is 'specificity', described by the acronym SAID: Specific Adaptation to Imposed Demands (Baechle et al, 2000). The adaptation produced in an athlete is dependent on the specific form of overload provided by the training stimulus (Stone et al, 2003). Strength training must therefore be specific to the sport or athletic event the athlete is training for. The obvious application of this is in exercise selection. Lifts that are most relevant to the demands the player faces on the pitch are preferred to alternative exercises for a particular muscle group. This is the principle of training movements, not muscles in isolation. Kinetic, kinematic and postural variables are all implicated in sport-specific exercise selection. Biomechanically, the closer the particular training exercise to the movement patterns and velocity of the sports-related action, the greater the degree of carry-over is likely to be (Stone, 1993).

Another application of specificity, which is typically not fully accounted for, is the format in which strength training workouts are performed. Here there is a distinction between athletic disciplines that comprise a single maximal effort, as in the case of field event athletes (jumpers, throwers etc), and performance requiring repeated maximal efforts performed consecutively. In the former case, the sole program goal is maximal strength, hence it is sufficient to perform consecutive sets to failure with a selected exercise allowing optimal rest in between sets. In the case of athletic performance comprising cyclical high-force movements (for example sprinters, cyclists or rowers) strength-endurance is an additional program goal. Therefore a key training variable is rest between sets of exercises replicating the cyclical sport movement. For field sports athletes, a wide array of movements in multiple directions must be executed repeatedly in an unspecified order with high force. Contact field sports feature the added element of movements executed against resistance, often with the upper body as the point of contact. For these athletes, the optimal training format has yet to be adequately investigated.

4.1.4. Strength Training Prescription for Elite Athletes

Meta-analysis of the strength training literature demonstrates that training responses vary depending on training status (Rhea et al, 2003). Accordingly, different levels of intensity, volume and training frequency are shown to produce maximal gains, based on the training experience of the subject population (Peterson et al, 2004). In recognition of this, exercise prescription guidelines increasingly make a distinction in terms of resistance training experience and feature separate recommendations for untrained, recreationally trained and advanced lifters (Kraemer et al, 2002).

Training experience is therefore a key consideration for strength training prescription. There is an obvious need to progress intensity, volume and frequency of training, as the neuromuscular system grows more accustomed to strength training with increased exposure (Rhea et al, 2003). It is therefore logical that individuals with different training experience will require different 'doses' of training parameters in order to elicit maximum training response in terms of strength gains.

Dose-response relationships to help specify the optimal resistance load, volume and frequency of strength training have previously not been identified in competitive athletes. A recent study undertook a meta-analysis of the thirty-seven studies of the strength training literature directly employing athletes as the subject group (Peterson et al, 2004). Summarising the findings of these studies, the authors found that the training parameters that optimise training effects (measured strength gains) in competitive athletes differ to those based on similar studies employing strength trained non-athletes. Training volume (sets per muscle group), training frequency (days per week for each muscle group) and training intensity (resistance load) found to be most effective in the studies examined differed markedly even to those for non-athlete subjects experienced in strength training.

The specific needs of competitive athletes are vastly different to those of recreationally trained individuals. It is logical that by extension the optimal training for athletes will likewise be different. There is recognition that training status and experience influences the particular form of training that will be effective in developing athletic performance (Cronin et al, 2001). On this basis, elite performers should be treated as a special population.

There appears to exist a continuum in terms of optimal training variables for maximal strength gains, which is dependent on the training status and training experience of the individual (Rhea et al, 2003). Maximal strength gains are demonstrated in untrained individuals training at an average intensity of 60% 1-RM (Repetition Maximum), whereas individuals experienced with strength training exhibit maximum gains with 80% 1-RM resistance. Competitive athletes appear to exist further still along this continuum. However, there is currently a lack of data pertaining to this athletic population, especially team sports athletes, hence there is often insufficient objective data upon which to base training prescription.

From the data that is available, some suggestions for training volume, training frequency and training intensity applicable to competitive athletes can be made. A mean training intensity of 85% 1-RM has been found to be most effective in competitive athletes from the majority of relevant studies (Peterson et al, 2004). This equates to 6-RM, i.e. the greatest weight that can be lifted for six repetitions, when lifting to failure. This is in general agreement with the finding that loads greater than 80% 1-RM were necessary to maintain or improve strength throughout the playing season in college American football players (Hoffman & Kang, 2003). Observation of elite weightlifters likewise noted a significant decrease in EMG recorded during the phase of the training year when training intensity dropped below 80% 1-RM, which recovered once training intensity was increased above 80% in the subsequent training period (Hakkinen et al, 1987). This requirement for greater average intensity appears to be a common theme for athletes as a special population. Of all training variables, training intensity was the only significant predictor of strength changes during an in-season period in college American football players (Hoffman & Kang, 2003). Training studies featuring protocols in which the athlete subject group lifted to failure report greater average strength gains (Peterson et al, 2004). Therefore it appears there is a need for strength training regimes to stipulate the athlete must lift to failure at the specified load, as training at lesser intensities is shown to elicit minimal improvements in competitive athletes (Hoffman & Kang, 2003).

In terms of frequency of strength training, recommendations are based on the number of times per week individual muscle groups should be trained. From data examining athletes, training a particular muscle group two or three days per week was observed to be similarly effective (Peterson et al, 2004). How many strength training sessions this equates to will depend on the layout of the workout. It could be two workouts per week in the case that both days are whole-body sessions. On the other hand, if a 'split routine' format is being used, isolating certain muscle groups (for example separating upper and lower body exercises) on particular training days, this may comprise four or more strength training sessions per week. There is some evidence that a five-day program incorporating split routine loading may offer greater strength and muscle mass gains (Hoffman et al, 1990). However, given the time constraints imposed in many team sports the former three-day whole body format is likely to be most time-efficient.

Recommendations for volume of strength training for competitive athletes are similarly made in terms of individual muscle groups. A mean number of eight sets per muscle group is found to maximise strength gains in groups of athletes (Peterson et al, 2004). This represents double the equivalent volume recommendations based on studies for non-athletes. The majority of studies employing non-athletes found four sets per muscle group per week to be effective in evoking maximal strength gains (Rhea et al, 2003). This was the case in both recreationally strength-trained and untrained subjects. Competitive athletes thus appear to require a much greater volume of strength training to provide an effective training stimulus for gains in strength. These distinct differences in optimal training observed for competitive athletes reinforce the specific needs of athletes as a special population.

4.1.5. Strength Characteristics of Rugby Football

Scores on strength and power measures are shown to distinguish elite professional players from those at lesser levels (Baker, 2001b, Baker, 2001d). This asserts the importance of developing strength properties for rugby football as a requisite for participation at the highest level (Baker, 2002). There is a significant progression in these qualities at each stage from high-school level, through college age, to senior professional level (Baker, 2002). Independent of any difference in lean body mass, elite professional rugby league players are able to express greater upper-body strength and power than semi-professional and college-aged players (Baker, 2001b, Baker, 2001d).

In professional rugby league players it has been identified that different playing position groupings vary in their performance on various strength, speed, and endurance measures (Meir et al, 2001). Specifically, forwards exhibit greater upper body strength than backs, whereas outside backs are faster over 15 m than forwards and all other positional sub groups over 40 m. Reflecting the frequent involvement in play and added endurance demands associated with the positional role, distributor positions are found to score significantly better on 5-minute run scores than the forward positions (Meir et al, 2001).

There is currently no such contemporary data for rugby union at elite level. However, the distinction between forward, back and distributor positions in rugby union is broadly similar to rugby league, therefore similar trends across playing positions would be expected. All playing positions irrespective of differences in body mass and positional demands require high levels of dynamic muscular strength to contend with the physical aspects of the sport (Baker, 2001b, Meir et al, 2001).

4.1.6. Strength Training Needs Analysis for Elite-level Rugby Union Football

The fundamental difference that separates rugby union from rugby league is the greater emphasis on the set piece phases. A scrum or line-out is used to restart play after technical infringements are committed or the ball has gone out of play. As a consequence of these primary aspects of rugby union match play, roles of different playing positions are more clearly delineated and their associated demands vary more strikingly. Notwithstanding the differences in performance measures between positions observed in elite rugby league players, playing positions in rugby league are far more homogenous. As a result there is a greater disparity between the physical attributes of positions in rugby union (Quarrie et al, 1995, Duthie et al, 2003). Individual players are naturally predisposed to, and selected for, particular playing positions on the basis of their anthropometric characteristics and strength capabilities (Quarrie et al, 1996, Quarrie & Wilson, 2000, Duthie et al, 2003). The other aspect that differentiates rugby union from league is that rugby union requires players to secure or contest possession of the ball at each tackle. This responsibility primarily falls to the forward positions, for whom there is a correspondingly greater need for absolute strength (Duthie et al, 2003). Needs analyses of individual positional roles within a rugby union team thus reveals that the various playing positions exist at different points on the maximum strength/speed-strength continuum.

From qualitative assessment of rugby union, relative strength is important for all playing positions from the point of view of overcoming the player's own inertia to change direction at speed, jump and accelerate. Absolute strength levels are likewise vital when initiating explosive movements against resistance (provided by opposition players), for example when tackling and forcefully engaging with opposition players in the vicinity of the tackle area to secure possession.

Larger body mass differentiates between playing grades in rugby union football. This aspect was also shown to correlate with the respective performance of national teams in the World Cup competition (Olds et al, 2001). Body mass is a significant predictor of force produced during the scrum (Quarrie & Wilson, 2000), which is the set piece used to re-start play after technical infringements. A team's success in producing force in the scrum will dictate their success in contesting possession and positively influence the quality of possession they receive from this phase of the game. Lean body mass is important in terms of accounting for the mass element in the *mass x velocity* momentum equation during collisions. Travelling at the same given velocity, a heavier player will be carried forward a greater distance in the collision when tackled by an opponent. This is significant, as possession is more likely to be retained if the ball carrier is able to travel some distance beyond the defensive line when tackled before he goes to ground and has to release the ball (Duthie et al, 2003). As in other collision sports such as American football, rugby union players' body mass and mesomorphy has risen at a disproportionate rate over the past twenty-five years, particularly since the advent of professionalism (Olds, 2001). Site-specific hypertrophy is also important in contact sports such as American football and rugby football (Kraemer, 1997). The shoulders are a key area for development as this is frequently the point of impact when tackling opponents.

Based upon qualitative assessment of the physical aspects of rugby union football, the predominant biomechanical action comprises simultaneous 'triple-extension' of hips, knees and ankles; often transmitting force through the shoulders as the point of contact during collisions with other players. This triple-extension characterises both the high-force activities involved in contesting possession and the high-power dynamic actions associated with jumping and tackling. The primary goal of the strength training program therefore is to enhance maximum strength and speed-strength for this triple-extension movement. There is a need for both strength (heavy load) training and explosive power training that emphasises this specific action.

Exercise selection favours primarily 'closed kinetic chain' (feet planted) multi-joint movements. There is a necessary emphasis on the high-force structural lifts (deadlift and variations of the squat). To account for speed-strength development for these multi-joint movements there is a requirement for specific speed-strength training, in particular Olympic lift exercises and their derivatives (Kraemer, 1997). Unilateral support resistance exercises are similarly key exercises to account for the fact that often force is generated whilst supported on one leg (Hedrick, 2002, McCurdy & Curdy, 2003). Additional exercises to develop the muscle groups that assist the prime mover musculature are necessary to develop active joint stability. Likewise, it is important to incorporate resistance training exercises to address areas typically prone to injury for a particular position, as well as accounting for players' pre-existing muscular imbalances or sites of previous injury (Baechle et al, 2000).

Consideration must be given to the physical stresses associated with team practices and matches that result from violent bodily contact with opponents and the playing surface. The consequent muscle tissue damage incurred has the potential to compromise the amount and intensity of strength training players are able to perform (Hoffman & Kang, 2003). Programming of strength training must also take account of the interaction effects of the concurrent metabolic conditioning and physical activity involved in the skill sessions and team practices players are required to perform. High-intensity endurance training has been shown to interfere with hormonal changes and negatively impact upon power development when strength training is performed on the same day following endurance training (Kraemer et al, 1995). A preceding acute bout of high-intensity endurance exercise is also shown to impair the ability to perform strength training (repetitions completed) (Leveritt & Abernethy, 1999). Although isokinetic strength parameters are also affected, isoinertial strength appears to be compromised to a greater extent by prior endurance exercise. It therefore appears that exercises requiring greater neuromuscular control and coordination may be more susceptible to these interference effects.

There is some evidence that manipulating the sequencing of the training day can influence the degree to which strength expression is compromised (Leveritt & Abernethy, 1999). Specifically, when strength training is prioritised and performed before conditioning these interference effects can be minimised. It has been shown that adopting this approach can optimise strength training responses to the extent that strength and power measures can be maintained, or even increased in younger players, during the course of a lengthy (twenty-nine weeks) in-season period (Baker, 2001).

As inferred previously, a key distinction between rugby football and other collision sports such as American football is that rugby football is far more continuous in nature. Unlike American Football, in rugby union play continues after the player is tackled. Play is only stopped when the ball goes out of play, a technical infringement is made, or a penalty is committed. As a result, rugby union features considerably higher work:rest ratios (Deutsch et al, 1998), and thus has a much greater metabolic demand. Consequently, strength-endurance is a vital program goal for rugby football. How best to address this need for strength-endurance for the myriad of movements performed with and without external resistance that feature in rugby football is yet to be elucidated, particularly with elite players.

Evaluation of a Circuit Strength Training Format for Elite Senior Professional Rugby Union Football Players

4.2.1. Introduction

Traditionally, strength training in a circuit format has been restricted to the use of lighter weights (40-60% 1RM) and higher (10-15) repetitions (Fleck & Kraemer, 1997). Circuit resistance training has thus become synonymous with a hybrid strength endurance and aerobic training modality (Fleck & Kraemer, 1997). The closest example of a circuit format being used for strength training reported in the literature is a strength-endurance oriented off-season program featuring 8-12RM loads used with American football players (Kraemer, 1997).

Re-evaluation of the circuit format for strength training appears warranted. It was hypothesised that the use of circuit format with strength and power training may offer specific benefits for team sports athletes. As a consequence of their intermittent and open nature, team sports comprise a myriad of movement patterns involving multiple muscle groups. One disadvantage with the conventional sequential workout format (i.e. completing the allocated sets with one exercise before moving on to the next lift) is that exercises placed later in the workout may be compromised by fatigue having trained exhaustively on previous lifts. The circuit format means that the lifter is in a comparable state of freshness or fatigue when performing all exercises in the workout, and fatigue is more progressive and consistent for all exercises. Hypothetically this should facilitate a more homogenous whole body training response. Likewise, the fact that the athlete continues to train during what would be a rest interval under the traditional straight sets format would appear to favour adaptations in whole body acid-base buffering. This has been identified as a primary factor in strength-endurance (Kraemer, 1997), which is a key program goal for team sports such as rugby football.

Over the past twenty-five years, the body mass and levels of mesomorphy of top-level rugby union players has shown consistent increases at five times the rate of that seen in the same period for the general population as a whole (Olds, 2001).

The importance of strength development in rugby football can likewise be inferred from the observations that strength and power measures differentiate between players at different playing grades (Baker, 2001b, Baker, 2002, Duthie et al, 2003). Upper and lower body power measures of elite rugby league players are shown to be heavily dependent on their levels of strength (Baker & Nance, 1999a). Given the observed importance of strength and lean body mass it is thus crucial to maximise the effectiveness of the strength training players are able to perform within the constraints of other training and team practices.

To the author's knowledge, there is currently no published data regarding strength training responses of rugby union players, particularly at elite level. There is growing evidence that athletes exhibit different training responses to trained non-athletes and untrained subjects (Peterson et al, 2004). Accordingly, there is a need to gather data pertaining specifically to competitive athletes.

The aim of the study was to evaluate strength training responses of elite professional rugby union football players to the circuit format manipulation. Periodised strength training for these athletes was performed exclusively in a circuit format for the duration of eight weeks' preseason training. Strength test results were examined to assess the effectiveness of the circuit format for strength training in these athletes.

4.2.2. Methods

Subjects

Twenty-nine players (age 25.7 ±4.5yrs height 185.0 ±9.0cm body mass 101.2 ±15.1kg, mean ±SD) were included in the study. All were members of the same professional rugby football team competing in the English Premier League. Criteria for inclusion were that players were fit to complete all test occasions for at least one of the lifts tested and had been in full-time training for a minimum of twelve months previously.

Preconditioning Phase Prior to the Study

At the end of the previous season players underwent testing. Prior to the training intervention, players were away for six weeks' off-season break. During this period, following two weeks active rest, the players were given an off-season strength training program to be performed independently for three days per week. This comprised free weights and resistance machine exercises (Table 4.2.1). To ensure compliance, each player was set individual targets for each of the three lifts assessed, based on their test results at the end of the playing season. Players were instructed that penalties and extra training would be imposed in the event they failed to meet their targets when they returned for preseason training. This served to ensure that the players did not enter the training period in a detrained state.

Table 4.2.1 – Offseason Strength Training (2-week cycle)

Day One **10RM** ***3 sets***	**Day Two** **8RM** ***3 sets***	**Day Three** **12RM** ***3 sets***
Overhead Dumbbell Squat Bench Dips Seated Cable Row EZ Bar Bicep Curls Single-leg Calf Raise	Dumbbell Split Squat Bench Press One-arm Dumbbell Row Seated Dumbbell Shoulder Press Back Extensions EZ Bar Upright Row	Leg Press Incline Dumbbell Bench Press Lat Pulldown Machine Hamstring Curl Dumbbell Upright Row + Bicep Curl
Day One **10RM** ***3 sets***	**Day Two** **12RM** ***3 sets***	**Day Three** **8RM** ***3 sets***
Leg Press Dumbbell Split Squat Back Extensions Machine Hamstring Curl Knee Extensions Single-leg Calf Raise	Bent-over Dumbbell Raises Dumbbell Pull-overs Lateral Dumbbell Raises EZ Bar Bicep Curls Cable Tricep Pushdown Dumbbell Front Raises Elastic Tubing Shoulder Rotation	Bench Press One-arm Dumbbell Row Seated Dumbbell Shoulder Press Seated Cable Row EZ Bar Upright Row Dumbbell Bicep Curls

Anthropometric Measurements

Prior to the study period and at its completion, body mass was recorded and sum of five skin folds was taken for each player. The five sites measured were biceps, triceps, subscapular, suprailiac, and abdomen. An experienced practitioner undertook the skin fold measurements at both test occasions, using methods consistent with the guidelines set out by Harman & Pandorf (2000).

Strength Tests

Testing was undertaken at the end of the previous season, prior to the training period, and at its completion. For three lifts, 3-RM strength scores were assessed, using the procedures described by Baechle et al (Baechle et al, 2000). The test-retest reliability of isoinertial repetition maximum strength testing is well documented, with intraclass correlation coefficients typically reported in the range of $r = 0.92$-0.98 in trained subjects (Abernethy et al, 1999, Matuszak et al, 2003).

The lifts tested were deadlift, bench press and bench pulls, to assess lower body strength and upper-body pushing and pulling strength, respectively. These particular lifts were selected on the basis that players had prior experience performing these tests, having used them for strength testing previously. Deadlift and bench press are commonly used powerlifts and were executed in the standard manner outlined by Earle & Baechle (2000). The bench pull is performed with the subject prone, on a bench supported by the cross pins on a box squat rack. For this test a repetition is deemed successful if the barbell is raised within a designated distance of the underside of the bench.

For all lifts, instructions to subjects were to aim to complete three repetitions. If the subject was able to complete three repetitions at their maximal weight, their 1-RM was estimated from the factor derived from RM tables (Baechle et al, 2000). If subjects failed after two repetitions, predicted 1-RM score was likewise derived from the corresponding RM table factor (Baechle et al, 2000). In the case that subjects failed after one repetition, this value was taken as the player's 1-RM. High correlations are reported between predicted and measured 1-RM, especially when the predicted score is taken from tests with low repetitions (Abernethy et al, 1995).

Circuit-based Strength Training

The circuit strength training workouts for each training microcycle are displayed in Tables 4.2.2.1 to 4.2.2.5. According to the goal of the respective microcycle, exercise order and rest periods were manipulated to allow a specific amount of recovery time between consecutive lifts with the same muscle group(s). Core stability exercises were performed at the conclusion of each circuit to provide rest between sets. In terms of exercise order, Olympic and multi-joint lifts were placed first in the circuit to ensure they were performed when the lifter was fresh at the start of the workout and rested following the active rest between circuits during later sets. Strength training was performed first in the day to minimise interference effects of other conditioning and team practices (Leveritt & Abernethy, 1999, Baker, 2001). Volume load was calculated for each weekly microcycle, according to the formula below (adapted from Stone et al, 1999):

Intensity (equivalent %1-RM) x Number of Sets x Number of Exercises in Circuit

The weekly volume load values were calculated as the sum of volume loads for all workouts performed in each respective week, presented in Table 4.2.3.

Table 4.2.2.1 – Hypertrophy Cycle (Preseason Weeks 1-2)

Monday **8RM** ***4 sets***	**Wednesday** **12RM** ***3 sets***	**Friday** **10RM** ***4 sets***
Snatch Pull	Bent-over Dumbbell Raises	Deadlift
Bench Press	Dumbbell (straight-arm) Pull-over	Incline Dumbbell Bench Press
Parallel Back Squat	Dumbbell Front Raise	Barbell Bench Row
Bent-over Barbell Row	Dumbbell Bicep Curls	Dumbbell Lunge
Dumbbell Split Squat	EZ Bar Tricep Extension	One-arm Dumbbell Row
Back Extensions	Dumbbell Lateral Raise	Wide-grip Dips
Single-leg Calf Raise	Elastic Tubing Shoulder Rotation	Dumbbell Step Up
Monday **8RM** ***4 sets***	**Wednesday** **10RM** ***3 sets***	**Friday** **12RM** ***3 sets***
Hang Clean	Incline Dumbbell Bench Press	Front Squat
Bench Press	Barbell Bench Row	Back Extension
Deadlift	Standing Dumbbell Shoulder Press	Dumbbell Split Squat
One-arm Dumbbell Row	One-arm Dumbbell Row	Single-leg Calf Raise
Dumbbell Step Up	Narrow-grip Dips	
Standing Dumbbell Shoulder Press	Dumbbell Upright Row + Bicep Curl	
Single-leg Knee Extension		

Table 4.2.2.2 – Strength Cycle (Preseason Weeks 3-4)

Monday **6RM** ***3 sets***	**Wednesday** **8RM** ***3 sets***	**Friday** **7RM** ***3 sets***
Snatch Pull	Single-arm Lat Cable Pull-down	Stop Clean
Bench Press	EZ Bar (straight-arm) Pull-over	Incline Dumbbell Bench Press
Split Jerk	Dumbbell Lateral Raises	Dumbbell Push Press
Barbell Bench Row	Dumbbell Bicep Curls	Front Squat
Deadlift	EZ Bar Tricep Extension	One-arm Dumbbell Row
Single-arm Cable Fly	Dumbbell Front Raise	Dumbbell Overhead Split Squat
	Elastic Tubing Shoulder Rotation	
Monday **5RM** ***4 sets***	**Tuesday** **8RM** ***3 sets***	**Friday** **6RM** ***3 sets***
Stop Clean	Incline Dumbbell Bench Press	Clean + Split Jerk
Bench Press	Bent-over Barbell Row	Bent-over Dumbbell Raise
Push Press	Standing Dumbbell Shoulder Press	Deadlift
One-arm Dumbbell Row	One-arm Dumbbell Row	Dumbbell (straight-arm) Pull-over
Parallel Back Squat	Bicep Curls	Dumbbell Single-arm Overhead Lunge
Back Extensions	Dumbbell Upright Row	Dumbbell Front Raise

Table 4.2.2.3 – Strength & Power Cycle (Preseason Weeks 5-6)

Monday 5RM *4 sets*
Bench Press
Barbell Bench Row
Standing DB Shoulder Press
One-arm Dumbbell Row
Dips
Dumbbell Upright Row

Monday 4RM *4 sets*	**Wednesday** 6RM *3 sets*	**Friday** 5RM *3 sets*
Stop Snatch Pull	Swiss Ball Hyper Push Up	Stop Snatch
Bench Press	Resisted Hip/Knee Drive	Incline Dumbbell Bench Press
Clean + Split Jerk	Bent-over Dumbbell Raise	Clean + Push Press
One-arm Dumbbell Row	Overhead Split Squat	Barbell Bench Row
Deadlift	Dumbbell Upright Row + Bicep Curl	Front Squat

Table 4.2.2.4 – Power Cycle (Preseason Week 7 –Training Camp)

Day One 6RM *4 sets*
Power Clean
Bench Press
Stop Clean + Press
Parallel Back Squat
Wide-grip Chins
Seated Cable Row

Table 4.2.2.5 – Peaking Cycle (Preseason Week 8)

Day One 4RM *4 sets*
Stop Snatch Pull
Incline Dumbbell Bench Press
Stop Clean + Press
Barbell Bench Row
Parallel Back Squat

Table 4.2.3 – Weekly Volume-load Values

Week	Number of Workouts	Weekly Sum of Volume-Loads
Off-season Weeks 1 and 3	3	**35.7**
Off-season Weeks 2 and 4	3	**42.0**
Preseason Week 1	3	**57.5**
Preseason Week 2	3	**43.9**
Preseason Week 3	3	**47.0**
Preseason Week 4	3	**50.6**
Preseason Week 5	1	**20.9**
Preseason Week 6	3	**43.8**
Preseason Week 7	1	**20.4**
Preseason Week 8	1	**18.0**

Statistical Analysis

Repeated measures ANOVA were used to examine changes at each test occasion for the three strength tests. In the case of significant effect, contrasts were used to identify differences for the strength measures between each test occasion. Differences between test occasions were considered statistically significant at $p<0.05$.

4.2.3. Results

Strength test results are presented in Table 4.2.4. Repeated measures ANOVA revealed a significant effect for all three lifts assessed. For all lifts there was no significant difference between end of season testing results and pre test scores.

Table 4.2.4 – Strength Test Scores

TEST	N	End Season (mean ±SD)	Pre (mean ±SD)	Post (mean ±SD)	% Change Pre-Post
Deadlift, kg	13	180.8 ±20.2	183.3 ±21.4	189.7 ±23.4**†	3.5%
Bench Press, kg	26	127.4 ±16.4	126.7 ±16.4	131.0 ±17.0*†	3.4%
Bench Pull, kg	23	105.3 ±12.7	104.8 ±13.1	110.4 ±12.0**†	5.3%

** Significant difference vs End Season (p<0.01)
* Significant difference vs End Season (p<0.05)
† Significant difference vs Pre (p<0.01)

Only thirteen players were able to complete deadlift testing on all three test occasions. This reflected previous data reporting that the lower limb is the most common site of injury in rugby football players (Bathgate et al 2002, Garraway et al, 1999, Wilson et al, 1999). These are typically sustained in collision phases, hence are commonly termed tackle injuries (Wilson et al, 1999). Simple and repeated measures contrasts for their data revealed post test deadlift scores were significantly improved both in comparison to pre-tests (p<0.01) and end season scores (p<0.01) (Figure 4.2.1). There was no significant difference between scores at the end of the previous playing season and the pre test results six weeks later for this lift.

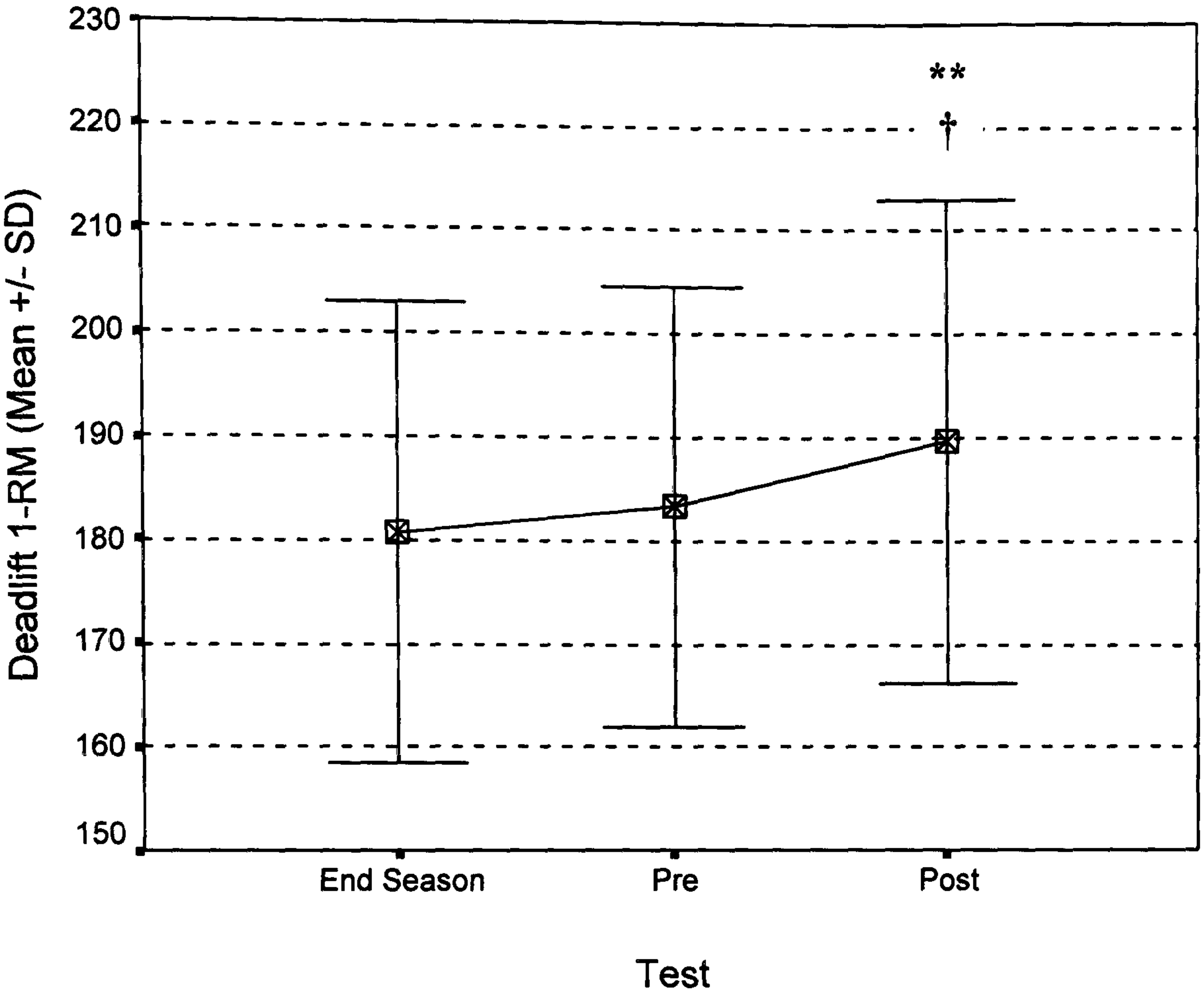


Figure 4.2.1 – Deadlift 1-RM Strength Test Scores

† Significant difference vs **Pre (p<0.01)**

** Significant difference vs **End Season (p<0.01)**

Bench press scores for the twenty-six players able to complete all test occasions were significantly improved following the training period (p<0.01). Likewise, repeated measures contrasts identified that post test bench press scores were improved relative to end season scores, albeit to a lesser extent (p<0.05) (Figure 4.2.2).

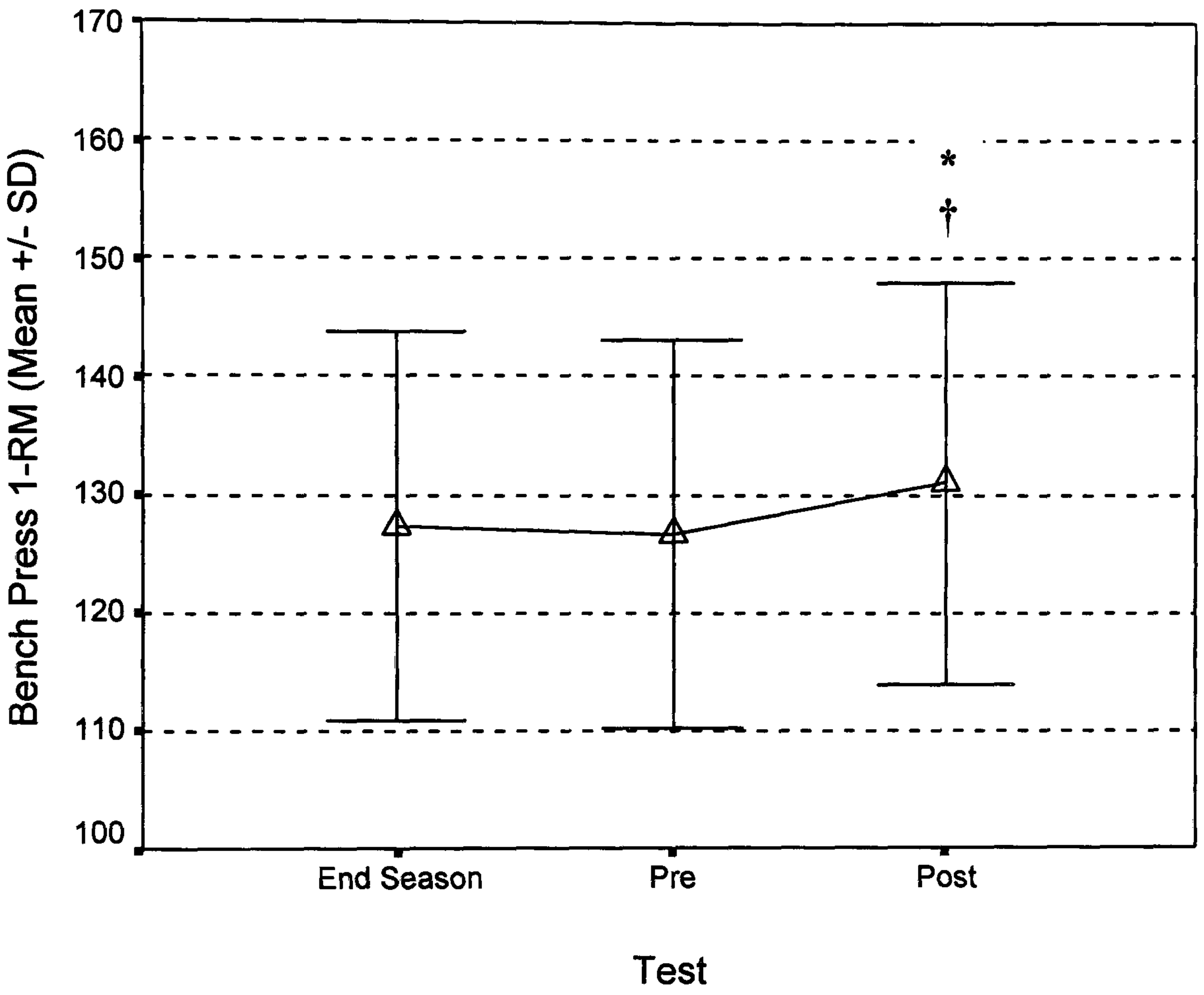


Figure 4.2.2 – Bench Press 1-RM Strength Test Scores

† Significant difference vs **Pre (p<0.01)**
* Significant difference vs **End Season (p<0.05)**

Twenty-three subjects completed bench pull testing on all three test occasions. Repeated measures contrasts revealed post test scores for the bench pull test were significantly improved both in comparison to pre-tests (p<0.01) and end season scores (p<0.01) (Figure 4.2.3).

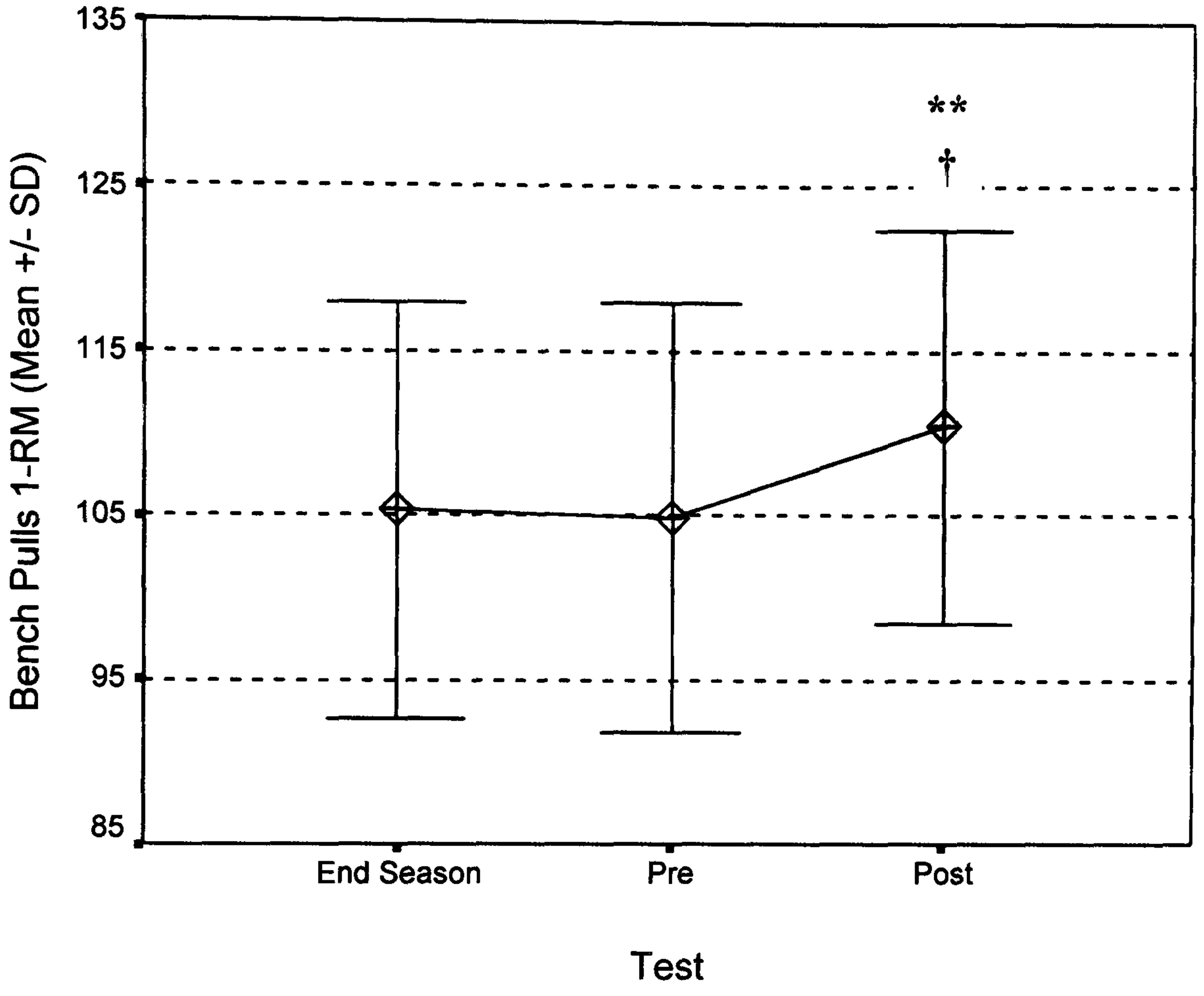


Figure 4.2.3 – Bench Pull 1-RM Strength Test Scores

†	Significant difference vs **Pre (p<0.01)**
**	Significant difference vs **End Season (p<0.01)**

Body mass and sum of skinfold measures pre- and post-training are presented in Table 4.2.5. There was a slight but significant decrease in body mass (≈1kg) over the training period (p=0.031). There was no significant change in sum of skin folds.

Table 4.2.5 – Anthropometric Measures

	Pre **(mean ±SD)**	**Post** **(mean ±SD)**	**p value**
Body Mass, kg	101.0 ±15.3	100.0 ±14.1	0.031
Sum of Skinfolds, mm	60.5 ±19.1	60.1 ±16.2	ns

4.2.4. Discussion

Strength training in a circuit format proved to be successful in improving strength scores for the three lifts following the preseason training period. The gains in strength were in the absence of any gains in lean body mass during the period, thus appear to have been due to neural factors and possibly qualitative changes in muscle proteins (Harris et al, 2000). End of season testing strength scores were maintained when measured at the beginning of the preseason strength training period, indicating that the off-season maintenance program was effective.

Gains in bench press (12.6%) and leg press 1-RM (18.9%) have been reported previously with college-aged American football players following a strength-endurance oriented (8-12RM) multi-set program performed in a circuit fashion (Kraemer, 1997). Relative to end of season values, the magnitude of increase in bench press 1-RM ($p<0.05$) did not reach the same level of statistical significance to those for the bench pull and deadlift ($p<0.01$, respectively). Lesser gains exhibited by strength trained team sports athletes for the bench press lift have been observed previously (Hoffman et al, 1990). The authors attributed this to athletes' tendency to place emphasis on the bench press in their previous training. The average increases in squat 1-RM reported with the college-aged players in the previous study (7.3-7.5%) were broadly similar to the gains in deadlift 1-RM in the current study. The gains in lower body strength (deadlift 1-RM) recorded in the current study likewise resemble average increases in back squat 1-RM (5.3-11.2%) reported elsewhere following a ten week periodised off-season strength training program in college American football players (Wilder et al, 2002). In support of the contention that the circuit strength training format favours whole body training effects, lower body strength and upper body strength for the pushing and pulling movements were all significantly improved.

To the author's knowledge this is the first published study to quantify strength training responses of elite rugby union players. Inevitably, there is a trade-off between attaining access to elite subjects and the scientific rigour it is possible to impose. In the context of professional sport it is difficult to justify interfering with athletes' training and development for the sake of experimental investigation

(Rienzi et al, 2000). Counterbalanced study design requires a control group to act as a baseline for comparison. No coaching staff would consent to having half their squad perform entirely different training, or even no training at all, to satisfy experimental protocol. The reality is it that it would be untenable to disrupt the preparation of a professional team to this extent in view of the financial rewards and consequences of failure (i.e. relegation and possible economic failure) contingent on the team's performance in the subsequent season. As a collision sport, levels of lean body mass and muscularity are significant correlates to success in rugby union football (Olds, 2001). Strength and power scores likewise discriminate elite players from those at lesser levels (Baker, 2001, Baker, 2002, Duthie et al, 2003). Given this crucial importance, individual players would be opposed to having their position on the squad and chances of selection jeopardised in the event they may have been assigned to the 'wrong' experimental group, and received inferior physical preparation to other players in their position as a result.

Such considerations likely contribute to the paucity of data from elite team sports athletes in particular. The absence of contemporary data concerning strength levels of elite players in rugby union football has been recently highlighted (Duthie et al, 2003). The lack of studies denies any opportunity for comparison of the current findings to existing data. Furthermore, recent data suggest that competitive athletes show different dose-response relationships with regard to strength training in comparison even to strength trained non-athletes (Peterson et al, 2004). It appears that a continuum exists in terms of optimal training variables for maximal strength gains, which is dependent on the training status and training experience of the individual (Rhea et al, 2003, Peterson et al, 2004). Elite athletes appear to exist further along this dose-response continuum, hence require considerably different intensity, frequency and volume of strength training to maximise strength gains (Peterson et al, 2004).

This consideration raises questions regarding the relevance of findings in the strength training literature based on investigations involving non-athletic populations, even using subjects with strength training experience (Peterson et al, 2004). There is a critical need to gather data pertaining specifically to athletes, in particular those engaged in team sports. Obtaining access to elite athletes is likely to require some compromise in terms of study design (Millet et al, 2002). Only in this way will it be possible to provide an objective alternative to the ongoing reliance of strength and conditioning coaches working in many team sports on their own observations and personal experience as the primary basis for selection of training modes and methods (Kraemer, 1997).

The lack of detraining evident prior to the circuit strength training intervention supports the assumption that the subsequent improvement in strength scores for the three lifts can be attributed to the effectiveness of the training per se. Had the subjects entered the training period in a detrained state, it could have been argued any form of systematic strength training would likely improve strength scores. The success of the circuit training format is reinforced by the observation that the weekly sum of volume-loads was actually less for three of the eight weeks' preseason circuit strength training program, in comparison to the off-season strength training undertaken (Table 4.2.3).

Given the time constraints imposed by extended playing seasons and high volumes of concurrent training and team practices common to all professional team sports, the efficiency and effectiveness of physical preparation is paramount (Peterson et al, 2004). This is particularly the case for rugby football, given the potential for interference effects from concurrent metabolic conditioning (Leveritt & Abernethy, 1999) and disruption due to the physical stresses of bodily contact during practices and matches (Hoffman & Kang, 2003). Both of these complications place even greater emphasis upon the effectiveness and efficiency of strength training. The reported gains in strength scores were achieved in a relatively short time (eight weeks) and with a limited number of strength training sessions, eighteen in total.

One of the benefits of the circuit format is that it is more time-efficient (Baechle et al, 2000). The time-efficiency of the circuit approach proved particularly advantageous during the latter stages of the preseason training period, due to warm-up games and increasing volumes of concurrent training and team practices.

In the second half of the study period only one weekly strength training session was undertaken during three of the final four weeks of preseason (Tables 4.2.2.1-5). By virtue of the fact that the lifter is able to train other muscle groups during what would be a rest interval under the classical sequential format, a higher volume of work can be performed in the allotted time. All of the strength training sessions were completed within the one-hour training slot allocated, which anecdotally would not have been possible using the traditional approach. Maximising the content of each workout is similarly key given the need to develop strength and power for a myriad of movements required for rugby football. In terms of practicality, the circuit approach favours training large number of athletes (Fleck & Kraemer, 1997 Baechle et al, 2000), and fits the need for the playing squad to perform a large volume of training within a restricted time.

Kraemer (1997) reported improvements in strength endurance (number of repetitions the subject was able to complete at 80 or 85% 1-RM) with American football players following a multi-set strength training at 8-12RM, performed in a circuit fashion. This was attributed in part to improvements in lactate buffering and whole body acid-base balance associated with the circuit format (Kraemer, 1997). The capacity to activate musculature under conditions of fatigue has been identified as a trainable quality (Behm, 1995). Under conditions of fatigue trained individuals appear to have superior ability to fully activate the fatigued muscle groups (Behm, 1995). The circuit strength training format involves all exercises in the workout being performed under similar conditions of progressive fatigue. This characteristic may favour training adaptations involving neural factors associated with the ability to more fully activate fatigued muscles. It is reported that when conventional periodised off-season training moves into strength and power phases, improvements in anaerobic performance (repetitions completed with 80% load) are halted (Wilder et al, 2002). In the current study, strength- and power-oriented microcycles in the training period were also performed in the circuit format. The present study did not include any measure of strength endurance. However, it seems reasonable to expect the continued use of the circuit format throughout the preseason training period should elicit similar or greater adaptations in strength-endurance and power-endurance to those observed previously (Kraemer, 1997).

All the intensity prescriptions for the preseason strength training period were based upon repetition maximum (RM) loads, for the stipulated number of repetitions. It has been shown that with adequate rest (3 minutes) between sets, RM loads can be lifted repeatedly (Kraemer, 1997). The crucial factor influencing capacity to repeatedly perform sets at RM load was identified as rest period between sets. When rest is reduced, ability to perform the prescribed number of repetitions at the RM load may be compromised (Kraemer, 1997). The sequential approach of lifting the prescribed sets for one lift before moving onto the next exercise may lead to insufficient rest between sets to successfully complete the stipulated repetitions with the RM load. Players typically self select rest between sets and may rush through the sets in a effort to perform all the exercises within the limited time allotted for the workout. The circuit format described avoids this, as the muscle groups involved in a particular lift are allowed to rest whilst the player completes the intervening exercises in the circuit, and core exercises between circuits, prior to performing next set. Examination of the players' training logs revealed that they were able to maintain or progress the load from the first set (excluding warm-up set) to the last, for all lifts. Manipulations to the traditional set configuration for Olympic lifts (adopting short rest intervals between consecutive repetitions) have proven to reduce impairments in lifting kinematics in successive repetitions in a set, by reducing residual fatigue (Haff et al, 2003). It is possible that the circuit format may allow similar enhanced lifting kinematics by offsetting fatigue between consecutive sets of a particular exercise.

Hypothetically, the combination of high loads and elevated blood lactates when training in the circuit format should favour augmented responses in the anabolic hormones testosterone and growth hormone, respectively (Kraemer, 2000). In fact, there were no changes noted in body composition and a slight but significant reduction in body mass. This finding is in contrast to the significant gains in lean body mass in college-aged American football players reported in response to ten weeks' off-season strength training (Wilder et al, 2002). This is perhaps unsurprising given the relatively low weekly training frequency for much of the training period in the current study. In addition to the younger subject group, training frequency in the latter study was also higher (four days per week) (Wilder et al, 2002). It has been identified that quite extreme training frequencies (four and five days per week) are required to elicit body mass gains in college-aged American football players experienced in strength training (Hoffman et al, 1990, Kraemer, 1997). It is probable the total weekly volume of work featured in the current study was insufficient to elicit significant increases in lean body mass in this group of athletes, given their advanced training status, and the volume of concurrent metabolic conditioning.

In terms of training specificity, the circuit format bears closer resemblance to the physical demands of match play. As opposed to performing repeated sets with a single movement consecutively, the circuit approach alternates movements and muscle groups in a way that is closer to the intermittent nature of rugby football. Theoretically, this more closely approximates the demands of match play, whereby a player is required to repeatedly develop high levels of strength and power for a wide variety of muscular actions in an unspecified order. The performance benefits of this observed specificity is an aspect that warrants further study.

4.2.5. Practical Applications

Crucially the data presented represent a first step in providing a body of evidence pertaining to the specific training responses of elite-level professional rugby union players. Further data from this population is required to gain greater insight and identify the optimal training parameters for this group of athletes. Maximising the content and effectiveness of strength training sessions available within the constraints of concurrent training and practices is of great practical importance to both players and coaches in rugby football. The present study represents a first step in providing data in support of the efficacy of the circuit approach to strength training. Further studies are required to gather equivalent data, employing conventional strength training approaches with rugby football players of a similar standard, to allow direct comparisons to be made between the respective strength training formats in these athletes.

POWER TRAINING

5.1. Overview

There are two major schools of thought regarding training methods to develop explosive muscular power. Some proponents have suggested it is sufficient to solely develop force-developing capabilities (i.e. strength) for the target movement (accounting for the force element in the force x distance / time equation for power) and then transfer the gains in strength by subsequent practice with the particular athletic activity (Kraemer, 1997). Power output for a given movement is dependent in part on strength. However, this leaves a significant portion of the variance unaccounted for (Baker & Nance, 1999a), particularly for movements featuring lighter resistance (Stone et al, 2003a).

The efficacy of specific power training is demonstrated by the observed improvements in explosive performance (e.g. jump-and-reach height) documented in elite athletes with short-term power training interventions in the absence of any maximal strength gains (Newton et al, 1999). Likewise, Olympic lifts have been found to increase concentric power (squat jump height) in elite strength athletes (champion weightlifters) (Hakkinen et al, 1987). This is particularly significant, as traditional heavy resistance training is relatively ineffective in developing lower body power (vertical jump height) in trained power athletes, despite significant concurrent gains in 1-RM strength (Baker, 1996).

Such considerations led to the genesis of a multidimensional construct for explosive muscular power. Several discrete elements of the neuromuscular system have been isolated, all of which influence power output (Newton & Kraemer, 1994, Newton, 2002). Each of these individual components of the neuromuscular system can be considered trainable. Mixed methods training strategies propose employing a range of training modalities to specifically train each neuromuscular capacity implicated in the expression of explosive power. These factors, targeted via appropriate training, can individually contribute to the development of explosive power capabilities (Newton & Kraemer, 1994).

Evidence as to the efficacy of mixed methods training is seen by the superior results elicited by combination training in comparison to either high force or high power training (Harris et al, 2000). Greater gains are reported with strength trained athletic subjects (college American Football players) on a wider range of performance measures representative of a broader spectrum of the force/velocity curve in response to a combination of both high-force and high-velocity 'power' training. Performed individually, the effects of high force training are limited to gains in maximal strength (1-RM) and heavy load speed-strength (hang pull 1-RM) measures, with no impact on dynamic athletic measures. Conversely, the high-velocity 'power' training resulted in gains in dynamic measures, with no impact on heavy load capabilities (Harris et al, 2000). Interestingly combination training not only yielded the benefits associated with both single training modes, but also produced gains on measures (ten yard shuttle agility run and average vertical jump power) not seen with either high-force or high-velocity training alone (Harris et al, 2000). Adaptation to high force or high velocity training performed in isolation by strength trained athletes is reflected in performance measures that are restricted to the region of the force/velocity curve that characterised the training. Furthermore, combined methods are observed to be most effective in developing vertical jump height (the standard measure of lower body power production) (Baker, 1996). Superior performance effects of combined training were attributed to exploiting different avenues of explosive performance development simultaneously.

The individual elements that have been implicated in the expression of explosive muscular power will be discussed in turn.

5.1.1. Factors in the Expression of Explosive Muscular Power

Rate of force development (RFD) describes the ability to develop force within a limited time frame. This component represents the slope of the force/time curve for a muscular action (Newton & Dugan, 2002). Accordingly it is associated with the ability to achieve rapid acceleration for a given movement (Stone, 1993). The time interval for force development in many athletic movements is very brief – typically within 300 ms (Newton & Kraemer, 1994). On this basis RFD has been identified as possibly the most important capacity influencing athletic performance (Wilson et al, 1995). It follows that the time in which to develop force allowed by the training exercise must be similarly brief to train the neuromuscular system to develop maximal force across these shorter time frames. An illustration of this is that the closer the time interval of a given dynamic strength measure to the contact time observed for an athletic movement the greater the correlation to performance (Young et al, 1995). Motor unit firing rates are appreciably higher during the short window for force development associated with maximal ballistic concentric actions (Hedrick, 1993, Behm, 1995). Traditional heavy strength training would appear to be unsuitable for developing this RFD component; a heavy barbell squat for example can take around 1.5-2 seconds to complete the concentric portion of the movement (Baker, 2001d). Under certain conditions improvements in isometric RFD have been noted following isometric training in non-athlete subjects (Behm & Sale, 1993), however the relevance to athletic performance of both isometric training (Morrisey et al, 1995) and isometric measures of RFD (Wilson et al, 1995) have been questioned.

Slow velocity (1-RM) strength is required at the initiation of any explosive movement to overcome inertia at zero or low movement speeds (Stone, 1993). Maximum strength has a major influence on the initial rate at which force is developed early in the movement (Stone et al, 2003). Maximum strength is a key element in power output for gross motor actions involved in athletic movements. For locomotion and jumping movements in particular, even in the absence of external resistance, there is a significant inertia component. Hence high correlations are observed between 1-RM strength and power output even for unloaded jumps. Furthermore, slow velocity strength development influences the relative resistance at which peak mechanical power output is manifested. Subjects with greater strength training levels exhibit peak power output against heavier resistance (40% 1-RM vs 10% 1-RM) during dynamic movements (loaded vertical jumps) than individuals with little or no prior strength training experience (Stone et al, 2003a).

High-velocity strength, or speed-strength, is the ability to exert force at high contraction velocities. Increases in maximum strength are of limited relevance if the athlete is unable to express this greater force at the movement velocity encountered in competition (Hedrick, 1993). The neuromuscular basis for improvements in force development at higher velocity regions of the force-velocity curve are neural adaptations in the capability to preferentially recruit high-threshold motor units (Stone, 1993, Cronin, 2001) and the capacity of these motor units to fire rapidly for short intervals (Hedrick, 1993).

Stretch-shortening cycle ('SSC') comprises series elastic contractile and connective tissue elements and neural potentiation via the stretch reflex. Stretch-shortening cycle performance characteristics are found to be independent of maximal muscle strength in highly trained athletes (Plisk, 2000). SSC performance in part depends on the capacity of the musculoskeletal complex to store and use elastic tension (Yessis, 1994, Newton et al, 1997). The neural component underlying the augmentation of power output immediately following pre-stretch is associated with the 'stretch reflex'. This is a peripheral reflex at local spinal level that acts to stimulate the stretched muscle to contract, in an attempt to return the muscle to its previous length (Potach & Chu, 2000). This stretch reflex-mediated neural drive is superimposed upon voluntary drive to the agonist muscles, which leads to augmentation of power output in the subsequent concentric phase (Newton et al, 1997).

The final component of explosive power is neuromuscular skill. This encompasses both inter-muscular and intra-muscular co-ordination. Intermuscular coordination concerns the interaction between agonist, synergist and antagonist muscle groups (Newton & Kraemer, 1994). Broadly, intramuscular co-ordination comprises the recruitment and firing of motor units of muscle groups involved in the movement. This encompasses both excitatory and inhibitory inputs to the muscles (Cronin et al, 2001).

5.1.2. Development of Explosive Muscular Power Capabilities

The neuromuscular firing patterns observed during strength-oriented and explosive movements are reported to be grossly different (Ives & Shelley, 2003). In the case of gross muscle actions, speed-strength exercises have been identified as the optimal means to target the elements of explosive power production described. As implied in their title, speed-strength exercises combine both high force (strength) and high velocity (Hydock, 2001). Speed-strength exercises are characterised by maximal rates of force development (Hedrick, 1993) throughout the movement range of motion (Stone, 1993). These power-oriented exercises have thus been termed 'full acceleration' exercises (Baker, 2003).

Speed-strength training is associated with preferential hypertrophy of high-threshold Type II muscle fibres (Stone, 1993). Intent is key to the neural factors underlying the adaptations in high-velocity strength and rate of force development associated with speed-strength training (Behm & Sale, 1993). Due to their explosive nature, speed-strength exercises are more suited to evoke explosive intent. In the case of conventional strength training lifts such as the bench press, athletes must be coached to make a conscious effort to lift with explosive intent to optimise training responses on explosive power scores (Jones et al, 1999). When subjects are left to self-select lifting velocity gains in strength and power following training are reportedly reduced by half (Jones et al, 1999)

5.1.3. Olympic Weightlifting

Olympic lifts are classified as speed-strength exercises. These lifts are unique in that the resistance (a barbell) is accelerated up the natural line of the body (Kraemer, 1997), so the lifter's feet merely come off the floor in the event that the barbell is still travelling upwards at the termination of the pulling phase. Likewise, gravity acts to decelerate the load, all of which means the neuromuscular system does not have to intervene to brake the motion of the barbell. Average mechanical power output values reported for the Olympic lifts are 3000W for Snatch and 2950W for the clean, which are nearly three times greater than for back squat or Deadlift (approximately 1100W) (Stone, 1993, Garhammer, 1993). Peak power output, measured during the 'second pull' phase, can be five times greater (5500W) (Stone, 1993). Elevating the athlete's own centre of mass represents a significant component of the work done when performing Olympic lifts (Garhammer, 1993). Peak propulsion forces for these lifts are similarly comparable to those during jumping movements (Stone, 1993).

Olympic lifts predominantly develop contractile elements, as opposed to SSC components, and this mode of speed-strength training primarily develops concentric performance. Observations of a year's weightlifting training in elite weightlifters registered significant improvements in unloaded and loaded squat jump height in the absence of any significant change in countermovement jump height (indicative of SSC performance) with equivalent loads (Hakkinen et al, 1987). Elite weightlifters record some of the highest squat jump heights of all power athletes. Similarly, these athletes also exhibit very small differences between squat jump and countermovement jump scores, indicating limited SSC augmentation of jumping performance (Baker, 1996).

The unique nature of Olympic lifts allows heavy loads to be handled in an explosive fashion (McBride et al, 1999). This enables speed-strength and maximum strength elements to be developed simultaneously. In accordance with this, Olympic lifters exhibit equivalent strength scores in addition to superior dynamic power scores to powerlifters (McBride et al, 1999). That said, Olympic lifters also perform classic strength oriented lifts in their training, which contributes to their strength development. On the basis of their biomechanical similarity and comparable time frames for concentric force production, Olympic lifts are routinely used in athletes' physical preparation as a means to replicate sport specific movements (Souza et al, 2002). Olympic lifts also offer the ancillary benefit of lesser impact forces to those experienced with other ballistic speed strength training modes when landing (e.g. Jump Squats) (Stone, 1993).

5.1.4. Ballistic Resistance Training

Ballistic resistance exercises represent the other major speed-strength training modality. This form of training is unique in that the load is released or projected into free space at the end of the movement. It is this characteristic that makes ballistic resistance training superior to conventional strength training exercises in developing elements of explosive muscular power (Cronin et al, 2003). Projection of load is identified as the most important factor influencing peak power output for a given training movement (Cronin et al, 2001). This is reflected in greater average and peak velocities with upper body movements for a range of loads (30-60% 1-RM) under conditions where the load is projected into free space (Cronin et al, 2003). Releasing the load at the end of the range of motion enables the resistance to be accelerated for longer; thereby greater movement velocities are produced as peak velocity is achieved later in the movement (Newton et al, 1996, Cronin et al, 2003).

Conventional strength training modes are unsuitable for explosive training as they require the load to be brought to a stop at the end of the range of motion. Attempting to use traditional strength training exercises in an explosive fashion (lifting the load as rapidly as possible, keeping hold of the barbell at the termination of the movement) has been shown to be counterproductive (Newton et al, 1996). Lifting lighter 'power training' loads (45% 1-RM) in this manner results in a significant deceleration component, which can be up to 40% of the range of motion (Newton et al, 1996). As a result, in the case of the bench press, beyond the initial 10% of the range of motion at the initiation of the concentric movement, both force and velocity are less than the corresponding values for the ballistic bench throw at equivalent loads (Newton et al, 1996). This is accompanied by a loss of motor activity in agonist muscles, reflected in reduced EMG recorded for the bench press versus bench throw movement at these loads (Newton et al, 1996). Antagonist co-contraction is likewise increased when explosively performing the bench press exercise, particularly with light loads (Cronin et al, 2001). As a result, the training stimulus is compromised for the affected portion of the movement (Cronin et al, 2001). Furthermore, efforts to lift a submaximal resistance with maximal acceleration results in the barbell gathering considerable kinetic energy, which will ultimately have to be absorbed by the muscles and joints at the end of its range of motion (Kraemer et al, 1994). Attempting to use conventional strength training exercises in this manner therefore engenders the risk of injury.

It has been contended that ballistic training with 'Pmax' loads that maximise mechanical power output is the optimal means of developing explosive muscular power (Wilson et al, 1993, Baker et al, 2001a, Baker et al, 2001b). These methods have been proven effective in developing power output and scores for dynamic athletic performance (Wilson et al, 1993). However, employing Pmax training modes in isolation tends to neglect the principles of specificity. Whereas a particular training load may be optimal for developing mechanical power output for a given movement, if the loading bears no relation to the resistances the athlete faces during competition, the transfer to performance if this is the sole training mode for developing explosive power appears questionable. It is similarly unlikely that training solely at Pmax resistance will provide optimal training responses at both extremes of the force/velocity curve, as suggested by some proponents (Cronin et al, 2001). Lower body intensive movements in particular are heavily dependent on maximum strength – reflected in the strong relationships between 1-RM strength and loaded vertical jump scores even with light resistance (Stone et al, 2003a). Conventional heavy load strength training is thus necessarily an integral component of physical preparation for most athletes. The use of lesser resistances to Pmax during the course of plyometric and specific speed and agility training may also be required for optimal adaptation at the high velocity/low resistance portion of the force/velocity curve (Baker et al, 2001b).

5.1.5. Plyometric Training

Plyometrics are a special class of ballistic training that emphasises both SSC and eccentric components (Matavulj et al, 2001). Plyometrics feature aspects of ballistic training benefits during the concentric phase, albeit often to a lesser extent than conventional ballistic exercises (Wilson et al, 1993). However, the major benefit of this training mode is that targeted plyometric training can develop the capacity to harness mechanical and reflex potentiation during the preparatory countermovement in SSC movements. Accordingly, the addition of plyometric training to the physical preparation of trained elite junior athletes is shown to elicit significant improvements in vertical jump performance in these athletes (Matavulj et al, 2001).

The underlying mechanisms for improvements in SSC performance with repeated exposure to plyometric training appear to implicate descending neural input from higher motor control centres. Specifically, this descending input is postulated to modulate locally mediated inhibition of stretch reflex neural pathways (via Golgi

Tendon Organ) immediately prior to and during the pre-stretch phase. Plyometric training thus leads to 'disinhibition' of stretch reflex-mediated neural drive during the countermovement, which serves to augment power output in the subsequent concentric phase (Newton & Kraemer, 1994). Performance improvements appear to be manifested in enhanced force and RFD capabilities of the hip extensors and knee extensors (Matavulj et al, 2001). Plyometric training in the form of depth jumps can also evoke improvements in eccentric RFD with short-term progressive training at increasing drop heights (Wilson et al, 1996). This improvement in rate of eccentric force production is suggested to enhance storage of elastic energy in the musculo-tendinous unit. In this way it appears there is potential for mechanical improvement in SSC performance in response to progressive plyometric training (Wilson et al, 1996).

One of the most notable applications of plyometric training is for sprinting. Sprinting is essentially a cyclic movement that comprises repeated stretch shortening cycles (Delecluse, 1997). Thereby there is a considerable series elastic component (SEC) contribution to power output and energy production, which becomes greater as velocity of locomotion increases (Delecluse, 1997). Similarly, the interval for force production during sprinting (dictated by foot contact time) is less than half that for vertical jumping, and much shorter than that allowed by speed strength training modes (Mero & Komi, 1994). This may be a factor in the frequent failure of speed-strength training studies to produce significant effects in sprint performance over longer distances (30-40m), despite concurrent improvements in vertical power measures and acceleration (10m sprint) parameters (Wilson et al, 1993, Lyttle et al, 1996, Harris et al, 2000). Cyclic horizontal bounding and jumping plyometric exercises therefore appear the most appropriate training modes to develop sprint capabilities. Bounding in particular features comparable horizontal propulsion forces, foot contact position and contact times, and muscle activation to those recorded during sprinting (Mero & Komi, 1994). Despite the extensive use of plyometric training in particular for lower body dominated athletic training, there is a lack of systematic investigation to determine the optimal load for plyometric exercises (Wilson et al, 1993). Standard methods for upper- and lower-body plyometric training are likewise yet to be established empirically (Vossen et al, 2000). In the absence of such data, body weight is typically used as resistance due to convenience. This may contribute to the lesser improvements in concentric performance with conventional plyometric training exercises.

5.1.6. Complex Training

Complex training, or contrast loading, is a method often used in conjunction with ballistic or plyometric exercises. Essentially, contrast loading incorporates a heavier load strength oriented exercise prior to performing a full acceleration (typically ballistic) exercise (Young et al, 1998, Baker, 2003). This scheme is an attempt to harness transient mechanical and neural effects of the preceding heavy load to augment power output when the speed strength exercise is subsequently performed (Baker, 2003). To date, acute contrast loading effects have been most widely documented with lower body exercises, typically with jump squats as the target ballistic activity. Acute potentiation of dynamic lower body performance has been consistently observed with standing long jump, vertical jump and jump squat scores when performed immediately following a heavy load set with a strength-oriented lower body exercise, typically a squat (Young et al, 1998, Baker, 2003). It appears that the primer lower-body exercise need not be a strength training exercise with heavy load; similar short-term performance enhancement has been observed by performing an intervening set at a heavier resistance with the same ballistic exercise (jump squats) (Baker, 2001). Significant positive correlation is reported between lower body strength and the degree of potentiation with contrast loading (Young et al, 1998). Hence, it appears the mechanisms underlying acute performance augmentation with this approach play an increasing role with advances in strength levels (Young et al, 1998, Baker, 2003).

Data for upper body complex training has been more equivocal. It has recently been elucidated that a lesser load (≈65% bench press 1-RM) for the primer exercise set appears to be more effective in producing enhanced power output in the subsequent target upper body power activity (Baker, 2003). This has been identified as the reason why previous studies featuring heavier upper-body contrast loads (85-90% bench press 1-RM) did not observe any acute performance augmentation effect (Baker, 2003).

Tension-sensitive mechanical and neural mechanisms have been identified as underlying the acute performance effects observed with contrast loading (Baker, 2003). Mechanical factors are suggested to involve transient changes in stiffness of series elastic components within the musculotendinous unit. The preceding heavier load is taken to modify the stiffness of these elements in a way that is favourable to power output with the ensuing power activity (Baker, 2003). The various postulated neural mechanisms principally involve acute changes in autogenic inhibitory inputs to motor units involved in the movement. The general consensus is that higher motor centres exert some descending input to modify the various peripheral pathways involved. The probable mediating factors at the level of the motor unit are the Golgi tendon organ (GTO) and Renshaw cell. The net peripheral effects likely comprise reduced inhibitory input to the agonist muscles and increased reciprocal inhibition of antagonist motor units (Baker, 2003). These mechanical and neural effects are transient and are believed to dissipate within minutes of performing the heavy contrast load exercise (Baker, 2003).

Due to the paucity of data regarding contrast loading, chronic effects associated with the use of complex training have to date received little research attention. As a result, possible mechanisms for any performance improvement elicited by the long-term use of complex training are yet to be determined.

5.1.7. Coordination Training

It is recognised that specific power training aimed at improving a particular aspect of athletic performance is only effective if muscular power developed through training transfers to performance of the particular athletic movement or sport skill (Harris, 2000). Power output for a given action exhibits learning effects with repeated exposure to the specific training movement (Ives & Shelley, 2003). In the case of fine motor skills, the training stimulus must feature a high degree of specificity to simulate the movement patterns and velocity encountered in competition in order to elicit improvements in power output for the particular skill movement, particularly with experienced athletes (Newton & Kraemer, 1994). The concept of coordination training has been introduced to describe training modes that satisfy these criteria. Specifically, coordination training modes should allow coordination of agonist, synergist and antagonist force output for the pattern and velocity of movement featured in the particular athletic activity (Newton & Kraemer, 1994).

A very high degree of specificity does however appear to be required. Despite the greater similarity noted for the force/time curve for the bench throw movement with regard to sport-specific movements, bench throw training was found not to offer any advantage to conventional bench press training in developing netball pass velocity in female players, despite the apparent greater biomechanical specificity (Cronin et al, 2001). Accordingly, successful coordination training modes typically apply resistance directly to the specific athletic movement. Pulleys have been used with some success for the over-arm throwing movement (Escamilla et al, 2000). Underweight and overweight versions of sports equipment have likewise been employed to offer a training stimulus whilst performing the sports skill (van den Tillar, 2004).

Application of Olympic Lift Training to Develop Game-Related Power in Junior Academy Rugby Union Football Players

5.2.1. Introduction

A key factor in success when participating in rugby football is the capacity to generate high power output against large external resistance. Power measures for both lower body and upper body distinguish elite players from those at lesser levels (Baker, 2002, Baker, 2001b). Expression of explosive power involves a combination of high-force 'speed strength' and rate of force development (RFD). These properties can be trained concurrently via the use of Olympic lifts, which combine heavy loads and high velocity of movement (McBride et al, 1999). Hereby, the Olympic lifts are unique, and are defined as speed-strength exercises (Stone, 1993), on this basis that they feature both a force (strength) and speed component (Hydock, 2001).

Olympic lifts are identified as combining strength, power and neuromuscular coordination elements in a way that favours transfer to athletic activities, such as vertical jump performance (Kraemer et al, 2002). Cross sectional studies show athletes for whom training predominantly comprises Olympic lifts and their associated exercises exhibit superior performance on dynamic tests of muscular power (McBride et al, 1999). Of further relevance to rugby football is that Olympic lifting ability is likewise shown to be highly correlated with 10m and 40m sprint performance in rugby league players (Baker & Nance, 1999b). Typical sprinting distances during matches in rugby union football are reported to be 20m (Duthie et al, 2003). As a result, both these 'off-the-mark' and short-moderate distance sprint abilities are fundamental components of successful performance in rugby union, particularly at elite level.

The aim of the study is to examine the transfer of Olympic lift training to the ruck clean movement. This action is unique to rugby union, arising from the fact that possession of the ball is actively contested after each tackle is made (Gamble, 2004). The effectiveness with which supporting players 'clean' opposing players from the vicinity of the tackled player is decisive in determining which team subsequently secures possession of the ball. Developing explosive power for this specific action is thus fundamental to success in rugby union football.

An Olympic lift training intervention was undertaken with junior academy–level rugby union players. The Clean Pull and Snatch Pull lifts were employed, which comprise the highest power output phase of the classical Olympic lifts; the 'second pull' (Souza et al, 2002). The effect of the addition of these lifts to the athletes' training on mean power during a simulated ruck clean movement was assessed. It was hypothesised that the biomechanical and kinematic specificity of this form of power training would be reflected in superior gains on the game-related power output measure.

5.2.2. Methods

Subjects

Twelve junior academy rugby players (age 17.0 ±1.0 yrs; height 179.4 ±5.7cm; weight 88.2 ±11.8kg, mean ±SD) were matched for playing position and assigned to Olympic lift (OL) training group or control (CON) training group. All subjects were members of the regional elite player development group. One subject in each group failed to complete the study period, due to injury or absence. Hence, five subjects completed the OL training and testing, and five subjects completed training and testing in the CON group.

Game-related Power Testing Apparatus

Purpose built test apparatus (Grunt 3000, University of Otago, New Zealand) was used to derive power output for the simulated ruck clean movement. The apparatus consists of two vertical pads mounted upon a heavy-duty trolley on fixed wheels. The front of the trolley was attached via steel cables to a rigid bar, which in turn was connected by steel cables to a bungee cord. The opposite end of the bungee cord was attached at one end to a force transducer; the other end of the force transducer was bound to an inelastic canvas belt, which was anchored to a metal loop sunk into the floor (see Figure 5.2.1.).

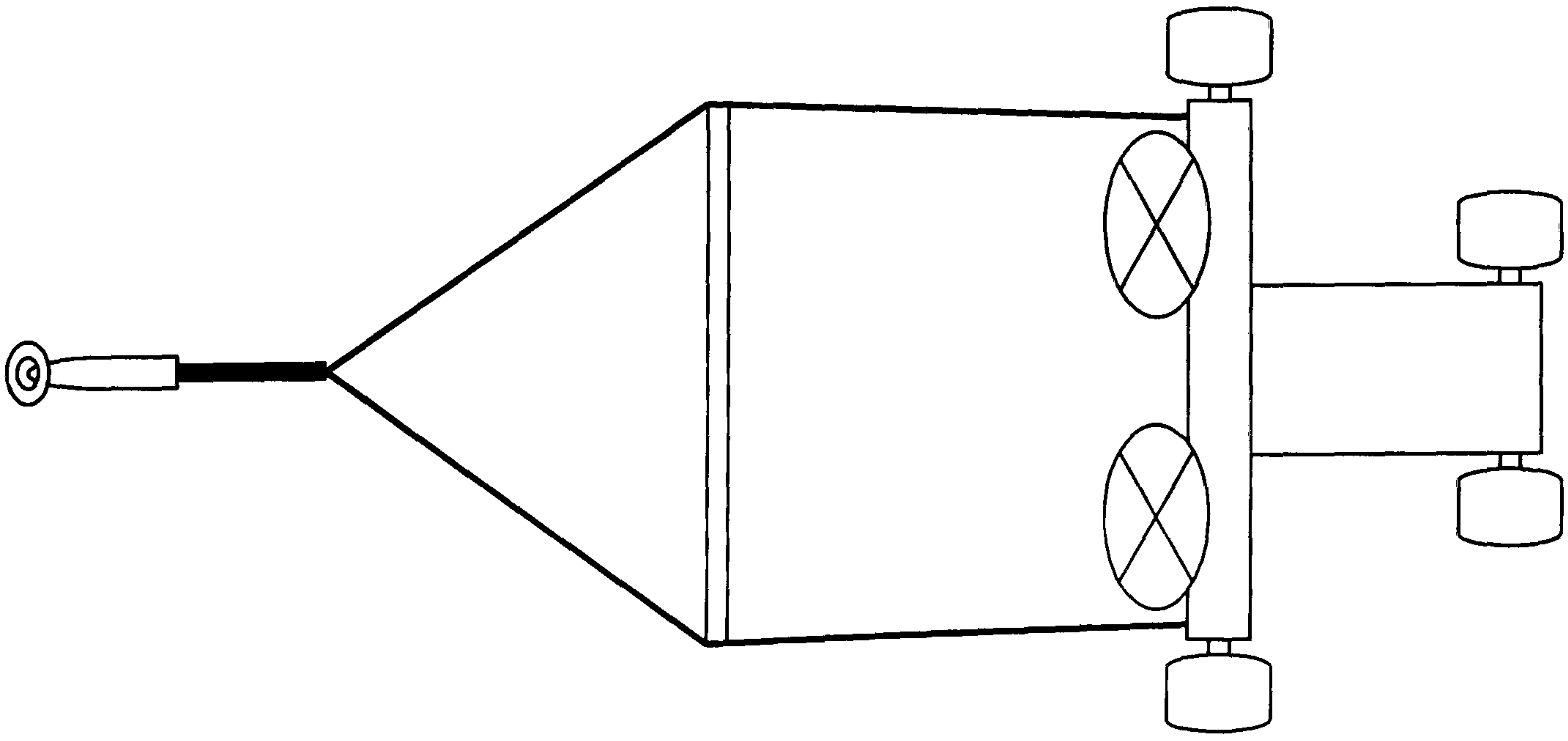


Figure 5.2.1. – Schematic of the Grunt 3000 Rucking Test Apparatus

Game-related Power Assessment

Testing was undertaken in the week prior to the start of the training period, and at its completion. For each trial, subjects positioned themselves at arms length from the pads when bent forward from the waist. From an upright position, the subject then stepped towards the apparatus and hit the pads with both shoulders. As the trolley moved back from the initial impact the subjects chased the unit, continuing to exert force for a few short steps before disengaging from the pads. Subjects were constrained to a window of 1000ms in which to exert force against the apparatus. If the power/time trace indicated they had exceeded this time interval before disengaging, the trial was discarded and repeated. The mean score of three valid trials for each subject was used for further analysis.

Computation of Peak Power Output

Software (Sportstec Grunt 3000, University of Otago, New Zealand) received inputs from the force transducer and a cadence sensor mounted to the rear wheel of the trolley. From this a power/time trace was produced and peak power for each trial was displayed.

Strength Testing

3-RM deadlift testing was undertaken two weeks prior to the training period and at its completion, using the procedures described by Baechle et al (2000). The test-retest reliability (ICC, r = 0.96) of an equivalent isoinertial lower body strength test (parallel squat 3-RM) has been established previously in a corresponding group of junior rugby league players (Coutts et al, 2004).

Instructions to subjects were to aim to complete three repetitions. If the subject was able to do complete three repetitions at their maximal weight, their 1-RM was estimated from the factor derived from RM tables (Baechle et al, 2000). If subjects failed after two repetitions, predicted 1-RM score was likewise derived from the corresponding RM table factor (Baechle et al, 2000). In the case that subjects failed after one repetition, this value was taken as the player's 1-RM. One subject in the OL groups was unavailable for strength testing prior to the study;

one subject in the CON group was unable to complete strength testing at post testing.

Training Protocol

Training was performed twice weekly, completing eight sessions in the four weeks of the training period. The OL training intervention alternated between Clean Pull and Snatch Pull lifts on consecutive sessions, depicted in Figures 5.2.2 and 5.2.3. Both these lifts are executed from the floor. In the case of the snatch pull, the lifter's centre of mass is slightly lower in the start position as a consequence of the wider grip width (Garhammer, 1993). Typically, the weight lifted for the snatch lifts are around 80% of that lifted for the respective clean lifts; however, power outputs for snatch and clean lifts tend to be comparable (Garhammer, 1993). Subjects performed three sets of six repetitions for clean pull or snatch pull after a warm-up set, as part of their normal workout. For these lifts a 'cluster set' configuration was employed. Specifically, subjects were instructed to replace the bar on the mat and pause for 10-15 seconds to 'reset' between each repetition. This approach is shown to better maintain lifting velocity during successive repetitions (Haff et al, 2003). The CON group in turn performed the dumbbell full squat exercise, matched for load and volume. All training sessions were supervised, and the strength training performed by the two groups was otherwise identical.

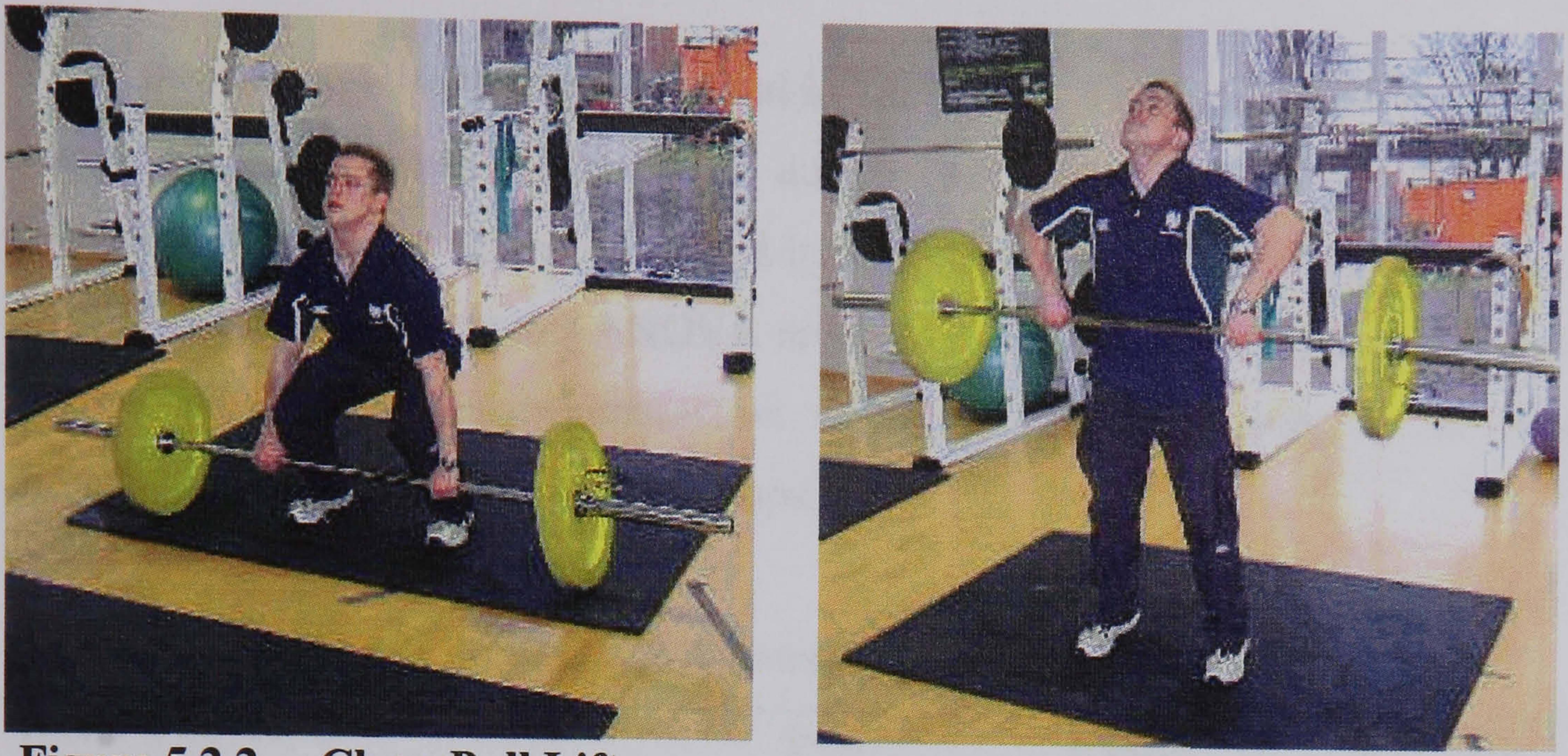


Figure 5.2.2. – Clean Pull Lift

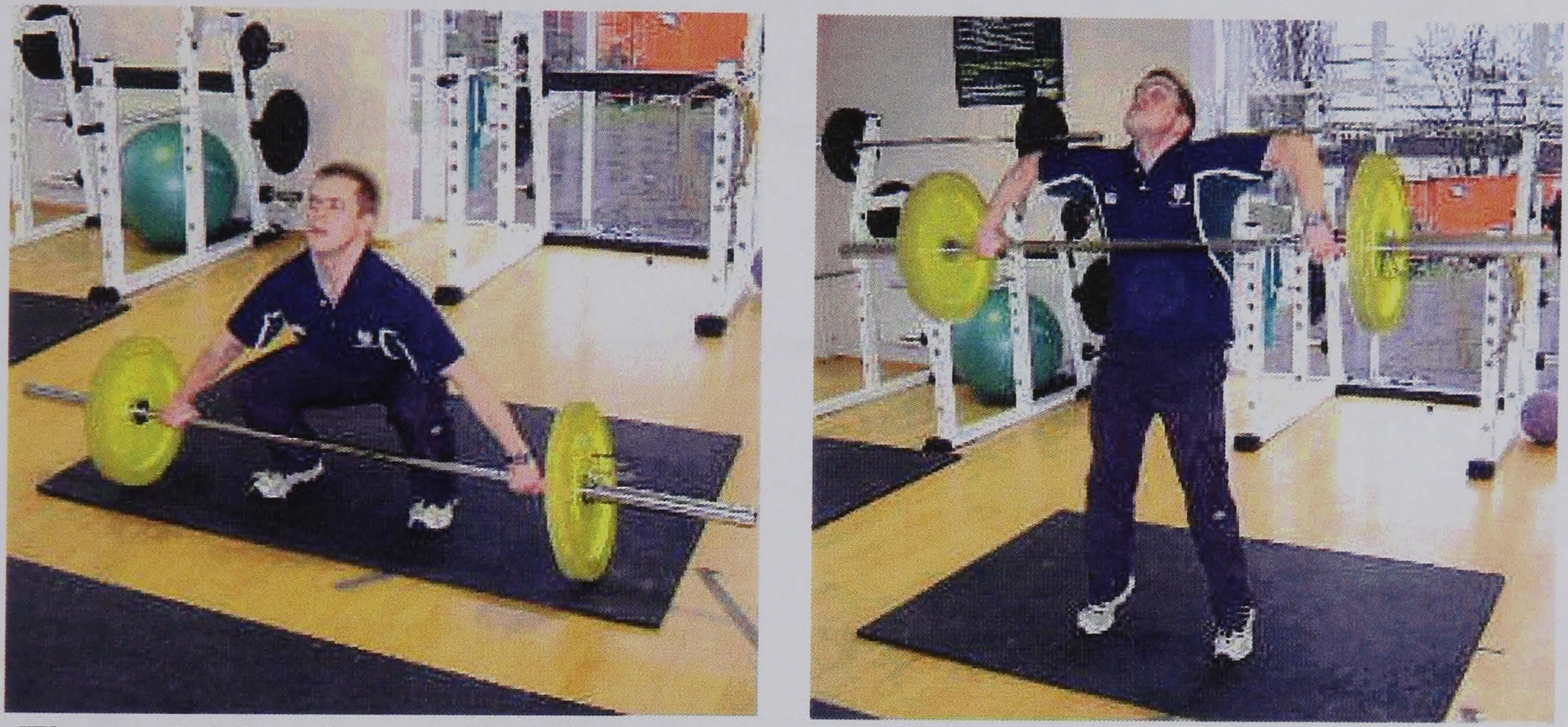


Figure 5.2.3. – Snatch Pull Lift

Statistical Analysis

For both mean power output and deadlift 1-RM data, 2 x 2 (test occasion x group) repeated measures ANOVA were performed to evaluate effects of training and training group. Paired Student's t-tests were used to assess differences on each test measures for control and training group, respectively. In all analyses, an alpha level of 0.05 was accepted as statistically significant.

5.2.3. Results

Mean power output scores are presented in Table 5.2.1. Both groups showed some improvement in mean power output during the rucking test on the post test occasion, however the gains registered by OL subjects were significantly greater ($p<0.01$). Repeated measures ANOVA revealed a significant main effect, but also demonstrated a significant interaction effect ($p<0.01$), indicating a different training response between the two groups.

Table 5.2.1 – Mean Power Output Scores

Power Output, W	Pre	Post	p value	% Change
OL	702 ±124.5	901 ±85.7	<0.01	28%
CON	666 ±90.3	722 ±111.2	<0.05	8%

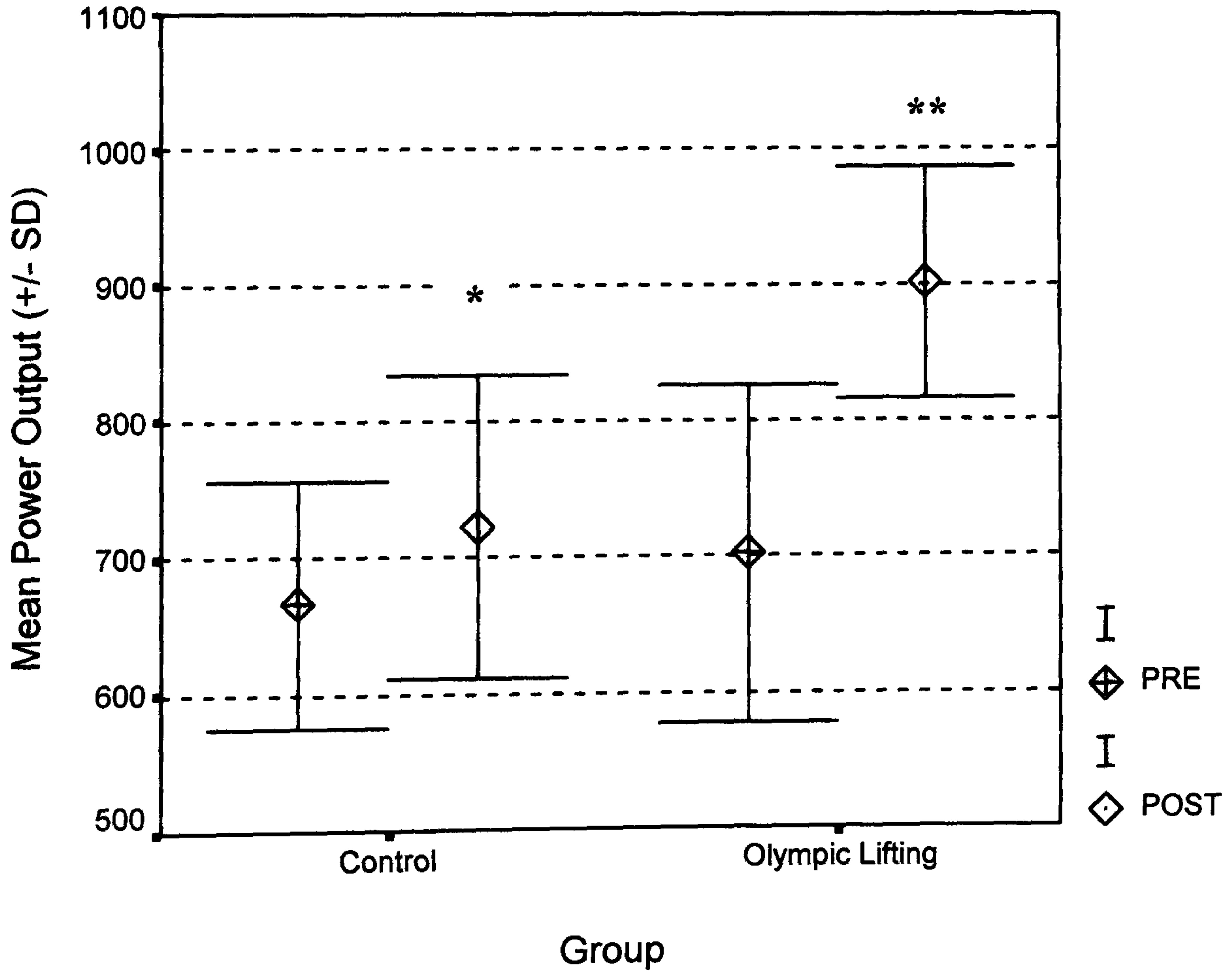


Fig 5.2.4. – Rucking Test Mean Power Output Scores

* Significant Increase ($p<0.05$). ** Significant Increase ($p<0.01$)

Deadlift 1-RM scores are presented in Table 5.2.2. Both groups showed an upward trend in strength scores, but only the improvement of the OL group reached significance ($p<0.05$). Repeated measures ANOVA revealed a significant main effect of training, however there was no interaction effect, suggesting no difference in the response to training for this measure between the two groups. The scheduling of the strength testing (two weeks prior to the start of the training intervention) meant that six weeks elapsed between pre and post tests, during which time subjects continued to engage in their normal strength training. This may partly account for the magnitude of change in both groups on this measure.

Table 5.2.2 – Deadlift 1-RM Strength Test Scores

Deadlift 1-RM, kg	Pre	Post	P value	% Change
OL	151.9 ±15.4	165.8 ±13.5	<0.05	10.9%
CON	143.8 ±20.3	157.8 ±11.2	Ns	9.7%

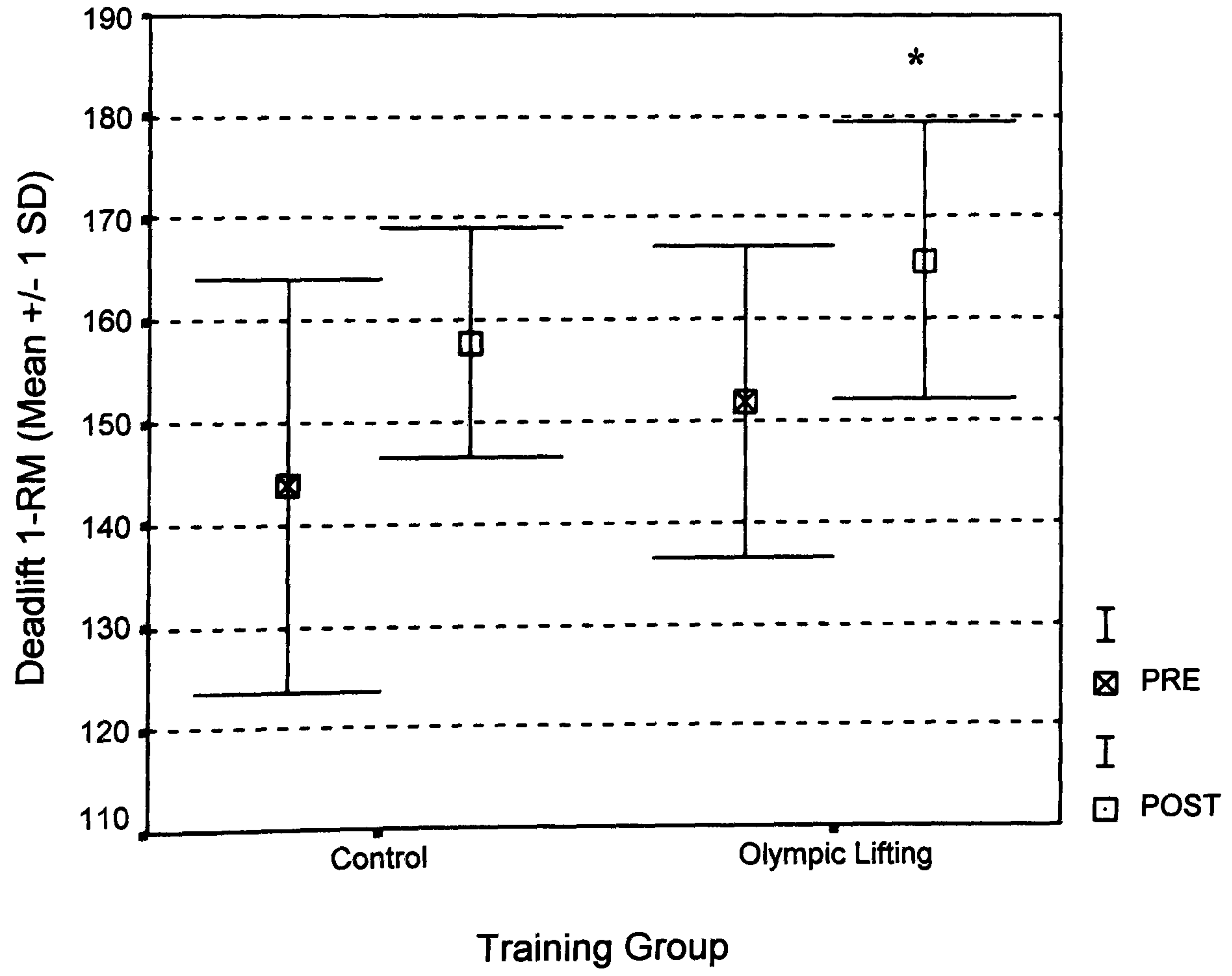


Fig 5.2.5. – Deadlift 1-RM Strength Test Scores

* Significant Increase ($p<0.05$)

5.2.4. Discussion

The Olympic lifts would appear to have a high degree of mechanical specificity in relation to gross motor actions featured in rugby union, such as tackling and clearing opposition players from the tackle area. It was hypothesised that this biomechanical similarity would be reflected in significant carry over of Olympic lift training to power output for the simulated ruck clean movement measured on the apparatus. In support of this contention, the increases in power output in the current study were significantly greater for the OL training group compared to the control group (28% increase vs 8%).

In agreement with the current findings, significant improvements in athletic performance (shot put distance) have been reported previously with collegiate throwers in response to strength training incorporating Olympic lifts (Stone et al, 2003b). The integration of strength, power and neuromuscular coordination offered by Olympic lift training has been identified previously as favouring transfer of training to athletic performance (Kraemer et al, 2002), which was affirmed by the current study. Concentric measures of speed strength (loaded squat jump) show high correlations with sprint start ability (Young et al, 1995). The ruck clean movement is biomechanically very similar to the sprint start. Assuming this is a causal relationship, gains in concentric speed strength developed by Olympic lift training would be expected to be reflected in improvements in power output for the ruck clean movement, and correspondingly sprint start performance.

Olympic lift training predominantly develops concentric force generating capabilities (Hakkinen et al, 1987), which are attributable to contractile elements, as opposed to stretch shortening cycle (SCC) components. The underlying mechanisms for the gains in concentric power output observed are generally ascribed to improvements in rate of force development (RFD) and high-velocity strength (Stone, 1993, Garhammer, 1993, McBride et al, 1998, Souza, 2002). Although not measured in the current study, increased peak RFD has been reported with concurrent gains in Olympic lift (Snatch) 1-RM and performance test (shot put distance) scores (Stone et al, 2003b). In turn, intermuscular and intramuscular coordination elements are implicated in these adaptations (Newton & Kraemer, 1994, Hedrick, 1993). Intermuscular coordination effects are observed in preferential recruitment of high threshold (high force) motor units, and reductions in co-contraction of antagonist muscles. Developments in intramuscular coordination are manifested in enhanced capability of individual motor units to fire rapidly for short intervals (Hedrick, 1993), which underpins improvements in RFD (Behm, 1995). These are neuromuscular learning effects associated with rapid muscular contractions (Morrissey et al, 1995). It has been suggested that there are learned neuromuscular responses associated with exposure to power training specifically, that enable athletes to maximise power output and do so against higher resistances (Baker et al, 2001). These learned 'neural strategies' include over-riding inhibitory input and an anticipatory priming of motor units during the interval immediately prior to initiating the movement (Baker et al, 2001).

The test apparatus used in the current study was designed to simulate the ruck clean movement. The specificity of the testing modality used to assess athletic training and performance is of crucial importance (Baker et al, 1994). To be of relevance, a test of muscular function must be able to not only detect adaptations induced by the specific training mode, but also be sensitive to changes in functional athletic performance following training (Murphy & Wilson, 1997). The fact that the training group performed significantly better at post testing would seem to support the validity of the test measure. This has to be qualified by the observation that the control group also improved on the test measure, albeit to a lesser extent. Whether this was due to the novelty of the testing procedures and a possible learning effect, or simply a result of concurrent gains in lower body strength (reflected in deadlift 1-RM scores) is open to question. It is the case that subjects only had access to the test apparatus on the two test occasions, hence were not able to acclimatise to the test apparatus and procedures before the day of the initial testing. However, the players had extensive experience in performing the rucking movement featured in the testing procedure as part of their regular training, typically against manual resistance. Furthermore, the testing did appear to be sensitive enough to detect the superior performance of the training group.

The relevance of game specific athletic performance tests is illustrated by the finding that vertical jump test performance is shown to be the most consistent determinant of playing time of any physical performance test in elite college basketball players (Hoffman et al, 1996). That is, superior performance on the vertical jump test was reflected in these players being selected by the coach and spending more time on court. The ruck clean testing apparatus described has the potential to serve a similar function in rugby union.

The pulling lifts comprise the highest power output phase of the classical Olympic lifts – the 'Second pull'. Power outputs have been quantified for the second pull in the order of 5500 W, which is roughly five times that generated during the classic squat (Stone, 1993). The clean pull variation featured in the current study has the same biomechanical characteristics of the power clean lift (minus the catch phase) and comprises the maximal power second pull portion of the lift (Souza et al, 2002). Likewise, the snatch pull also features the second pull phase, and power outputs during the second pull for the snatch and clean are found to be very similar (Garhammer, 1993). The pull variations of the Olympic lifts allow higher loads (≈110-120%) to be handled relative to the classical clean and snatch lifts, which tend to be more limited by deficiencies in lifting technique (Hydock, 2001). Purely in terms of concentric power production, the 'catch' phases that characterise the classical Olympic Snatch and Clean lifts are of little consequence (Hydock, 2001). Hence, the pull variations of these lifts are more than adequate for developing these qualities in team sports athletes. Limitations imposed by technique flaws in the catch phase when employing the classical Olympic lifts can potentially restrict team sports athletes to loads that are suboptimal for developing speed-strength capabilities (Hydock, 2001).

Olympic lifters are reported to generate greater velocity and power than powerlifters when performing countermovement jumps with or without added loading (McBride et al, 1999). Similarly, Olympic lifters exhibit superior strength (1-RM squat) in comparison to sprinters (McBride et al, 1999). From these data it could be inferred that Olympic lift training is similarly effective to sprint training and more effective than powerlifting training in developing dynamic power, and more effective than sprint training in developing maximal strength. However, without controlled prospective studies to test this hypothesis it is not possible to draw definitive conclusions. Of particular relevance to rugby football is the observation that Olympic lifters perform better than sprinters in dynamic movements against resistance. (McBride et al, 1999). The ability to generate greater force and power output against external resistance (i.e. opposing players) is a key program goal for rugby football players. It can be inferred from the superior performance exhibited by Olympic lifters in this capacity that heavy load speed-strength training provided by Olympic lifting has the potential to develop this ability to generate power against resistance. The current data tend to support this notion.

The kinetic and kinematic specificity of Olympic lifts with regard to the vertical jump movement are suggested to develop speed-strength in a way that transfers more readily to jumping performance (Baker, 1996). Likewise, on the basis of their biomechanical similarity to sports movements, Olympic lifts and their variations are extensively used for sport-specific preparation in various strength- and power-oriented sports (Hydock, 2001), including volleyball and basketball (Souza et al, 2002). Speed-strength training in the form of jump squats has proven successful in developing lower body power in elite power athletes (Baker, 2001a). Power outputs during Olympic lifts (hang clean) are highly correlated with the corresponding measures for the jump squat, to the extent that the respective measures are determined to reflect the same capabilities in trained athletes (Baker & Nance, 1999a). It follows that Olympic lifts should be similarly effective. Both Olympic lift (hang clean) and jump squat power measures relative to body mass are also shown to be significant predictors of acceleration (10m) and short distance (40m) sprint scores in rugby league athletes (Baker & Nance, 1999b). Some of the highest correlations were shown with heavy load (100kg) jump squat and 3-RM hang clean (Baker & Nance, 1999b). All of which points to the practical significance and potential benefits of heavy load speed-strength training and specifically the use of Olympic lifts for rugby football.

Given the widespread use of Olympic lifts in physical preparation for rugby football players, there is a paucity of data relating to this type of training with this group of athletes. What data there is concerning speed-strength training with rugby football players tends to feature the use of jump squats. Olympic lifts may be a superior training modality to jump squats, both biomechanically and in terms of practicality. Relative to jump squats, Olympic lifts involve a greater balance component (Baker & Nance, 1999a) as the athlete is required to balance both themselves and the barbell in three dimensions as they apply force to accelerate the external load through the lift. In contrast, jump squats are often performed in apparatus that only permits uni-directional movement of the barbell. This may be a factor in the failure of jump squat scores to reflect changes in strength and sprint performance following training (Murphy & Wilson, 1997).

It has been postulated that repeated exposure to high propulsion forces associated with Olympic lift training leads to adaptation in non-contractile structures in the joints concerned (Stone, 1993). This being the case, the use of Olympic lifts by rugby football players may confer an ancillary benefit, in terms of injury prevention. In view of the high degree of biomechanical specificity mentioned, it follows that loading joints during training in a manner consistent with what occurs during high-power activities encountered during match play should make players less susceptible to injury, for example when tackling, jumping or cleaning rucks (Stone, 1993). Olympic lifts also feature lesser impact forces to those experienced upon landing when performing alternative ballistic speed strength exercises, such as jump squats (Stone, 1993).

5.2.5. Practical Applications

The current findings support the assertion that performing Olympic lift training as part of the physical preparation for rugby football players will yield benefits in terms of power output generated in specific activities against resistance provided by opposing players on the pitch. Such data forms an objective basis for including these lifts in training for these athletes. Performing speed strength training in combination with conventional strength training favours development of a wider range of maximal strength and dynamic power measures than when high-power or high force training is implemented in isolation (Harris et al, 2000). Hence, these lifts should not be viewed as a substitute for the squat and deadlift, but rather should be used to complement these high-force structural exercises. Olympic lifts develop predominantly concentric performance; the addition of appropriate plyometric training to develop SSC elements may therefore offer further improvements in performance.

A Weighted Ballistic Push Up Training Modality to Develop Upper-body Explosive Muscular Power in Junior Academy Rugby Football Players

5.3.1. Introduction

Explosive power is a learned motor skill of the neuromuscular system that is distinct from maximal force production (Ives & Shelley, 2003). Although maximal power output is dependent upon strength to a varying extent depending on the resistance involved (Stone et al, 2003a), expression of sport-specific power has elements that are independent of the basic force-generating capacity of the musculature. This is illustrated by the dissociation of maximum (1-RM) strength and explosive power scores in elite athletes (McBride et al, 1999, Delecluse et al, 1995). Accordingly, the addition of speed-strength training has been shown to produce gains in anaerobic power beyond those elicited by heavy resistance training alone (Newton et al, 1999, Baker, 1996, Delecluse et al, 1995).

Ballistic resistance training is distinct from traditional resistance training because the load is released at the culmination of the movement. This allows power to be generated throughout the full range of motion, as there is no requirement to brake the motion of the load to bring it to a halt at the end of the movement. Thus, the acceleration phase is not terminated before the end of the range of motion (ROM) for the exercise; this in turn allows higher peak velocity (hence peak power) to be attained later in the movement (Newton et al, 1996). Accordingly, Cronin and colleagues have identified projection (i.e. release) of the load as the most crucial factor influencing expression of peak power (Cronin et al, 2003, Cronin et al, 2001).

Jump squats have been identified as the most effective single training modality for developing measures of lower body explosive power (vertical jump height) in elite power athletes (Newton et al, 1999, Wilson et al, 1993, Baker, 1996). The obvious upper-body equivalent to the jump squat is the bench throw. Accordingly, this mode of training has been shown to elicit significant upper-body power gains

(Lyttle et al, 1996), particularly with loads that maximise mechanical power output. It is suggested the greater velocity and movement pattern specificity of ballistic training is more likely to stimulate functional high-velocity adaptations (Cronin et al, 2003) than traditional resistance training. Accordingly, bench throw training is shown to elicit significant improvements in functional performance in elite baseball players (McEvoy & Newton, 1998). However, this ballistic training mode requires costly apparatus to safely restrict the barbell to vertical-only movement and to brake the descent of the bar once it is released.

A solution that circumvents the need for expensive specialised equipment to catch an external load is to use the athlete's own body mass as the load to be projected into free space; specifically a ballistic push-up. When compared to standard modified push-ups (supported on the knees), ballistic modified push-up training (hands leaving the floor at the top of the movement) is reported to elicit significantly greater improvement in ballistic power, as assessed by medicine ball throw distance, and similar gains in strength (chest press 1-RM) scores in female subjects (Vossen et al, 2000). Similarly, if weights are attached to the athlete with this training mode it is possible to provide the magnitude of loading (55% bench press 1-RM) proven to maximise mechanical power output with bench throws (Baker et al, 2001a). Hereby the weighted ballistic push up training solution also offers the elements of progression and overload.

The purpose of the study was to evaluate changes in measures of upper body power following weighted ballistic push-up training in a group of junior academy-level rugby football players. The athlete's body mass was supplemented with additional loading, via the use of a custom designed shoulder harness. It was hypothesised that the ballistic training modality would result in an augmented training response, reflected in superior improvements in measures of upper body power output.

5.3.2. Methods

Subjects

Fourteen players (age 17.1±0.91yrs; height 178±3.0cm; weight 87.2±16.1kg, mean±SD) were recruited from the England Elite Player Development Group for the region (south-west London, UK). Players in this 14-18yrs age group are individually selected as the top percentile based on playing ability for their age group in the region. Following informed, written consent, seven players undertook the ballistic push-up (BPU) training, whilst seven players matched for age and playing position served as controls, undertaking standard push-up training (SPU). The specific power training intervention was performed alongside in-season strength training and metabolic conditioning. The content and volume of concurrent strength training was standardised for both groups.

One subject in the training group was absent for four of the seven training sessions, due to international representative training and playing commitments, hence this subject was excluded from further analyses.

Figure 5.3.1 – Weighted Ballistic Push Up Shoulder Harness

Apparatus

Experimental conditions featured the use of a specially designed shoulder harness, which served to supplement the subject's body mass (Figure 5.3.1). Standard barbell plates were mounted onto a barbell peg on the back of the shoulder harness, at sternum level (so as to be perpendicular to the point of force application at the bottom of the push-up position) and secured with a standard commercially available spring collar.

Strength Tests

3-RM bench press testing was undertaken prior to the training period and at its completion, using the procedures described by Baechle et al (Baechle & Earle, 2000). High test-retest reliability scores have been reported for 3-RM bench press scores (intraclass correlation coefficient, r = 0.98) has been reported previously in an equivalent group of junior rugby league football players (Coutts et al, 2004).

Instructions to subjects were to aim to complete three repetitions. If the subject was able to do complete three repetitions at their maximal weight, their 1-RM was estimated from the factor derived from RM tables (Baechle & Earle, 2000). If subjects failed after two repetitions, predicted 1-RM score was likewise derived from the corresponding RM table factor (Baechle & Earle, 2000). In the case that subjects failed after one repetition, this value was taken as the player's 1-RM.

Work Output Assessment

Prior to the study and at the completion of the power training intervention participants undertook two ballistic push-up tests (with projection of the body into free space). Ballistic push-up height was quantified using a contact mat jump meter system (Powertimer Contact Mat, Newtest, Oy, Finland). Test 1 was a concentric-only ballistic push-up, similar to that described by Wilson et al (1996). Subjects descended to the bottom push-up position and paused for a count of two, before initiating the ballistic push-up from a static position, without preparatory dip. Trials were discarded and repeated if counter-movement was noted. Test 2 was a counter-movement push-up test, with full and continuous rapid eccentric and concentric motion, also adapted from Wilson et al (1996). The subject's body mass (kg) was quantified in push-up position (see *Load Assignment*). Work output (Nm) was then calculated using the formula (Baker et al, 1996):

Body mass (kg) in push-up position x Gravity (9.816ms^{-2}) x push-up height achieved (m)

Load Assignment

Preliminary testing was undertaken to quantify each player's body mass component in the bottom position of the push-up. This was achieved by the use of a one-metre board with brackets on the underside to fit the footplate of a commercially available calibrated floor scale (Seca analogue floor scale, Germany). With the floor scale secured directly underneath the mid-point of the board, the subject assumed push-up position with arms fully extended. In this way, the subject's body mass (kg) (minus the weight of the wooden board) was quantified in push-up position. The amount of added mass required for the shoulder harness (to achieve 65% of bench press 1-RM) was thus derived, based on this body mass component and the player's calculated bench press 1-RM.

Training Protocol

The training intervention comprised either stretch-shortening cycle (SSC) ballistic push-ups from the floor, with rapid counter-movement (BPU) in which subject propelled their body off the floor at the end of the movement, or standard push-ups (SPU) at a self-selected pace. For both conditions, the training load was provided by the players' body mass component in the push-up position, supplemented as necessary by the shoulder harness to achieve a combined external loading of 65% of the subject's calculated bench press 1-RM. Thus, the training load was individualised for the athlete's body mass and bench press 1-RM. The rationale for selecting 65% bench press 1-RM for the weighted BPU training load is that this value is at the upper end of the load spectrum used previously for upper body ballistic power training. Baker (2001) reported the ability to develop power against heavy resistance distinguished elite rugby league football players from those competing at lesser levels. This training load is also below 70% 1-RM; resistances above which compromise the ability to project the load (barbell in the case of a bench throw) (Cronin et al, 2003).

Training Regimen

Ballistic push-up (BPU) training was undertaken once per week for the duration of the seven-week training period. Players completed five sets of six repetitions in each training session. Each repetition was performed maximally, i.e., subjects were instructed to pause to reset between each push-up. Subjects were encouraged to aim for maximal height for each repetition. Each set was interspersed with 10 mins active rest during which time subjects completed other exercises. Subjects in the SPU group performed standard push-ups while the BPU group performed ballistic push-ups. These were matched for load, volume (repetitions) and rest periods.

Statistical Analysis

Scores for both push up tests and bench press 1-RM were assessed using 2 x 2 (test occasion x training group) repeated measures ANOVA. In the event of significant differences, Student's t-tests were used to examine the data for each training group. For all analysis, significance was set at $p \leq 0.05$.

5.3.3. Results

For the majority of subjects a load equivalent to 65% 1-RM bench press was achieved by adding the harness alone (~4.5kg). The maximum added load was the harness, plus a 5kg plate (two players in the SPU group). The heavier subjects (three in the BPU training group; one in the SPU group) did not require added loading for the duration of the study, as their body weight in push-up position supplied (or exceeded) the requisite 65% bench press 1-RM loading.

Repeated measures ANOVA identified a significant overall effect of training ($p<0.05$; pre- vs post-intervention) and a significant interaction effect of training modality ($p<0.05$; SPU vs. BPU). This indicated that the training response of the BPU training group on this measure was significantly different to the SPU group (see Figure 5.3.2). Paired T-tests revealed a significant improvement pre- to post for the BPU training group for work output during the concentric-only push test ($p<0.05$), presented in Table 5.3.1. There was no significant difference for the SPU subjects.

Table 5.3.1 – Concentric-only Push-Up Work Output Scores

Concentric-only Push Up Work Output, Nm	Pre Mean +/- SD	Post Mean +/- SD	p-value	% Change
SPU	71.10 ±13.59	70.28 ±18.73	ns	-1.2%
BPU	65.52 ±14.45	80.45 ±14.21	P<0.05	22.8%

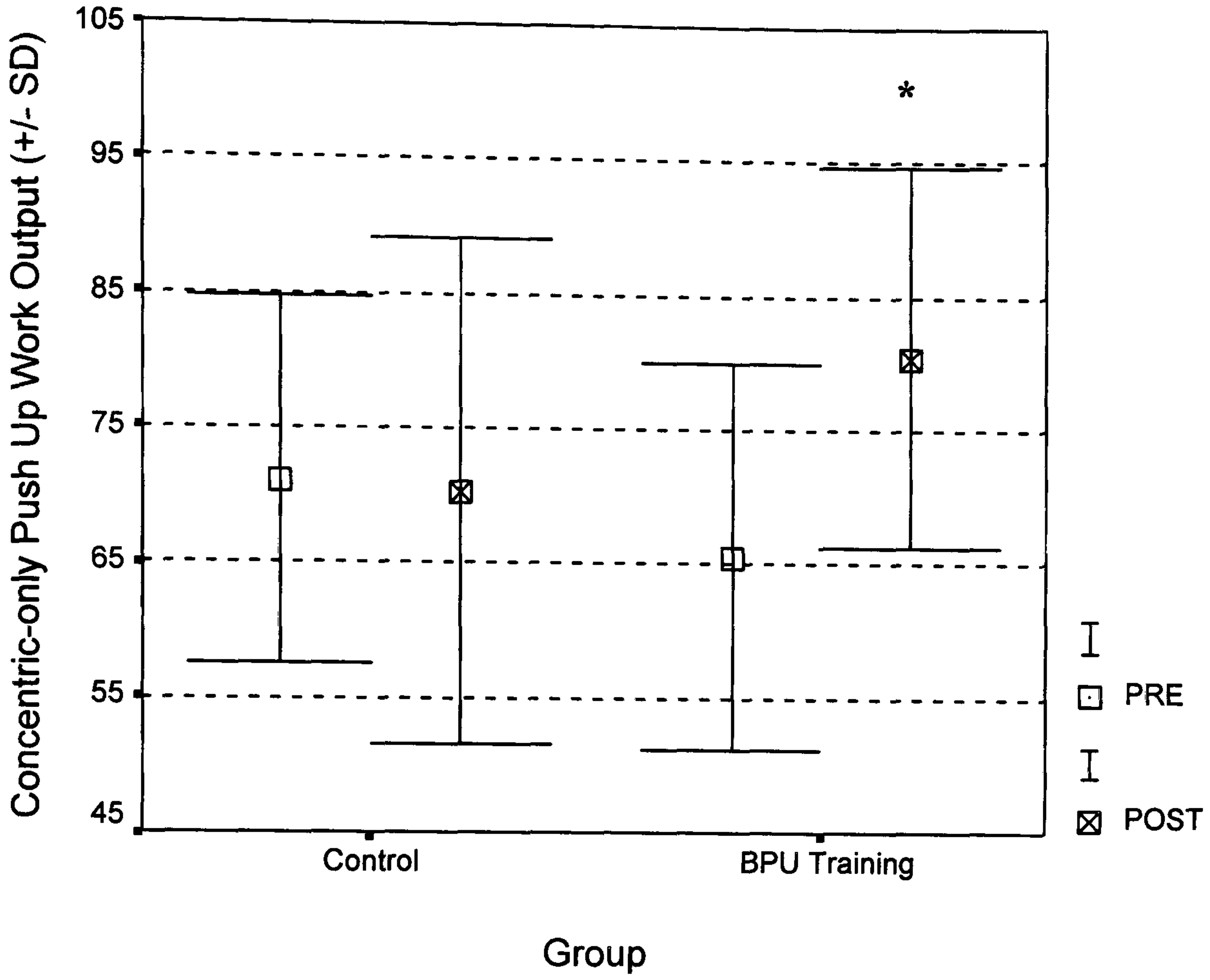


Figure 5.3.2 – Concentric-only Push Up Work Output Scores

* Significant Increase ($p<0.05$)

There was no significant overall effect of training identified by repeated measures ANOVA. However, there was a significant group interaction effect ($p<0.05$), indicating the groups responded significantly differently across the training period (see Figure 5.3.3). The improvement in work output during the countermovement push-up revealed by paired T-tests for the BPU training group approached significance ($p=0.063$), displayed in Table 5.3.2. The change on this measure for the SPU group was non significant.

There was a trend for greater work output scores for the push-up test with countermovement for both groups. However this was non-significant at both pre and post-testing. Similarly there was no difference in this relationship between training groups.

Table 5.3.2 – Countermovement Push-Up Work Output Scores

Countermovement Push Up Work Output, Nm	Pre Mean +/- SD	Post Mean +/- SD	p-value	% Change
SPU	79.70 ±13.23	76.85 ±18.73	0.460	-3.6%
BPU	71.70 ±14.64	83.38 ±14.16	0.063	16.3%

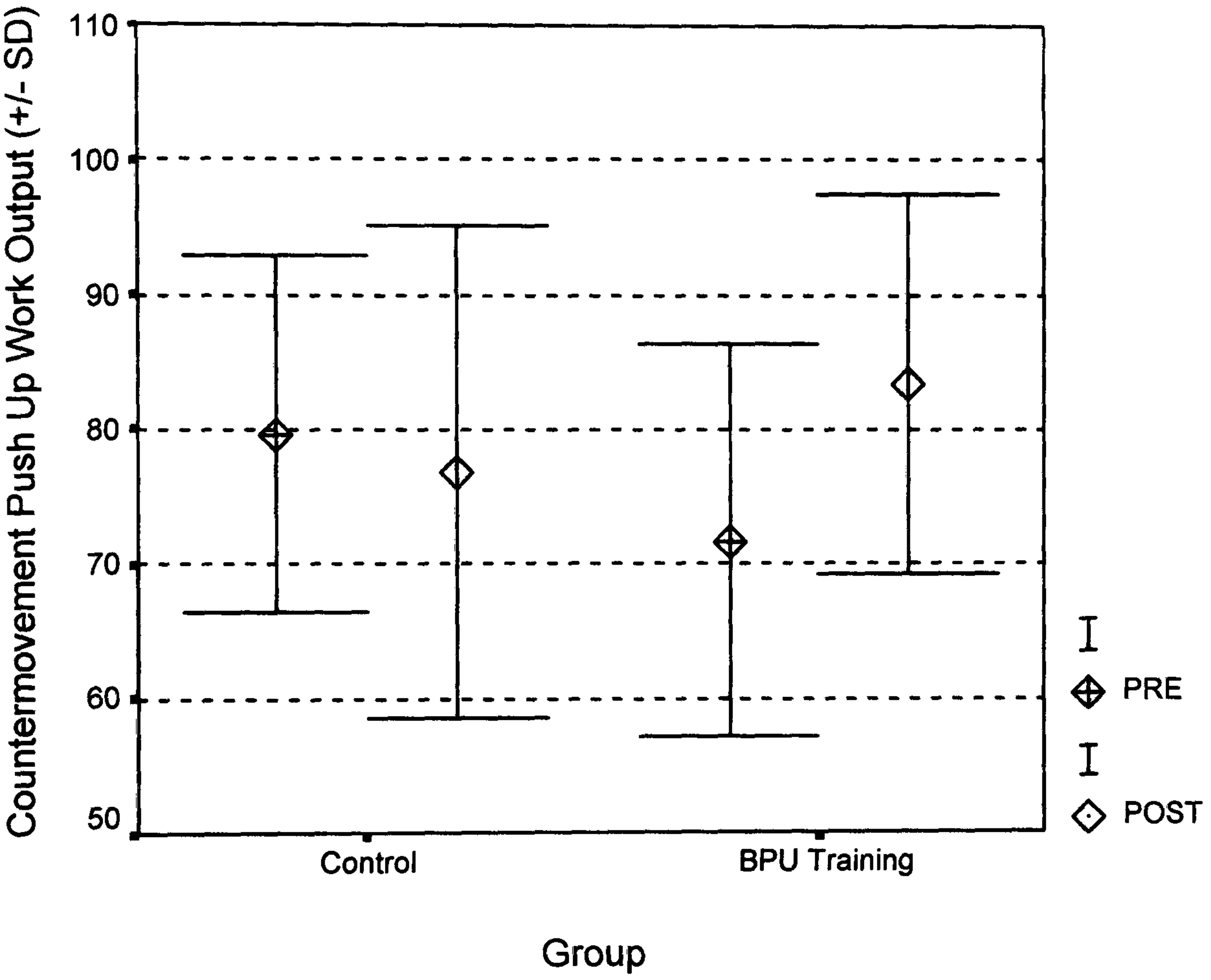


Figure 5.3.3 – Countermovement Push Up Work Output Scores

Repeated measures ANOVA revealed a significant overall effect across the training period (pre- vs. post-intervention). There was no interaction effect for training modality (BPU vs SPU), indicating no significant difference in training responses with regard to bench press strength between training groups (see Figure 5.3.4). Paired T-tests identified significant improvement in predicted 1-RM bench press scores for the BPU training group ($p<0.05$), displayed in Table 5.3.4. The strength improvement for SPU subjects approached significance ($p=0.069$).

There were no significant correlations between changes in predicted 1-RM bench press and changes in either concentric-only or counter-movement push up performance.

Table 5.3.3 – Bench Press 1-RM Strength Test Scores

Bench Press 1-RM, kg	Pre Mean +/- SD	Post Mean +/- SD	p Value	% Change
SPU	74.7 ±12.07	78.6 ±11.48	p = 0.069	5.2%
BPU	77.8 ±12.29	84.6 ±11.86*	p<0.05	8.7%

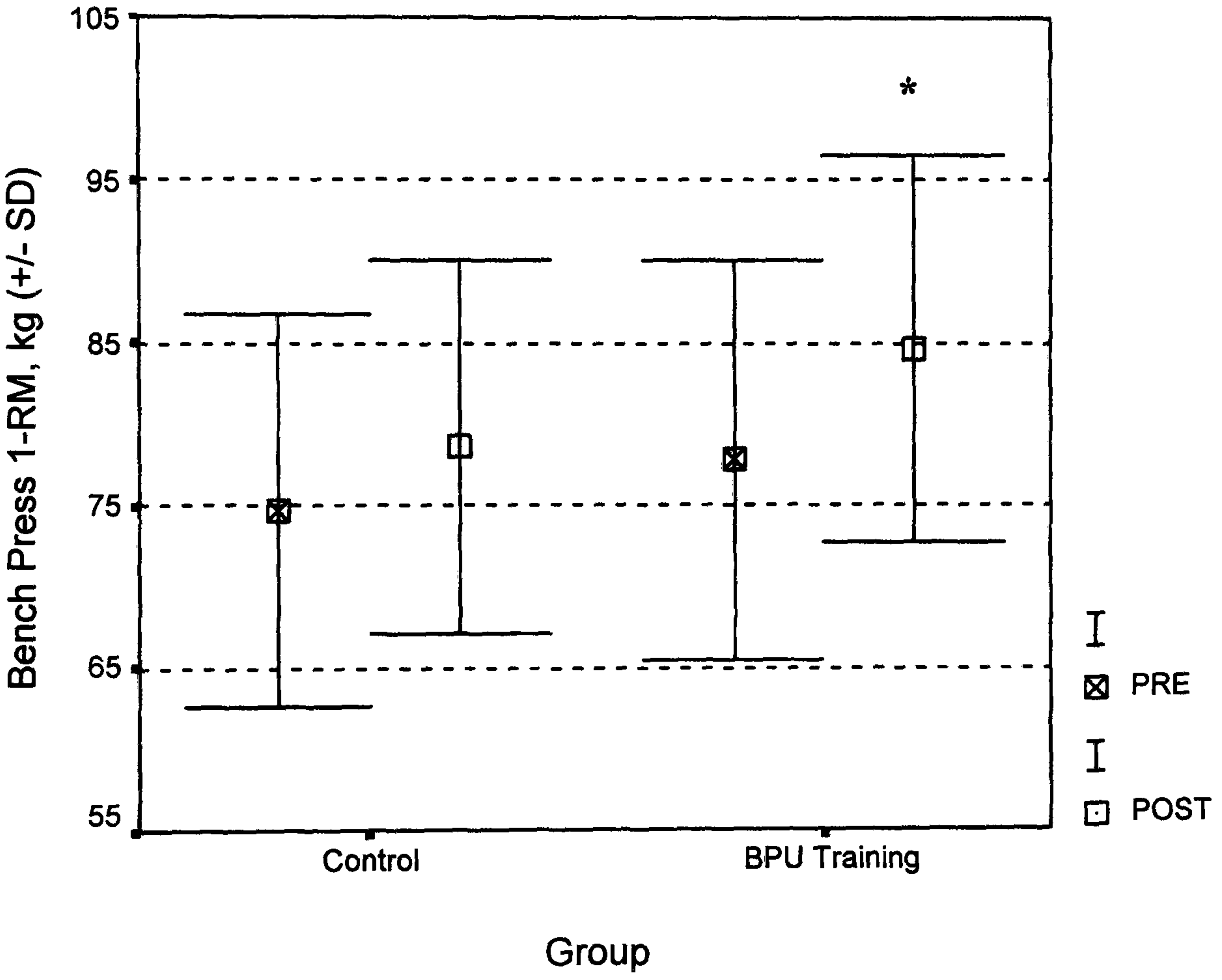


Fig 5.3.4 – Bench Press 1-RM Strength Test Scores

* Significant Increase (p<0.05)

5.3.4. Discussion

The data presented show weighted BPU training elicited significant increases in the work output measure for the concentric-only push-up tests. The improvement in counter-movement push-up work output for the BPU training group also approached statistical significance. There were no such improvements shown by the SPU group on either test. There was no corresponding difference in upper body strength gains (predicted 1-RM bench press) between the respective training groups. These results are consistent with a previous upper body ballistic training study employing variations of a modified push up (supported on the knees) with female subjects (Vossen et al, 2000), which reported gains in a measure of upper body explosive power (medicine ball put distance). The current study is the first to employ a ballistic version of a standard push up (supported on the toes) and to report positive results with junior academy-level male rugby players. This is likewise the first study to incorporate added loading for this training modality to supplement the individual's body mass.

The relative increases in work output reported for the concentric-only and countermovement push up tests seen in the BPU training group were of comparable magnitude to gains in impulse registered on a force platform for the corresponding push up tests following eight weeks of bench throw training (Lyttle et al, 1996). In the current study, both pre- and post testing, there was a trend for higher work output scores for the counter-movement push up test in relation to the concentric only test. Greater average force, peak force and power output have been reported previously for SSC bench throws, relative to concentric-only bench throws with equivalent loads (Newton et al, 1997). This effect is consistent with augmentation of force output with 'rebound' or countermovement, derived from the stretch-shortening cycle (Cronin et al, 2003). However, in the current study these differences in work output (based upon push-up height) between concentric only and countermovement tests did not reach significance. Similarly, in the previous bench throw study by Newton et al (1997), the relative augmentation of force and power output in the SCC throw condition were not translated into significant differences in height thrown or barbell velocity. In the current study, the relationship between performance measures for the counter-movement and concentric-only test condition did not change post training.

Taken with the lesser average gains in the countermovement push up test (Tables 5.3.1 and 5.3.2), the improvements elicited by BPU training thus appeared to be predominantly concentric, with SSC performance remaining relatively unchanged. Improvements in dynamic measures (vertical jump) reported previously with equivalent ballistic training for the lower body have been attributed predominantly to increased concentric force output, and in particular enhanced rate of force development. Large increases (48%) on a dynamic measure of RFD have been reported previously following ballistic (jump squat) training (Newton et al, 1999). Accordingly, mechanisms underlying the specific improvements in upper body concentric performance observed in the current study likely include high-velocity strength and rate of force development (RFD) (Hedrick, 1993, Newton & Kraemer, 1994).

Underlying neural adaptations influencing high-velocity strength include improved recruitment and firing of high threshold motor units at the high contraction velocities associated with the ballistic training movement (Stone, 1993, Hedrick, 1993). Intermuscular coordination, involving reduced co-contraction of agonist and antagonist muscle groups, may also play a role (Newton & Kraemer, 1994). Rate coding is the major factor influencing RFD; specifically the maximal firing rates of motor units within the window for force development allowed by the movement (Behm, 1995). These adaptations result in a preferential improvement in the region of the force/velocity curve at the movement velocities associated with the training movement (Stone, 1993). The slope of the force-time curve for a given movement denotes RFD (Newton & Kraemer, 1994), hence represents an index of how quickly peak force can be attained. Improving RFD thus enables the athlete to express a greater proportion of their maximal strength within the limited time frame allowed by a given sports action (Newton & Kraemer, 1994). Maximal ballistic muscle actions involve appreciably higher motor unit firing rates than those observed with conventional strength training (Behm, 1995, Hedrick, 1993). It is this increased firing rate that has been identified as enhancing RFD (Behm, 1995). It follows that repeated exposure will favour developments in the ability for motor units to fire rapidly during the short interval for force development allowed by the ballistic action.

Neuromuscular firing patterns associated with strength and explosive movements are shown to be grossly different (Ives & Shelley, 2003). Ballistic contractions appear to be part pre-programmed by higher motor centres in anticipation of how the ballistic action is expected to occur, with some modification of motor unit activation based upon sensory feedback during the movement (Behm, 1995). As a consequence, power output for a ballistic action exhibits learning effects with repeated exposure to the specific training movement (Ives & Shelley, 2003). Antagonist co-contraction is likewise largely pre-programmed, and is believed to be a protective mechanism acting to maintain joint integrity in anticipation of the forces and limb accelerations during the ballistic action (Behm, 1995). Fine-tuning of antagonist input with repeated exposure to the ballistic training movement may occur to reduce co-contraction to increase net concentric force output. The acceleration/deceleration profiles associated with bench throw training have been suggested to more closely resemble sporting activities (Cronin et al, 2003). This being the case, similar advantages in terms of mechanical specificity should be conferred by BPU training.

Intent has been identified as a key factor in eliciting training responses in RFD and high-velocity strength (Behm & Sale, 1993). The conventional bench press exercise appears to require specific coaching to make conscious effort move the barbell rapidly to evoke optimal responses (Jones et al, 1999). Strength and power training effects are reportedly reduced by half, when lifters are left to self-select lifting velocity for the bench press movement (Jones et al, 1999). By its explosive nature, the ballistic push-up training modality will likely favour training responses mediated by conscious intent. Previously the bench throw was the sole means to develop this capability with Pmax loads. This is a consequence of the unsuitability of conventional strength training exercise for lifting submaximal loads in this manner, as the neuromuscular system intervenes to brake the motion of the barbell in order to prevent injury (Newton et al, 1996). The observed efficacy of the BPU training modality would appear to offer an alternative means for explosive upper body training with Pmax loads.

Despite the neural benefits associated with the BPU training movement, traditionally the limitation of standard BPU training is that resistance is constrained by the body mass of the athlete and there is no means to provide progressive overload as training advances. The addition of the shoulder harness enables athletes to add resistance to allow for advances in maximal strength (bench press 1-RM) to provide progressive overload. By accounting for the element of progression, it should be possible to elicit continued gains in upper-body explosive power with long-term application of resisted BPU training. The current study featured young athletes with limited strength training experience, which is reflected in their low 1-RM bench press scores (around 1 times body mass). In contrast, senior elite rugby league players bench press strength is reported to be 148% of the athlete's body mass (Baker, 2002), and the corresponding scores of elite senior professional rugby union players are typically 1.5 times body mass (unpublished observations). Consequently, the necessity for added loading to achieve Pmax resistance will be greater with senior professional players, and the shoulder harness apparatus will therefore have greater application in these athletes.

The efficacy of weighted BPU training as a specific upper body power training modality has particular relevance for elite athletes. In untrained individuals a variety of training interventions will produce adaptations in explosive performance measures, as almost any form of training represents a novel stimulus to the neuromuscular system (Newton & Kramer, 1994, Newton et al, 1999). Training specificity attains greater importance in elite athletes, as a consequence of their advanced training experience (Stone et al, 2003a). Although measures of upper body strength and power are strongly interrelated, strength levels do not explain a significant portion of the variance between strength and power scores with tests involving similar movement pattern (Baker & Nance, 1999). Hence it is evident that there is scope for optimisation of upper body power output in these athletes. The introduction of ballistic upper body training is shown to have the capacity to improve functional performance (throwing velocity) in elite baseball players with extensive strength training experience (McEvoy & Newton, 1998). This is reinforced by the observation that elite professional rugby league players exhibit much lower correlations between upper body measures of strength and power than semi-professional players, which was ascribed to the greater exposure to specific upper body power training of the professional players (Baker, 2001b). The progression in power training status of elite rugby league players appears to be manifested in enhanced ability of professional players to lift a given absolute load with greater velocity (Baker, 2001b, Baker, 2001d).

The need for specific tests of dynamic neuromuscular performance has been established previously (Baker et al, 1994, Newton & Dugan, 2002). Push up tests offer an upper body equivalent to vertical jump tests (Lyttle et al, 1996), which is the standard measure of lower-body speed-strength performance (Matavulj et al, 2001, Baker, 1996). Concentric-only and SSC variations of the push-up test were included in the present study to distinguish between neuromuscular components underlying improvements in ballistic push-up performance. In this way they are analogous to the squat jump and countermovement jump, respectively. The efficacy of any test measure is largely determined upon its ability to differentiate changes in performance following training (Murphy & Wilson, 1997, Newton & Dugan, 2002). The results of the present study confirm the utility of concentric-only and counter-movement push up tests in monitoring improvements in upper body neuromuscular performance, in agreement with the results of a previous study (Lyttle et al, 1996). A depth variation push-up test has also been used previously (Jones et al, 1999), which is likewise analogous to depth jump tests of lower-body reactive strength.

It has been noted previously that specific upper-body power training is under prescribed by strength coaches (Baker & Nance, 1999a). The majority of plyometric exercises featured in training and research are typically lower-body intensive (McEvoy & Newton, 1998), with training to develop SSC capabilities in upper body movements receiving little attention in the literature (Newton et al, 1997). The few upper-body targeted plyometric exercises that are implemented typically employ weighted medicine balls to provide resistance. The training stimulus provided by such weighted implements represents a far smaller external loading compared to the corresponding lower body plyometric exercises. Practically, to project a medicine ball or other weighted implement heavy enough to provide the requisite external loading (46-63% 1-RM) from a supine position is untenable without the use of specialised equipment. Accordingly, drop medicine ball throws failed to produce the enhancement in rate of eccentric force development conferred by 'equivalent' lower body plyometric depth jump training (Wilson et al, 1996). With the resisted BPU solution presented it is possible to provide the required magnitude of loading for upper body ballistic training. Similarly, depth push-up variations of the resisted BPU training mode are possible, by dropping from raised blocks to execute a BPU movement (Jones et al, 1999). In this way it should be possible to provide the magnitude of pre-stretch loading to develop upper body eccentric RFD in a similar manner to that seen with depth jump training (Wilson et al, 1996). Resisted BPU training thus offers a mode of upper body progressive plyometric training to harness potential benefits with regard to upper body SSC performance equivalent to those documented with lower body plyometrics.

5.3.5. Practical Applications

The present study suggests that weighted ballistic push-up training offers an effective alternative to bench throw training. Furthermore, the BPU training movement has direct application to the sport of rugby football, on the basis that it is biomechanically similar to the 'hand-off' action used to fend tacklers when players are carrying the ball. Training effects associated with BPU training should therefore have direct transfer to this aspect of match performance. Further study assessing training responses of senior professional rugby football players with this training modality is warranted.

Heavy Ball Complex Training for Development of Pass Velocity in Elite Academy-level Rugby Football Players

5.4.1. Introduction

Strength and power training aimed at enhancing athletic performance can only be considered successful to the extent that capabilities developed by training transfer to the particular skill set required by the sport (Harris et al, 2000). There is a consensus that transfer of training effects, in terms of carryover to dynamic athletic performance, is dependent upon the extent to which the training activity replicates the movement conditions encountered in competition (Stone et al, 2000, Baechle et al, 2000, Wilmore & Costill, 1999a). Given the greater levels of coordination and motor control required when executing fine game-related motor skills, it follows that a greater degree of specificity is required in terms of the training mode employed to develop power output for such movements (Kraemer et al, 2002).

The rationale behind the use of weighted implements when carrying out game-related motor skills is that the resistance training stimulus is provided during the actual target movement. The greater specificity of this loading method in terms of kinetic and kinematic similarity favours carryover of strength training effects to the sports activity. Thus, as sports skill-specific neuromuscular firing patterns are employed throughout, this form training may offer superior training for the muscles involved, in relation to traditional resistance exercises. In accordance with this contention, studies have shown training employing overweight balls has the potential to significantly increase over-arm throwing velocity with regulation balls (DeRenne et al, 1994, DeRenne et al, 1990). Crucially, throwing accuracy also appears to be maintained at the enhanced throwing velocities post-training (Escamillia et al, 2000).

Complex training, or contrast loading, is a widely used practice for both lower body and upper body power training (Baker, 2003). This approach employs a heavier load set of the same or similar exercise immediately prior to a set with the target 'power' exercise. Preceding the training exercise with a heavier 'primer' load is shown to enhance power output when the targeted power set is subsequently performed; essentially, the athlete is able to generate higher power with the target movement than is usually the case (Baker, 2001d). The authors of this study postulated that this loading regimen may have applications with regard to power development for fine motor skills, via the use of heavy sports implements.

The majority of studies examining power development for throwing have examined over-arm throwing (van den Tillar, 2004). Throwing a rugby ball requires the use of two hands. Rugby football involves passing laterally to teammates positioned behind the player (passing forwards is against the laws of the game). Passing beyond short distances typically involves imparting spin on the ball with the top hand, whilst the other hand helps guide the ball to the target. This rugby 'spin' pass is a different skill to that seen in other two-handed throwing sports, such as netball and basketball.

The purpose of the study is to employ a commercially available overweight rugby ball in a training intervention aimed at developing power in the fine motor skill of passing a rugby ball. A contrast loading scheme was incorporated, alternately performing intervention sets of overweight ball passes, and passes with a regulation ball.

5.4.2. Methods

Subjects

Nine male full-time academy professional rugby union players served as subjects. Subjects' age, height and body mass were 20.05±1.00yrs, 183.3±5.6cm and 90.6±9.6kg (mean±SD), respectively. All subjects were right-handed. The players who served as subjects were fully informed about the nature of the study and voluntarily participated in testing and training. All the players were members of the same premier division professional rugby union team. The heavy ball complex training intervention was undertaken as part of their normal training, and all subjects were involved in the same matches and concurrent training during the study period.

Eight players completed the training period having undergone pre-testing. One of the players initially recruited was injured and so unable to undertake pre-testing. This subject was excluded from the main analysis of training effects, but undertook the remainder of the training intervention and completed testing to assess acute effects contrast loading with the overweight ball at the end of the study. Another player completed all testing up to and including week four but was absent for post testing. The data for this player was included in the main analysis.

Evaluation of Pass Velocity

Pass velocity was measured prior to the study period, at two weeks and four weeks into the study, and at the end of the training period. Ball velocity was assessed over ten metres during trials of passes aimed at a partner. Release velocity was measured to the nearest 0.1km/hr using a handheld radar speed gun (Sports Pro Handheld Radar, Astro Products, California, USA). The manufacturer's guidelines stated that the radar gun measures 99.6% of the actual velocity when positioned within a five-degree angle of the trajectory of the oncoming projectile at the point of release. To satisfy this constraint the radar gun was held by a tester within a metre adjacent to the player catching the ball, with the radar gun aimed directly at the ball as it was released by the subject. The radar gun was calibrated prior to each testing session using a tuning fork calibrated to 90 km/h.

The 'spin' pass was used for all pass velocity measurements. Subjects were advised that only trials for which the ball was accurately delivered to their partner at sternum level would be accepted, but within these constraints were actively encouraged to aim for maximal pass velocity. In the event that the delivery of the ball was above or below sternum height, or the subject's partner had to move to catch the pass, the trial was discarded and repeated. Four trials were performed on each side (left- and right-handed). The worst trial was discarded; peak and mean pass velocities for the remaining three trials were used for statistical analysis.

Assessment of Acute Effects of Contrast Loading with the Heavy Ball

During the test session at the completion of the training period, eight players (including one subject who was unable to complete pre-testing hence was excluded from the main analysis) undertook additional testing. The aim of this was to elucidate the acute effects of contrast loading with the heavy ball on pass velocity with the regulation ball. Following trials to assess pass velocity, the player completed five passes with the heavy ball with the same hand, followed by five more passes (again with the same hand) with the regulation ball. All passes with either heavy or regulation balls involved imparting spin on the ball. Release velocity was recorded for these additional heavy and regulation ball trials in the same manner described above.

Training Equipment

A commercially available overweight ball (Morgan Pass Developer, Gilbert, UK), weighing approximately 0.8kg, was used for the training intervention. Regulation balls (Gilbert, UK) weighing approximately 0.3kg were also used.

Training Protocol

A single group repeated measures design was used, with all subjects performing the same training intervention. The training protocol incorporated a contrast loading regimen, so that a series of overweight ball passes was performed prior to a set of throws with a regulation ball. Training was performed three times per week. Each training session comprised four sets of six passes on each side (right- and left-handed) with the overweight and regulation balls respectively. Players worked in pairs, ten metres apart, running the width of the pitch with each player completing six passes (on the run) within that distance. On the opposite side players switched sides after picking up a regulation ball and turned around to complete six passes from the same hand, crossing the width of the pitch in the opposite direction. The pair then walked back to the opposite side of the pitch to pick up the overweight ball again, to complete a set passing with the opposite hand. A set (for each hand) thus consisted of twelve passes: six with the overweight ball, followed by six with the regulation ball.

The study was undertaken during the competitive season. Hence the overweight ball training intervention was scheduled to fit around concurrent strength training, conditioning and team practices and matches in the period.

Statistical Analysis

The pooled data was analysed using a 4 x 2 (test occasion x hand) repeated measures ANOVA for both mean velocity and peak velocity scores. Significant differences were investigated for right-handed and left-handed pass data individually using one-way repeated measures ANOVA. Simple and repeated measures contrasts were used to identify significant differences between test occasions. Students t-tests were used to assess any differences in pass velocity between right- and left-handed passes at each test occasion. Paired t-tests were used to determine any differences between regulation ball pass velocity with either hand preceding and following an intervening set of heavy ball passes. Pearson's product correlations were used to assess relationships between heavy ball pass velocity and regulation ball pass velocity with either hand. Significance level was set at $p<0.05$ for all analyses used in the study.

5.4.3. Results

When velocity data for right-handed and left-handed passes were grouped, repeated measures ANOVA revealed a significant main effect of test occasion for both mean and peak pass velocity scores. Simple contrasts showed significant improvement in mean velocity ($p<0.01$) from week two, which persisted to post testing. This was similarly the case for peak velocity scores. There was no interaction effect for either mean velocity or maximum velocity data, indicating there was no significant difference in improvement for right- or left-handed pass on either measure. Individual players' data are presented in Tables 5.4.1.1 and 5.4.1.2.

Table 5.4.1.1. – Individual Players' Right-handed Pass Data

	Pre		Week 2		Week 4		Post	
	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean
Player A	55.3	54.4	55.5	54.0	59.7	59.4	Absent	
Player B	56.8	55.8	60.3	59.2	61.3	60.3	60.5	59.8
Player C	52.4	50.8	55.0	53.3	57.7	54.6	55.3	53.8
Player D	51.3	50.4	50.5	48.7	53.2	52.5	53.4	51.5
Player E	54.2	53.2	55.0	54.1	51.0	50.4	52.6	51.8
Player F	51.6	51.1	55.0	54.0	57.9	57.3	58.5	57.7
Player G	50.3	49.1	Injured		50.8	50.1	53.2	51.8
Player H	51.8	51.2	53.1	51.7	53.5	53.3	55.3	54.1

Table 5.4.1.2. – Individual Players' Left-handed Pass Data

	Pre		Week 2		Week 4		Post	
	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean
Player A	51.9	50.9	55.0	54.4	56.1	56.1	Absent	
Player B	53.3	54.0	58.7	58.0	58.2	57.9	56.9	56.9
Player C	50.3	49.3	52.3	51.1	54.3	52.8	55.6	53.3
Player D	49.0	48.7	51.1	50.0	51.8	51.5	48.9	48.0
Player E	50.2	49.5	Injured		48.9	48.4	49.0	48.9
Player F	47.6	47.2	50.8	49.9	53.4	51.5	53.2	52.5
Player G	46.5	45.8	Injured		46.0	45.9	48.6	48.0
Player H	52.1	50.4	51.9	51.0	54.3	53.0	53.1	52.0

When data for right-handed and left handed pass velocity were examined individually, significant improvements were apparent for both peak and mean pass velocity (Tables 5.4.2 and 5.4.3). Graphs displaying peak pass velocity and mean pass velocity for eight of the nine subjects (excluding the player who was absent for post testing) are presented in Figures 5.4.1 and 5.4.2, respectively.

Table 5.4.2. – Left-handed and Right-handed Peak Pass Velocities

Peak Pass Velocity, km/h	Pre (mean ±SD)	Week 2 (mean ±SD)	Week 4 (mean ±SD)	Post (mean ±SD)
Left Handed	50.4 ±2.8	52.3 ±3.9	52.9 ±3.9*	52.2 ±3.4*
Right Handed	53.0 ±2.2	54.4 ±3.1*	55.6 ±4.0	55.5 ±2.9*

* Significant difference vs Pre (p<0.05)

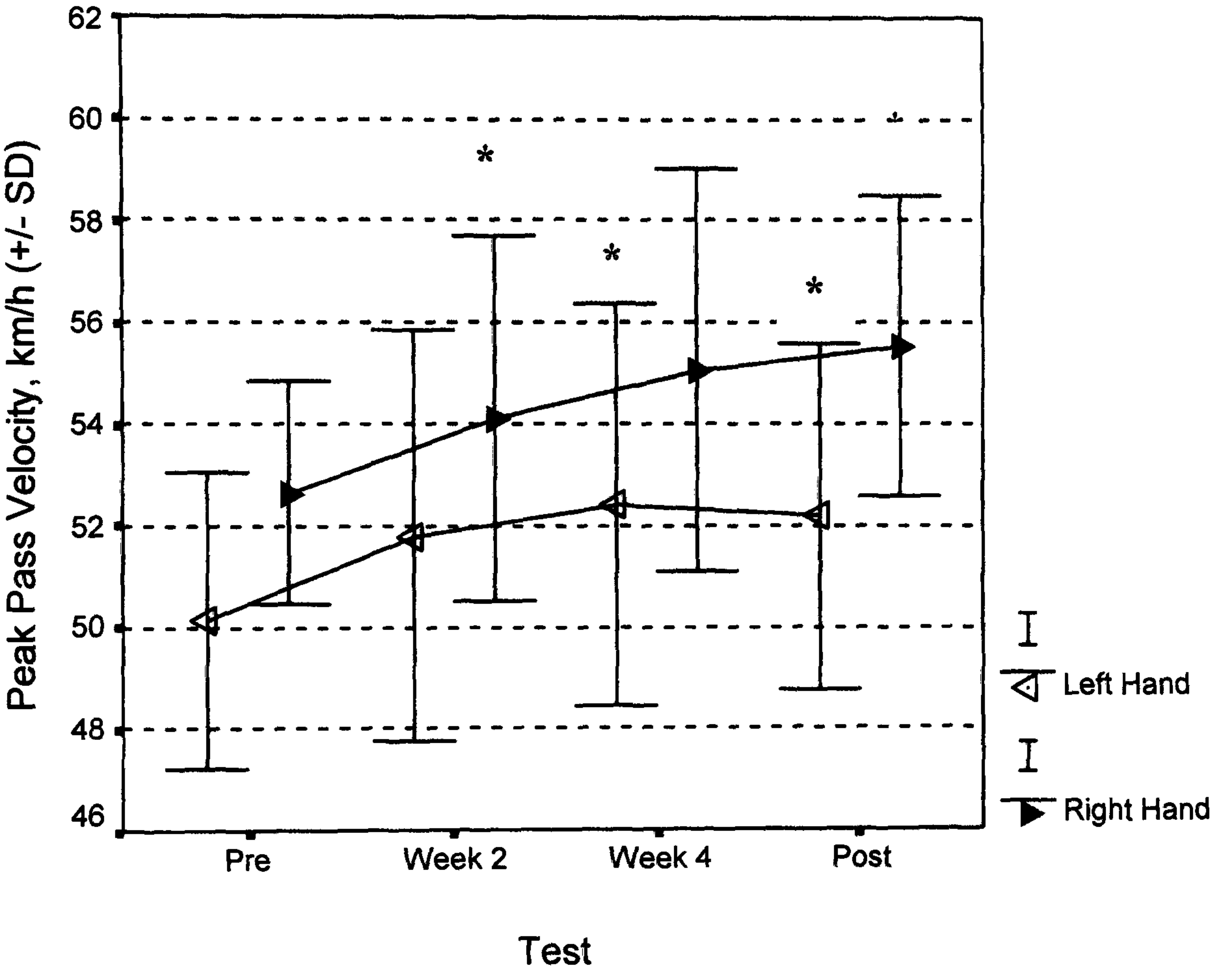


Figure 5.4.1 – Left-handed and Right-handed Peak Pass Velocities

* Significant Increase vs Pre (p<0.05)

Table 5.4.3. – Left-handed and Right-handed Mean Pass Velocities

Mean Pass Velocity, km/h	Pre (mean ±SD)	Week 2 (mean ±SD)	Week 4 (mean ±SD)	Post (mean ±SD)
Left Handed	49.5 ±2.5	51.5 ±3.8*	52.1 ±3.9†	51.4 ±3.3*
Right Handed	52.0 ±2.3	53.1 ±3.2	54.7 ±3.9	54.4 ±3.2*

* Significant increase vs Pre (p<0.05). † Significant increase vs Pre (p<0.01)

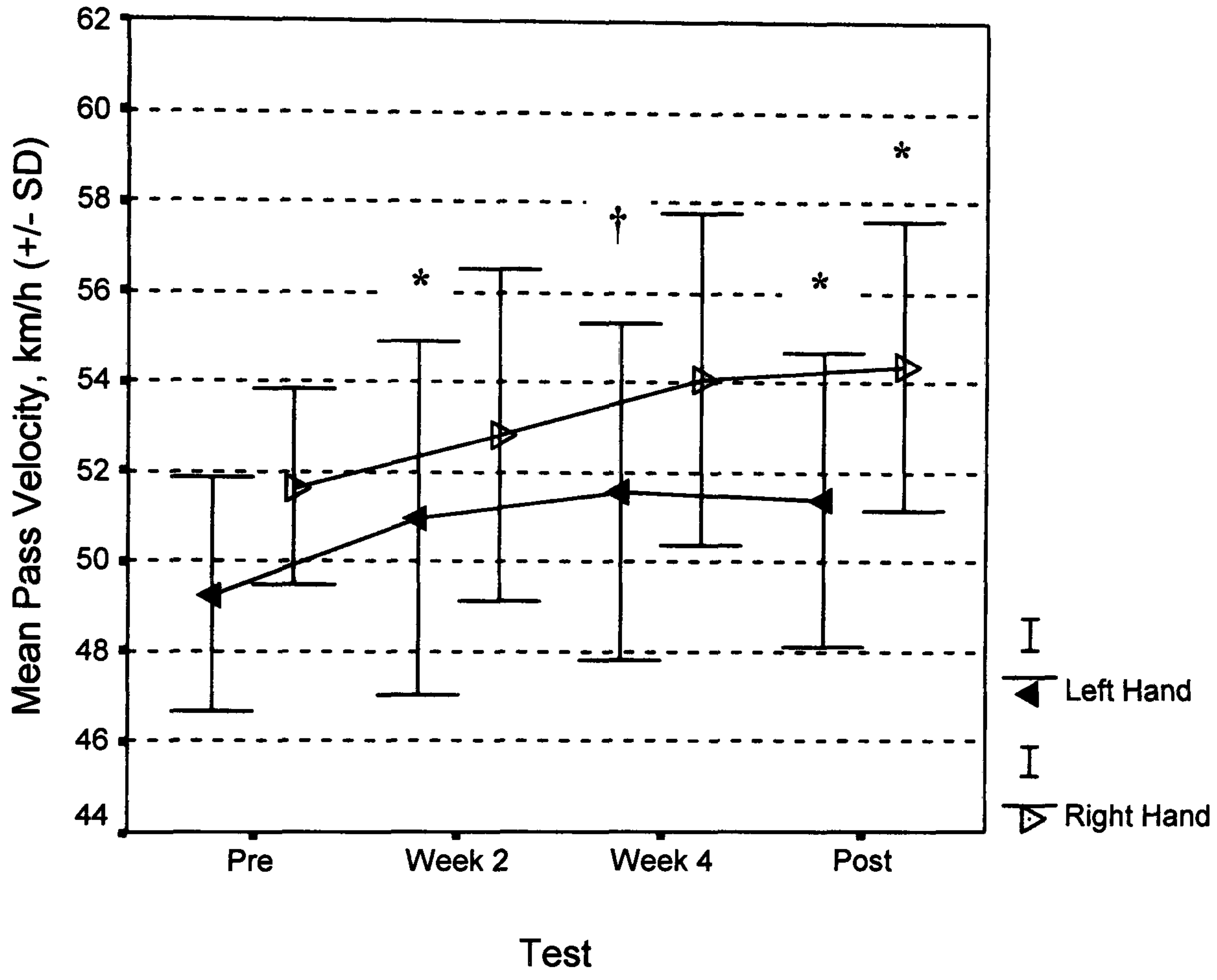


Figure 5.4.2 – Left-handed and Right-handed Mean Pass Velocities

* Significant increase vs Pre (p<0.05). † Significant increase vs Pre (p<0.01)

Independent t-tests were undertaken to assess whether there were significant differences for right-handed versus left-handed pass velocity. Differences for both mean pass velocity ($p=0.051$) and maximum pass velocity ($p=0.059$) approached significance at pre-testing. However, from week two until the completion of the study period these differences were no longer significant at any test occasion.

Testing to assess acute effects of contrast loading with the heavy ball revealed peak and mean pass velocity did not differ significantly when passes with a regulation ball were preceded with sets of throws with a heavy ball. This lack of significant acute effect of one set of heavy ball contrast loading was consistently observed when passing off either hand.

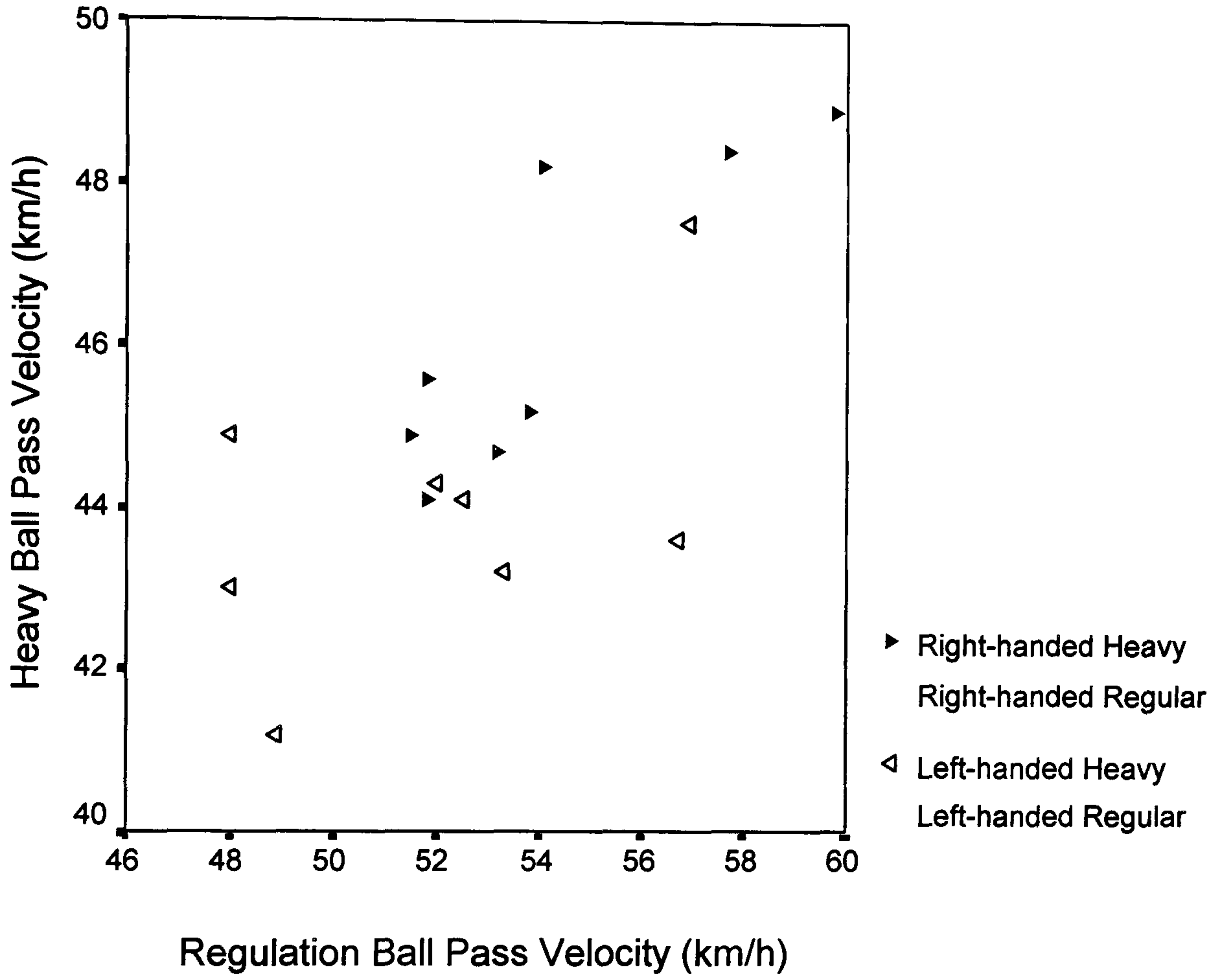


Figure 5.4.3 – Scatter Plot of Right-handed and Left-handed Passes with Heavy versus Regulation Balls

Mean pass velocity for heavy and regular balls recorded for the eight subjects who undertook additional testing were 44.0±1.8 km/h and 52.0±3.6 km/h, respectively, for passes with the left hand imparting spin on the ball. The corresponding mean values for right hand pass velocity were 46.3±1.9 km/h (heavy ball) and 54.2±3.0 km/h (regulation ball). These values, measured at the completion of the training study, thus indicate pass velocity was 15% slower with the heavy ball when passing both right- and left-handed, compared to passes with a regulation ball. This translated to a difference of 8 km/h with either hand.

In these subjects there was significant correlations between both average and peak pass velocity with heavy balls and regulation balls when passing right-handed. The corresponding correlations for left-handed passes were much less, and well below significance levels.

5.4.4. Discussion

This is the first study to report velocity measures for the 'spin' pass sports skill featured in rugby football. The heavy ball contrast loading training intervention successfully elicited significant improvement in peak and mean velocity scores for both right-and left-handed passes within the six weeks of the training period. Overall, the eight subjects improved similarly with both right- and left-handed passes.

All of the eight subjects who were included in the main analysis, and the ninth player who also undertook testing at the completion of the study (having completed the training intervention), were right-handed. Accordingly, subjects tended to exhibit greater pass velocity with their dominant right hand as the top hand imparting spin on the ball. Differences between right-handed and left-handed mean and peak pass velocities approached significance at the onset of the training period. These differences were not close to significance levels at any other test occasion following the initiation of the training intervention, largely due to considerable improvements in left-handed pass velocity at week two. The improvement in left-handed pass velocity thus appeared to help equalise skill performance relative to the subjects' dominant right hand. However, additional testing at the completion of study revealed a lack of significant correlation between performance with heavy and regulation balls when passing left-handed. This was in contrast to the close relationship between right-handed heavy and regulation ball passing velocity. The reason for the observed difference in relationships in terms of performance with heavy ball and regulation ball between left hand and right hand is unclear. The more variable performance exhibited with the non-dominant (left) hand may reflect less advanced levels of skill acquisition associated with left-handed passing in these players.

The precise mechanisms for increases in throwing velocity with modified (heavy and light) ball training are yet to be elucidated. The increases in velocity for the passing skill observed in the current study are likely to be mediated by neural factors, on the basis that the relative loading offered by the heavy ball is probably insufficient to elicit morphological changes. These underlying neural factors likely include improvements in rate of force development (RFD). This RFD parameter is dependent on the rate at which the musculature is activated (Stone et al, 2003b), and increases can be attributed primarily to enhanced motor firing in the brief time interval for force production allowed by the sports skill (Behm, 1995). Gains in high velocity strength in the specific musculature involved in the passing movement may also have been a factor. Authors of a previous overarm throwing study hypothesised that improvements in the ability to selectively recruit high threshold motor units may play a role (DeRenne et al, 1994). It is likewise possible that improved intermuscular coordination of agonist, synergist and antagonist muscle firing may also have contributed in particular to the significant early gains in passing velocity with the non-dominant (left) hand. The complex training format featured in the study implies a contrast loading effect. Augmentation of power output with contrast loading is taken to originate from super-stimulation of the neuromuscular system elicited by the preceding heavier load set. The postulated mechanism for this potentiation is a transient disinhibition of tension-sensitive reflex and descending inhibitory inputs induced by the heavy primer load, which effectively raises the ceiling for power development when the target load is subsequently performed (Baker, 2003).

When trials to assess contrast loading effects were undertaken at the completion of the training period, acute augmentation of ball throwing speed was not observed to any significant extent. A lack of potentiation in throwing velocity associated with contrast loading has been reported previously, in an overarm throwing study that used warm up throws with a heavy ball (Straub, 1966). The study by Straub (1966) featured high school students with low skill level, so it is questionable whether these findings are representative of athletes with greater skill level and training experience (van den Tillar, 2004). Another study examining employing college baseball players did report a significant enhancement in throwing velocity immediately following warm-up throws with a heavy ball (van Huss et al, 1962). Acute potentiation of force output with contrast loading is widely documented for lower body athletic activities and recently also upper body movements (Young et al, 1998, Baker, 2001, Baker, 2003). It may be the lack of acute augmentation in the current study simply reflects fundamental differences in the nature of gross athletic movements and fine motor skills. Alternatively, it may be a consequence of the fact that testing was undertaken at the completion of the study. Investigations of contrast loading to date have focussed primarily on acute effects, with chronic effects associated with complex training receiving little attention. Neural adaptations resulting from the previous six weeks' exposure to the complex training intervention may have masked any potentiation, when acute effects were finally assessed at the end of the study period. Anecdotally, subjects did experience the sensation that the regulation ball 'felt lighter' following heavy ball passes during the training intervention, which is consistent with a contrast loading effect (Baker, 2001d).

An obvious constraint of the current study is the lack of a control group. However, it was necessary to compromise in terms of counterbalanced study design in order to attain access to subjects of the calibre featured in the study. Another issue with splitting the sample into two groups was the limited numbers involved, which would have an impact in terms of statistical power. More pertinently, the academy players featured have a narrow window of opportunity to earn a senior contract. Given the stakes involved, these players would therefore be averse to being denied the opportunity to participate in the heavy ball complex training intervention at the expense of other players in their position as a consequence of being randomly assigned to the control group. This would have been particularly problematic in view of the perceived benefit of the training intervention among the players.

It is becoming increasingly evident that elite athletes are a special population in terms of their specific responses to training. The training parameters that are optimal for elite athletes are quite distinct from those of untrained or even trained non-athletes. (Peterson et al, 2004). It is recognised that the particular training methods that will improve performance are dependent on the individual's skill level and training experience (Cronin et al, 2001). It has been highlighted recently that there is a paucity of contemporary data from elite level rugby union players in particular (Duthie et al, 2003). Concessions in terms of experimental protocol may therefore be necessary to allow elite athletes to serve as subjects as a means to gather data from this special population.

Due to the absence of counterbalanced experimental design as a means to establish conclusively that the effects observed were attributable to the training intervention per se, it is necessary to discuss other factors that could potentially account for the observed effects. Firstly, it could be argued that the increases in pass velocity were merely a consequence of the extra passing with a regulation ball that featured in the training intervention. In young subjects particularly, due to their lack of training and playing experience it can be argued that almost any form of systematic throwing practice would yield significant results. This is illustrated by significant gains made by younger subjects in control groups training solely with regulation balls in some overarm throwing studies (van den Tillar et al, 2004). This is not applicable to the current study. The subjects featured were full-time academy professional players, all of whom had representative honours for their country at various age-grades.

Similarly, the study was undertaken five weeks into the playing season. Hence the players who served as subjects had recently completed eight weeks of preseason training, during which time the players were fully integrated into senior squad training and practices. Furthermore, in the weeks prior to the study period, the players participated in their normal in-season training and competitive matches, which featured a substantial volume of individual skills and team practices. As a result, the subjects in the study had completed a considerable amount of skill training before the overweight ball training intervention. A criticism of a previous over-arm throwing study that did not feature a control group was that it was initiated during the off-season. At this time, it can be argued, a subject's throwing arm is deconditioned, and on this basis any form of throwing practice would yield positive effects (van den Tillar, 2004). This again does not apply to the current study, given that the subject group entered the training period in peak condition and having performed a large volume of skill practice.

The second potential confounding factor is the effects of concurrent training undertaken by the players during the study period. In the case of individuals with limited strength training experience, strength training can elicit improvements in functional skill performance (Cronin et al, 2001, van den Tillar, 2004). Increases in throwing velocity have been observed following strength training in female netball players with no strength training experience (Cronin et al, 2001). Increases in both throwing velocity and upper body strength are likewise documented in both elite junior and college baseball players when introduced to conventional strength training (Newton & McEvoy, 1994, Lachowetz et al, 1998). The subjects in the current study had significant strength and power training experience, so had previously attained a considerable base level of strength and power. On this basis it is unlikely that concurrent strength training alone would be sufficient to produce the magnitude of performance gains seen. In addition, significant improvements were registered as early as two weeks into the study (Tables 5.4.1 and 5.4.2), which is inconsistent with a progressive strength training effect.

The term 'coordination training' has been introduced to describe training modes that allow coordination of force output of agonist, synergist and antagonist muscle groups in a way that is specific to the movement patterns and velocity of an athletic activity (Newton & Kraemer, 1994). The heavy ball complex training intervention described clearly fits this definition. Ballistic resistance training for sports skills must be highly specific to the target activity. Despite the apparent functionality of ballistic bench throw training with regard to the two-handed chest pass in netball, this training mode was no more effective in developing netball chest pass velocity than conventional (bench press) strength training (Cronin et al, 2001). The authors concluded that the movement velocity involved in the bench throw was too dissimilar to the netball chest pass movement to evoke superior gains in chest pass velocity in relation to conventional bench press training. Likewise, the divergence in motor patterns involved with two-handed overhead and chest pass medicine ball throws are apparently too great to stimulate a training effect for baseball throwing velocity, even in junior players with no resistance training experience (Newton & McEvoy, 1994). It follows that the training implement employed for ballistic resistance training must be of the same dimensions as that used for the particular sports activity. With reference to throwing sports, a variety of underweight and overweight balls have been employed as a means to provide overload in the form of velocity and force, respectively (van den Tillar, 2004). However, results of studies featuring overweight ball training interventions in over-arm throwing sports players have been more variable (Escamilla et al, 2000, van den Tillar, 2004).

In the current study, with either hand heavy ball pass velocity was around 15% less than that with a regulation ball. From observing the subjects, there were no apparent qualitative differences in passing mechanics when using the heavy ball, with respect to passes with a regulation ball. The high correlation between heavy ball and regulation ball velocity exhibited by subjects when passing with their dominant hand would tend to support this. It has been hypothesised that throwing modified (under- or over-weight) balls may interfere with the player's 'feel' for throwing a regulation ball (Escamilla, 2000). In this aspect the relative volume and order of presentation of the modified ball throws may be important. A ratio of 2:1 overweight throws in relation to regulation ball throws has previously been advocated for overarm throwing interventions (Escamilla, 2000). The current study featured a 1:1 ratio of overweight and regulation ball passes, performing sets with each alternately. It is possible that the regulation ball passes interspersed between heavy ball sets acted to reinforce motor patterns and helped prevent any disruption to the passing skill.

The degree of loading for the preceding 'primer' exercise found to be effective with upper body movements is somewhat less (around 65% bench press 1-RM) than that for the lower body (Baker, 2003). In the case of fine motor skills it has been proposed that if the contrast load is too great then disruption of the precise motor patterns of the sports skill would occur, thereby nullifying any benefits of training (Baker, 2001d). Previously, the data of DeRenne et al (1994) indicated that a load variation of +/- 20% regulation weight was successful for under- and over-weight training interventions, which is consistent with previous data for athletic throwing events (Escamilla et al, 2000). Other over-arm throwing studies have reported success with balls that are 100% overweight (van den Tillar, 2004). The heavy ball intervention found to be successful in the current study represented a greater relative loading, being around 166% heavier than the regulation ball. The over-arm warm-up study by van Huss et al (1962) that successfully showed acute enhancement of throwing velocity employed 11oz balls, which were 120% heavier than regulation ball weight. However, over-arm training studies employing overweight balls of this degree of difference (>100% regulation weight) have typically not reported improvements in throwing velocity (van den Tillar, 2004). In the study by Straub (1966), subjects threw balls that were progressively increased in weight each week, culminating with 17oz balls (240% heavier than regulation) in the final week of the study, and no improvement in velocity was noted. That said, as noted previously the low skill level of the high school students examined may have been a confounding factor in this study. The two-handed rugby spin pass is fairly unique, and certainly different to over-arm throwing movements. This difference in findings may therefore simply reflect the fundamental dissimilarity between the respective sport skills.

The benefits of underweight ball training interventions have been reported previously by a number of studies examining over-arm throwing sports (van den Tillar, 2004). Likewise, combination training featuring both overweight and underweight (over-arm) ball throws has repeatedly proven to be successful. The findings of the current study support the efficacy of overweight ball training for the two-handed rugby 'spin' pass. Future research employing underweight balls, and a combination of both forms of training may reveal further benefits for the passing skill in rugby football.

5.4.5. Practical Applications

A heavy ball complex training intervention significantly improved velocity for the two-handed 'spin' pass skill in elite academy professional rugby union football players. Both right- and left-handed pass velocities were similarly improved by training. These findings are of relevance to rugby football players and coaches at all levels. The underlying mechanisms for the improvements reported are yet to be elucidated. Further research is necessary to examine chronic effects associated with complex training, and resolve the specific role of contrast loading effects in the observed augmentation of pass velocity for the two-handed rugby passing skill. The application of underweight ball training, employed independently, and in combination with heavy ball training, is another area for future study

6. Synthesis of Data

This section will focus initially on the first, second and final studies in the thesis. These three studies all adopted a single experimental group design and featured senior and academy professional rugby union football players.

The results of the metabolic conditioning study support the efficacy of skill-based conditioning games to develop cardiorespiratory fitness in elite-level professional rugby union football players. Significant improvement was seen post-training for two markers of endurance fitness, specifically HR recovery and %HRmax recorded from the final stage of a submaximal intermittent multi-stage shuttle test.

Strength training in a circuit format proved to be successful in improving lower body strength and upper-body strength for the pushing and pulling movements. Following the preseason training period strength scores for the deadlift, bench press and bench pull lifts were all improved.

A heavy ball complex training intervention significantly improved velocity for the two-handed 'spin' pass skill in elite academy professional rugby union football players. Mean and peak velocities for both right- and left-handed passes were similarly improved by training.

These three studies provide data in support of the respective novel approaches to training employed in eliciting a response in these professional rugby union football players. To date, there have been no contemporary prospective studies published employing rugby union football players at elite level since the advent of professionalism in 1996, particularly in the northern hemisphere. Whatever the shortcomings of the studies in terms of experimental design, they do represent a first step in establishing a body of knowledge relating to these athletes.

In this void, coaches in the sport at top level continue to rely on their own experience, inherited knowledge and convention as the basis for their training design. The absence of quantitative data relating to rugby union football players discourages the use of evidence-based training practices. Professional rugby union is still in its infancy and sport science has yet to fully pervade into the sport. There remains a high degree of variation in the approaches and methods used by strength and conditioning coaches, and the quality of physical preparation players are exposed to, even between the top professional clubs.

The sport of rugby football is unique, featuring a broad array of body types and sizes on a par with American football, and metabolic demands more similar to rugby league. In addition, rugby union features physical elements – such as lifting team-mates in a line-out, scrummaging, ruck cleans and driving mauls that are not seen in any other sport. As a result even if the relevant data did exist for elite players in rugby league and American football (which it does not for elite players), it is questionable whether these could be generalised as being applicable rugby union football players. All of which reinforces the need to gather data directly from these athletes to establish a quantitative basis for training prescription in professional rugby union. Without applied research studies, which will tend to necessarily have to make compromises, it will not be possible to bridge this ongoing gap between purest ideals of exercise physiology and what is relevant and applicable in the field.

The Olympic lift training study demonstrated significant carry over of Olympic-style pulling lifts to game-related power output for the simulated ruck clean movement. The Olympic lift training group exhibited increases in power output that were significantly greater than those of the control group (28% increase vs 8%). These results indicate that Olympic lift training as part of the physical preparation for rugby football players may yield benefits in terms of power output generated in specific activities against resistance provided by opposing players.

Ballistic push-up training using the prototype shoulder harness proved effective as an upper body ballistic training modality. Weighted BPU training was shown to elicit significant increases in the work output measure for the concentric-only push-up tests. The improvement in counter-movement push-up work output for the BPU training group also approached statistical significance.

7. Conclusions

Specificity of training has become acknowledged as a fundamental aspect governing training responses. Studies in the literature do not always fully account for principles of specificity, particularly with regard to the calibre of subjects they employ.

The five training studies featured directly observed the training responses of rugby union football players, including elite senior and academy professional players and junior academy players of elite level in their respective age-grade. Improvements in performance elicited by the respective training interventions were consistent with the principles and proposed benefits conferred by metabolic and mechanical specificity.

The findings of the present thesis have direct application for coaches and players, in particular those competing at elite level. All of the training interventions described have the potential for wider application in the field.

8. Study Limitations

The major limitation that featured in the three studies featuring senior and academy professional players was the lack of counterbalanced study design. As covered at some length in the respective discussion sections, this was a necessary compromise to secure the participation of these players as subjects. Previously, certain studies examining team sports athletes have resolved this problem by recruiting control subjects from another team participating at the same level of competition. That was not possible in this case, due to my position with the team that supplied the subjects for the training studies.

In the Olympic lift training study, certain methodological issues arose from the fact that access to the test facility and apparatus was limited. The Grunt 3000 testing unit is housed at the national stadium in Twickenham, and to the author's knowledge, is the only one of its kind in the United Kingdom. Conducting the study was therefore contingent on the goodwill of Dave Reddin, and the English Rugby Football Union. Consequently, subjects only had access to the testing apparatus on the two scheduled visits to the test facility, for pre- and post-testing. The improvement of the control group on the performance test measure in this study did indicate a learning effect, as a consequence of the novelty of the testing procedure. In addition, a limitation of the software that accompanied the apparatus was that it only provided instantaneous feedback of power output, without any facility to interrogate the data. It was for this reason that the somewhat arbitrary 1000ms time limit for force development was adopted for the test protocol.

The weighted ballistic push up study also had limitations imposed by the test apparatus. The contact mat system used did not offer measurement of the duration of force development, which would have allowed power output to be calculated.

An oversight in the heavy ball complex training study was that assessment of heavy ball pass velocity and contrast load trials were not undertaken prior to the training intervention. Additional testing to examine acute contrast loading effects performed at the completion of the training period offered was limited in terms of the insight it could offer.

9. Future Research Directions

The heart rate-based submaximal intermittent test protocol described has the potential to allow future studies to assess changes in cardiorespiratory fitness for a preseason period using alternative conditioning formats. Such a study employing traditional conditioning methods with elite professional players would allow direct comparison with the skill-based conditioning games data presented.

More data is required to quantify strength training responses of elite rugby football players. Studies providing equivalent data to that presented in the present thesis would offer an objective basis upon which to assess the effectiveness of different training modes and approaches to strength training with these athletes.

The rucking test apparatus featured in the Olympic lift study illustrates the potential benefits of test modes that simulate game-related actions. Development of similar testing modes to evaluate performance capabilities for specific movements that feature in other sports is a topic for further study. This has the potential to provide a means to objectively evaluate transfer of training effects to performance.

Applications of the prototype shoulder harness used as part of the weighted ballistic push up training described should be explored further. Investigations employing players with greater strength training experience will enable the potential benefits of this training modality to be more fully examined. Studies assessing training responses of senior professional rugby football players with this training mode would be of particular interest.

Further research should focus upon chronic effects associated with complex training for upper-body and lower-body movements. There is also a requirement for future research to examine the underlying mechanisms for the gains in velocity observed with heavy ball complex training for various sports skills, including, but not limited to, the two-handed rugby spin pass. The application of underweight ball training, possibly in combination with heavy ball training, is another area for future study.

References

1. Abernethy, P., G. Wilson & P. Logan. (1995). Strength and Power Assessment: Issues, Controversies and Challenges. *Sports Medicine.* 19(6): 410-417.
2. Ali, A., & M. Farrally. (1991a). A Computer-Video Aided Time Motion Analysis Technique for Match Analysis. *Journal of Sports Medicine and Physical Fitness.* 31: 82-88.
3. Ali, A., & M. Farrally. (1991b). Recording Soccer Players' Heart Rates During Matches. *Journal of Sports Sciences.* 9: 183-189.
4. American College of Sports Medicine. (1998). The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults: Position Stand. *Medicine & Science in Sports & Exercise.* 30: 975-991.
5. Baechle T.R., R.W. Earle, & D. Wathen. (2000). In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp. 395-425). Champaign, IL: Human Kinetics.
6. Baker, D. & S. Nance. (1999a). The Relation Between Strength and Power in Professional Rugby League Players. *Journal of Strength & Conditioning Research.* 13(3): 224-229.
7. Baker, D. & S. Nance. (1999b). The Relation Between Running Speed and Measures of Strength and Power in Professional Rugby League Players. *Journal of Strength & Conditioning Research.* 13(3): 230-235.
8. Baker, D. (1996). Improving Vertical Jump Performance Through General, Special, and Specific Strength Training: A Brief Review. *Journal of Strength & Conditioning Research.* 10(2): 131-136.
9. Baker, D. (2001a). Acute and Long Term Power Responses to Power Training: Observations on the Training of an Elite Power Athlete. *Strength & Conditioning Journal.* 23(1): 47-56.
10. Baker, D. (2001b). Comparison of Upper-Body Strength and Power Between Professional and College-Aged Rugby League Players. *Journal of Strength & Conditioning Research.* 15(1): 30-35.
11. Baker, D. (2001c). The Effects of an In-Season of Concurrent Training on

the Maintenance of Maximal Strength and Power in Professional and College-aged Rugby League Football Players. *Journal of Strength & Conditioning Research.* 15(2): 172-177.

12. Baker, D. (2001d). A Series of Studies on the Training of High Intensity Muscle Power in Rugby League Football Players. *Journal of Strength & Conditioning Research.* 15(2): 198-209.
13. Baker, D. (2002). Differences in Strength and Power Among Junior-High, Senior-High, College-Aged, and Elite Professional Rugby League Players. *Journal of Strength & Conditioning Research.* 16(4): 581-585.
14. Baker, D. (2003). Acute Effects of Alternating Heavy and Light Resistances on Power Output During Upper-Body Complex Power Training. *Journal of Strength & Conditioning Research.* 17(3): 493-497.
15. Baker, D., G. Wilson, & B. Carlyon. (1994). Generality Versus Specificity: A Comparison of Dynamic and Isometric Measures of Strength and Speed-Strength. *European Journal of Applied Physiology.* 68: 350-355.
16. Baker, D., S. Nance, & M. Moore. (2001a). The Load that Maximises the Average Mechanical Power Output During Explosive Bench Press Throws in Highly Trained Athletes. *Journal of Strength & Conditioning Research.* 15(1): 20-24.
17. Baker, D., S. Nance, & M. Moore. (2001b). The Load that Maximises the Average Mechanical Power Output During Jump Squats in Power Trained Athletes. *Journal of Strength & Conditioning Research.* 15(1): 92-97.
18. Balsom, P.D., J.Y. Seger, B. Sjodin, & B. Ekblom. (1992). Maximal-Intensity Intermittent Exercise: Effect of Recovery Duration. *International Journal of Sports Medicine.* 13(7): 528-533.
19. Bangsbo, J. (1994). The Physiology of Soccer, with Special Reference to Intense Intermittent Exercise. *Acta Physiologica Scandinavica.* 151(suppl 619).
20. Bangsbo, J. (1998). The Physiological Profile of Soccer Players. *Sports Exercise & Injury.* 4(4): 144-150.
21. Bangsbo. J., L. Norregaard, & F. Thorso. (1991). Activity Profile of Competition Soccer. Canadian *Journal of Sports Sciences.* 16(2): 110-116.

22. Bathgate, A., J.P. Best, G. Craig, & M. Jamieson. (2002). A Prospective Study of Injuries to Elite Australian Rugby Union Players. *British Journal of Sports Medicine*. 36: 265-269.

23. Behm, D.G. & D.G. Sale. (1993). Intended Rather than Actual Movement Velocity Determines Velocity-Specific Training Response. *Journal of Applied Physiology*. 74(1): 359-368.

24. Behm, D.G. (1995). Neuromuscular Implications and Adaptations of Resistance Training. *Journal of Strength & Conditioning Research*. 9(4): 264-274.

25. Bell, G.J., G.D Snydmiller, D.S. Davies, & H.A. Quinney. (1997). Relationship Between Aerobic Fitness and Metabolic Recovery From Intermittent Exercise in Endurance Athletes. *Canadian Journal of Applied Physiology*, 22(1): 78-85.

26. Billat, V.L., P. Sirvent, G. Py, J-P. Koralsztein, & J. Mercier. (2003). The Concept of Maximal Lactate Steady State. *Sports Medicine*. 33(6): 407-426.

27. Bogdanis, G.C., M.E. Nevill, L.H. Boobis, & H.K.A. Lakomy. (1996). Contribution of Phosphocreatine and Aerobic Metabolism to Energy Supply During Repeated Sprint Exercise. *Journal of Applied Physiology*. 80(3): 876-884.

28. Boulay, M.R., J.A. Simoneau, G. Lortie, & C. Bouchard. (1997). Monitoring High-Intensity Endurance Exercise with Heart Rate and Thresholds. *Medicine & Science in Sports & Exercise*. 29(1): 125-132.

29. Boyle. P.M., C.A. Mahoney, & W.F.M. Wallace. (1994). The Competitive Demands of Elite Male Field Hockey. *Journal of Sports Medicine and Physical Fitness*. 34(3): 235-241.

30. Brewer, J. & J. Davis. (1995). Applied Physiology of Rugby League. *Sports Medicine*. 20(3): 129-135. 1995.

31. Bulbulian, R., A.R. Wilcox, & B.L. Darabos. (1986). Anaerobic Contribution to Distance Running Performance of Trained Cross-country Athletes. *Medicine & Science in Sports & Exercise*. 18(1): 107-113. 1986.

32. Coutts, A., P. Reaburn, & G. Abt. (2003). Heart Rate, Blood Lactate Concentration and Estimated Energy Expenditure in a Semi-Professional

Rugby League Team During a Match: A Case Study. *Journal of Sports Sciences*. 21: 97-103.

33. Cronin, J., P.J. McNair, & R.N. Marshall. (2001a). Developing Explosive Power: A Comparison of Technique and Training. *Journal of Science & Medicine in Sport*. 4(1): 59-70.

34. Cronin, J., P.J. McNair, & R.N. Marshall. (2001b). Velocity Specificity, Combination Training and Sport Specific Tasks. *Journal of Science & Medicine in Sport*. 4(2): 168-178.

35. Cronin, J.B., P.J. McNair, & R.N. Marshall. (2003). Force-Velocity Analysis of Strength-Training Techniques and Load: Implications for Training Strategy and Research. *Journal of Strength & Conditioning Research*. 17(1): 148-155.

36. Coutts, A.J., A.J. Murphy, & B.J. Dascombe. (2004). *Journal of Strength & Conditioning Research*. 18(2). 316-323.

37. Daniels, J. (2001). Aerobic Capacity for Endurance. In: High-Performance Sports Conditioning. B. Foran Ed. Champaign, IL: Human Kinetics, 2001. pp 193-212.

38. Darr, K.C., D.R. Bassett, B.J. Morgan, & D.P. Thomas. (1988). Effect of Age and Training Status of Heart Rate Recovery after Peak Exercise. *American Journal of Physiology*. 254: H340-H343.

39. Delecluse, C. (1997). Influence of Strength Training on Sprint Running Performance. *Sports Medicine*. 24(3): 147-156.

40. Delecluse, C., H. Van Coppenolle, E. Willems, M. Van Leemputte, R. Diels, & M. Goris. (1995). Influence of High-Resistance and High-Velocity Training on Sprint Performance. *Medicine & Science in Sports & Exercise*. 27(8): 1203-1209.

41. Den Duyn, N. (1996). Game Sense. *Sport Coach*. 19(3): 6-9.

42. Den Duyn, N. (1997). Game Sense Its Time To Play. *Sport Coach*. 19(4): 9-11.

43. DeRenne, C., H. Kwok, & A. Blitzblau. (1990). Effects of Weighted Implement Training on Throwing Velocity. *Journal of Applied Sports Science Research*. 4(1): 16-19.

44. DeRenne, C., B.P. Buxton, R.K. Hetzel, & K. Ho. (1994). Effects of

Under and Overweighted Implement Training on Pitching Velocity. *Journal of Strength & Conditioning Research.* 8(4): 247-250.

45. Deutsch, M.U., G.J. Maw, D. Jenkins, & P. Reaburn. (1998). Heart Rate, Blood Lactate and Kinematic Data of Elite Colts (Under-19) Rugby Union Players During Competition. *Journal of Sports Sciences,* 16: 561-570.

46. Docherty, D., H.A. Wenger, & P. Neary. (1988). Time-motion Analysis Related to the Physiological Demands of Rugby. *Journal of Human Movement Studies.* 14: 269-277.

47. Drust, B., T. Reilly, & E. Rienzi. (1998). Analysis of Work Rate in Soccer. *Sports Exercise & Injury.* 4(4): 151-155.

48. Drust, B., T. Reilly, & N.T. Cable. (2000). Physiological Responses to Laboratory-based Soccer-Specific Intermittent and Continuous Exercise. *Journal of Sports Sciences.* 18: 885-892.

49. Durstine, J.L. & P.G. Davis. (2001). Specificity of Training and Testing. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th Ed). J.L. Roitman Ed. Lippincott Williams & Wilkins. pp 484-491.

50. Duthie, G., D. Pyne, & S. Hooper. (2003). Applied Physiology and Game Analysis of Rugby Union. *Sports Medicine.* 33(13): 973-991.

51. Earle, R.W. & T.R. Baechle. (2000). Resistance Training and Spotting Techniques. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning,* 2nd Ed (pp. 343-389). Champaign, IL: Human Kinetics.

52. Enoka, R.M. (1997). Neural Adaptations with Chronic Physical Activity. Journal of Biomechanics. 30(5): 447-455.

53. Escamilla, R.F., K.P. Speer, G.S. Fleisig, S.W. Barrentine, & J.R. Andrews. (2000). Effects of Throwing Overweight and Underweight Baseballs on Throwing Velocity and Accuracy. *Sports Medicine.* 29(4): 259-272.

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

55. Foster, C., L.L. Hector, R. Welsh, M. Schrager, M.A. Green, & A.C. Snyder. (1997). Effects of Specific Versus Cross-Training on Running Performance. *European Journal of Applied Physiology.* 70: 367-372.

56. Franklin, B.A. & J.L. Roitman. (2001). Cardiorespiratory Adaptations to Exercise. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th Ed). J.L. Roitman Ed. Lippincott Williams & Wilkins. pp 160-166.

57. Gabbett, T.J. (2002). Training Injuries in Rugby League: An Evaluation of Skill-Based Conditioning Games. *Journal of Strength & Conditioning Research.* 16(2): 236-241.

58. Gaiga, M.C., & D. Docherty. (1995). The Effect of an Aerobic Interval Training Program on Intermittent Anaerobic Performance. *Canadian Journal of Applied Physiology.* 20(4): 452-464.

59. Gamble, P. (2004). Physical Preparation of Elite Level Rugby Union Football Players. *Journal of Strength & Conditioning* 26(4): 10-23.

60. Garhammer, J. (1993). A Review of Power Output Studies of Olympic and Powerlifting: Methodology, Performance Prediction, and Evaluation Tests. *Journal of Strength & Conditioning Research.* 7(2): 76-89.

61. Garraway, W.M., A.J. Lee, D.A.D. Macleod, J.W. Telfer, I.J. Deary, & G.D. Murray. (1999). Factors Influencing Tackle Injuries in Rugby Union Football. *British Journal of Sports Medicine.* 33: 37-41.

62. Gilman, M.B. & C.L. Wells. (1993). The Use of Heart Rates to Monitor Exercise Intensity in Relation to Metabolic Variables. *Sports Medicine.* 14(6): 339-344.

63. Gilman, MB. (1996). The Use of Heart Rate to Monitor the Intensity of Endurance Training. *Sports Medicine.* 21(2): 73-79.

64. Green, H., P. Bishop, M. Houston, R. McKillop, R. Norman & P. Stothart. (1976). Time-motion and Physiological Assessments of Ice Hockey Players. *Journal of Applied Physiology.* 40(2): 159-163.

65. Gregoire. J., S. Tuck, Y. Yamamoto, & R.L. Hughson. (1996). Heart Rate Variability at Rest and Exercise: Influence of Age, Gender, and Physical Training. *Canadian Journal of Applied Physiology.* 21(6): 455-470.

66. Haff, G.G., A. Whitley, L.B. McCoy, H.S. O'Bryant, J.L. Kilgore, E.E. Haff, K. Pierce, & M.H. Stone. (2003). Effects of Different Set Configurations on Barbell Velocity and Displacement During a Clean Pull. *Journal of Strength & Conditioning Research.* 17(1): 95-103.

67. Hakkinen, K., P.V. Komi, M. Alen, & H. Kauhanen. (1987). EMG, Muscle Fibre and Force Production Characteristics During a One Year Training Period in Elite Weight-Lifters. *European Journal of Applied Physiology*. 56: 419-427.

68. Handford, C., K. Davids, S. Bennett, & C. Button. (1997). *Journal of Sports Sciences* .15: 621-640.

69. Harman, E., J. Garhammer, & C. Pandorf. (2000). Administration, Scoring, and Interpretation of Selected Tests. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp. 287-317). Champaign, IL: Human Kinetics.

70. Harris, G.R., M.H. Stone, H.S. O'Bryant, C.M. Proulx, & R.L. Johnson. (2000). Short-term Performance Effects of High Power, High Force, or Combined Weight-Training Methods. *Journal of Strength & Conditioning Research*. 14(1): 14-20.

71. Hedrick, A. (1993). Literature Review: High Speed Resistance Training. *NSCA Journal*. 15(6): 22-30.

72. Hedrick, A. (2002). Manipulating Strength and Conditioning Programs to Improve Athleticism. *Strength & Conditioning Journal*, 24(4): 71-74.

73. Helgerud, J., L.C. Engen, U. Wisloff & J. Hoff. (2001). Aerobic Endurance Training Improves Soccer Performance. *Medicine & Science in Sports & Exercise*. 33(11): 1925-1931.

74. Hoff, J., U. Wisloff, L.C. Engen, O.J. Kemi, & J. Helgerud. (2002). Soccer Specific Aerobic Endurance Training. *British Journal of Sports Medicine*. 36(3). 218-221.

75. Hoffman, J.R., & J. Kang. (2003). Strength Changes During an In-Season Resistance Training Program for Football. *Journal of Strength & Conditioning Research*. 17(1): 109-114.

76. Hoffman, J.R., G. Tenenbaum, C.M. MARESH, & W.J. Kraemer. (1996). Relationship Between Athletic Performance Tests and Playing Time in Elite College Basketball Players. *Journal of Strength & Conditioning Research*. 10(2): 67-71.

77. Hoffman, J.R., W.J. Kraemer, A.C. Fry, M. Deschenes, & M. Kemp. (1990). The Effect of Self-Selection for Frequency of Training in a Winter

Conditioning Program for Football. *Journal of Applied Sports Science Research.* 4(3): 76-82.

78. Hofmann, P., R. Pokan, S.P.V. Duvillard, F.J. Seibert, R. Zweiker, & P. Schmid. (1997). Heart Rate Performance Curve During Incremental Cycle Ergometer Exercise in Healthy Young Male Subjects. *Medicine & Science in Sports & Exercise.* 29(6): 762-768.

79. Holly, R.G. & J.D. Shaffrath. (2001). Cardiorespiratory Endurance. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th Ed). J.L. Roitman Ed. Lippincott Williams & Wilkins, 2001. pp 449-459.

80. Hydock, D. (2001). The Weightlifting Pull in Power Development. *Strength & Conditioning Journal.* 23(1): 32-37.

81. Imai, K., H. Sato, M. Hori, H. Kusuoka, H. Ozaki, H. Yokoyama, H. Takeda, M. Inoue, & T. Kamada. (1994). Vagally Mediated Heart Rate Recovery After Exercise is Accelerated in Athletes but Blunted in Patients with Chronic Heart Failure. *Journal of American College of Cardiology,* 24(6): 1529-1535.

82. Ives, J.C. & G.A. Shelley. (2002). Psychophysics in Functional Strength and Power Training: Review and Implementation Framework. *Journal of Strength & Conditioning Research.* 17(1): 177-186.

83. Jeffreys, I. (2004). The Use of Small-sided Games in the Metabolic Training of High School Soccer Players. *Strength & Conditioning Journal.* 26(5). 77-78.

84. Jones, A.M. & H. Carter. (2000). The Effect of Endurance Training on Parameters of Aerobic Fitness. *Sports Medicine.* 29(6): 373-386.

85. Jones, K., G. Hunter, G. Fleisig, R. Escamilla, & L. Lemak. (1999). The Effects of Compensatory Acceleration on Upper-Body Strength and Power in Collegiate Football Players. *Journal of Strength & Conditioning Research.* 13(2): 99-105.

86. Karvonen, J., & T. Vuorimaa. (1988a). Recovery Time in Interval Training for Increasing Aerobic Capacity. *Annals of Sports Medicine.* 3: 215-219.

87. Karvonen, J., & T. Vuorimaa. (1988b). Heart Rate and Exercise Intensity

During Sports Activities. *Sports Medicine*. 5: 303-311.

88. Kindermann, W., G. Simon, & J. Keul. (1979). The Significance of the Aerobic-Anaerobic Transition for the Determination of Work Load Intensities During Endurance Training. *European Journal of Applied Physiology*. 42: 25-34.

89. Kraemer, W.J. & A.L. Gomez. (2001). Establishing a Solid Fitness Base. In: High-Performance Sports Conditioning. B. Foran Ed. Champaign, IL: Human Kinetics, 2001. pp 3-17.

90. Kraemer, W.J. (1997). A Series of Studies – The Physiological Basis for Strength Training in American Football: Fact Over Philosophy. *Journal of Strength & Conditioning Research*. 11(3): 131-142.

91. Kraemer, W.J. (2000a). Endocrine Responses to Resistance Exercise. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp. 91-114). Champaign, IL: Human Kinetics.

92. Kraemer, W.J. (2000b). Physiological Adaptations to Anaerobic and Aerobic Endurance Training Programs. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp.137-168). Champaign, IL: Human Kinetics.

93. Kraemer, W.J., J.F. Patton, S.E. Gordon, E.A. Harman, M.R. Deschenes, K. Reynolds, R.U. Newton, N.T. Triplett, & J.E. Dziados. (1995). Compatibility of High-intensity Strength and Endurance Training on Hormonal and Skeletal Muscle Adaptations. *Journal of Applied Physiology*. 78(3): 976-989.

94. Kraemer, W.J., K. Adams, E. Cafarelli, G.A. Dudley, C. Dooly, M.S. Feigenbaum, S.J. Fleck, B. Franklin, A.C. Fry, J.R. Hoffman, R.U. Newton, J. Potteiger, M.H. Stone, N.A. Ratamess, & T. Triplett-McBride. (2002). American College of Sports Medicine Position Stand: Progression Models in Resistance Training for Healthy Adults. *Medicine & Science in Sports & Exercise*. 34(2): 364-380.

95. Lachowetz, T., J. Evon, & J. Pastiglione. (1998). The Effect of an Upper Body Strength Program on Intercollegiate Baseball Throwing Velocity. *Journal of Strength & Conditioning Research*. 12(2): 116-119.

96. Lawson, E. (2001). Incorporating Sport-specific Drills into Conditioning.

In: High-Performance Sports Conditioning. B. Foran Ed. Champaign, IL: Human Kinetics, 2001. pp 215-266.

97. Leger, L. & C. Gadoury. (1989). Validity of the 20m Shuttle Run Test with 1min Stages to Predict VO2max in Adults. *Canadian Journal Sports Science*, 14(1): 21-26.

98. Leger, L.A., D. Mercier, C. Gadoury, & J. Lambert. (1988). The Multistage 20-metre Shuttle Run Test for Aerobic Fitness. *Journal of Sports Sciences* 6: 93-101.

99. Leveritt, M., & P.J. Abernethy. (1999). Acute Effects of High-Intensity Endurance Exercise on Subsequent Resistance Activity. *Journal of Strength & Conditioning Research.* 13(1): 47-51.

100. Li, R., P. Deurenberg, & G.J.A.J. Hautvast. (1993). A Critical Evaluation of Heart Rate Monitoring to Assess Energy Expenditure in Individuals. *American Journal of Clinical Nutrition.* 58:602-607.

101. Lyttle, A.D., G.J. Wilson, & K.J. Ostrowski. (1996). Enhancing Performance: Maximal Power Versus Combined Weights and Plyometrics Training. *Journal of Strength & Conditioning Research.* 10(3): 173-179.

102. Magel, J.R., G.F. Foglia, & W.D. McArdle. (1975). Specificity of Swim Training on Maximal Oxygen Uptake. *Journal of Applied Physiology.* 38: 151-155.

103. Matavulj, D., M. Kukolj, D. Ugarkovic, J. Tihanyi & S. Jaric. (2001). Effects of Plyometric Training on Jumping Performance in Junior Basketball Players. *Journal of Sports Medicine & Physical Fitness.* 41: 159-164.

104. Matuszak, M.E., A.C. Fry, L.W. Weiss, T.R. Ireland, & M.M. McKnight. (2003). Effect of Rest Interval Length on Repeated 1 Repetition Maximum Back Squats. Journal of Strength & Conditioning Research. 17(4). 634-637.

105. McBride, J.M., T. Triplett-McBride, A. Davie, & R.U. Newton. (1999). A Comparison of Strength and Power Characteristics Between Power Lifters Olympic Lifters and Sprinters. *Journal of Strength & Conditioning Research.* 13(1): 58-66.

106. McConnell, T.R. (2001). Cardiorespiratory Assessment of Apparently

Healthy Individuals. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th Ed). J.L. Roitman Ed. Lippincott Williams & Wilkins. pp 361-366.

107. McCurdy, K., & C. Conner. (2003). Unilateral Support Training Incorporating the Hip and Knee. *Strength & Conditioning Journal*, 25(2): 45-51.

108. McEvoy, K.P., & R.U. Newton. (1998). Baseball Throwing Speed and Base Running Speed: The Effects of Ballistic Resistance Training. *Journal of Strength & Conditioning Research.* 12(4): 216-221.

109. McInnes, S.E., J.S. Carlson, C.J. Jones, & M.J. McKenna. (1995). The Physiological Load Imposed on Basketball Players During Competition. *Journal of Sports Science*, 13: 387-397.

110. McLean, D.A. (1992). Analysis of the Physiological Demands of International Rugby Union. *Journal of Sports Sciences.* 10: 285-296.

111. Meir, R., D. Arthur, & M. Forrest. (1993). Time and Motion Analysis of Professional Rugby League: A Case Study. *Strength and Conditioning Coach.* 3(1): 24-29.

112. Meir, R., P. Colla, & C. Milligan. (2001a). Impact of the 10-Meter Rule Change on Professional Rugby League: Implications for Training. *Strength & Conditioning Journal*, 23(6): 42-46.

113. Meir, R., R.U. Newton, E. Curtis, M. Fardell, & B. Butler. (2001b). Physical Fitness Qualities of Professional Rugby League Football Players: Determination of Positional Differences. *Journal of Strength & Conditioning Research.* 15(4): 450-458.

114. Mero, A., & P.V. Komi. (1994). EMG, Force, and Power Analysis of Sprint-Specific Strength Exercises. *Journal of Applied Biomechanics.* 10: 1-13.

115. Millet, G.P., R.B. Candau, B. Barbier, T. Busso, J.D. Rouillon, & J.C. Chatard. (2002). Modelling the Transfers of Training Effects on Performance in Elite Triathletes. *International Journal of Sports Medicine.* 23: 55-63.

116. Morrissey, M.C., E.A. Harman, & M.J. Johnson. (1995). Resistance Training Modes: Specificity and Effectiveness. *Medicine & Science in*

Sports & Exercise. 27(5). 648-660.

117. Murphy, A.J. & G.J. Wilson. (1997). The Ability of Tests of Muscular Function to Reflect Training Induced Changes in Performance. *Journal of Sports Sciences*. 15: 191-200.

118. Newton, R.U. & W.J. Kraemer. (1994). Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy. *Strength & Conditioning*. 16: 20-31.

119. Newton, R.U., & E. Dugan. (2002). Application of Strength Diagnosis. *Strength & Conditioning Journal*. 24(5): 50-59.

120. Newton, R.U., & K.P. McEvoy. (1994). Baseball Throwing Velocity: A Comparison of Medicine Ball Throwing and Weight Training. *Journal of Strength & Conditioning Research*. 8(3): 198-203.

121. Newton, R.U., A.J. Murphy, B.J. Humphries, G.J. Wilson, W.J. Kraemer, & K. Hakkinen. (1997). Influence of Load and Stretch Shortening Cycle on the Kinematics, Kinetics and Muscle Activation that Occurs During Explosive Upper-Body Movements. *European Journal of Applied Physiology*. 75: 333-342.

122. Newton, R.U., W.J. Kraemer, & K. Hakkinen. (1999). Effects of Ballistic Training on Preseason Preparation of Elite Volleyball Players. *Medicine & Science in Sports & Exercise*. 31(2): 323-330.

123. Newton, R.U., W.J. Kraemer, K. Hakkinen, B.J. Humphries, & A.J. Murphy. (1996). Kinematics, Kinetics and Muscle Activation During Explosive Upper Body Movements. *Journal of Applied Biomechanics*. 12: 31-43.

124. Nicholas, C.W. (1997). Characteristics of Rugby Union Football Players. *Sports Medicine*. 23(6): 376-394.

125. Olds, T. (2001). The Evolution of Physique in Male Rugby Union Players in the Twentieth Century. *Journal of Sports Sciences*. 19: 253-262. 2001.

126. Peterson, M.D., M.R. Rhea, & B.A. Alvar. (2004). Maximising Strength Development in Athletes: A Meta-Analysis to Determine the Dose-Response Relationship. *Journal of Strength & Conditioning Research*. 18(2): 377-382.

127. Pettitt, R.W. & E.R. Bryson. (2002). Training for Women's Basketball: A

Biomechanical Emphasis for Preventing Anterior Cruciate Ligament Injury. *Strength & Conditioning Journal*, 24(5): 20-29.

128. Plisk, S.S. & V. Gambetta. (1997). Tactical Metabolic Training: Part 1. *Strength & Conditioning*. 19(2): 44-53.

129. Plisk, S.S. (2000). Speed, Agility, and Speed-Endurance Development. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp.471-491). Champaign, IL: Human Kinetics.

130. Plisk, S.S., & M.H. Stone. (2003). Periodisation Strategies. *Strength & Conditioning Journal*. 25(6): 19-37.

131. Potach, D.H., & D.A. Chu. (2000). Plyometric training. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp.427-470). Champaign, IL: Human Kinetics.

132. Potach, D.H., & R.A. Borden. (2000). Rehabilitation and Reconditioning. In Baechle & Earle (Eds), *Essentials of Strength Training & Conditioning*, 2nd Ed (pp. 529-546). Champaign, IL: Human Kinetics.

133. Potteiger, JA & B.W. Evans. (1995). Using Heart Rate and Ratings of Perceived Exertion to Monitor Intensity in Runners. *Journal of Sports Medicine & Physical Fitness*. 35(3): 181-186. 1995.

134. Quarrie, K.L., & B.D. Wilson. (2000). Force Production in the Rugby Union Scrum. *Journal of Sports Sciences*. 18: 237-246.

135. Quarrie, K.L., P. Handcock, A.E. Waller, D.J. Chalmers, M.J. Toomey, & B.D. Wilson. (1995). The New Zealand Rugby Injury and Performance Project III Anthropometric and Physical Performance Characteristics of Players. *British Journal of Sports Medicine*. 29(4): 263-270.

136. Quarrie, K.L., P. Handcock, M.J. Toomey, & A.E. Waller. (1996). The New Zealand Rugby Injury and Performance Project IV: Anthropometric and Physical Performance Comparisons Between Positional Categories of Senior A Rugby Players. *British Journal of Sports Medicine*. 30(1): 53-56.

137. Ramsbottom, R., J. Brewer, & C. Williams. (1988). A Progressive Shuttle Run Test to Estimate Maximal Oxygen Uptake. *British Journal of Sports Medicine*. 22: 141-144.

138. Reilly, T. (1994). Physiological Aspects of Soccer. *Biology of Sport*. 11(1): 3-20.

139. Reilly, T. (1997a). Energetics of High-Intensity Exercise (Soccer) with Particular Reference to Fatigue. *Journal of Sport Sciences*. 15: 257-263.

140. Reilly, T. (1997b). The Physiology of Rugby Union Football. *Biology in Sport*. 14: 83-101.

141. Reilly, T., J. Bangsbo, & A. Franks. (2000). Anthropometric and Physiological Predispositions for Elite Soccer. *Journal of Sports Sciences*. 18: 669-683.

142. Rhea, M., B. Alvar, L. Burkett, & S. Ball. (2003). A Meta-analysis to Determine the Dose-Response Relationship for Strength. *Medicine & Science in Sports & Exercise*. 35: 456-464.

143. Rienzi, E., B. Drust, J.E.L. Carter, & A. Martin. (2000). Investigation of Anthropometric and Work-Rate Profiles of Elite South American International Soccer Players. *Journal of Sports Medicine & Physical Fitness*. 40(2): 162-169.

144. Rienzi, E., T. Reilly, & C. Malkin. (1999). Investigation of Anthropometric and Work-rate Profiles of Rugby Sevens Players. *Journal of Sports Medicine and Physical Fitness*. 39: 160-164.

145. Savin, W.M., D.M. Davidson, & W.L. Haskell. (1982). Autonomic Contribution to Heart Rate Recovery from Exercise in Humans. *Journal of Applied Physiology*, 53(6): 1572-1575.

146. Sawka, M.N., R.G. Knowlton, & J.B. Critz. (1979). Thermal and Circulatory Responses to Repeated Bouts of Prolonged Running. *Medicine & Science in Sports & Exercise*. 11(2): 177-180.

147. Siff, M.C. (2002) Functional Training Revisited. *Strength & Conditioning Journal*. 24(5): 42-46.

148. Souza, A.L., S.D. Shimada, & A. Koontz. (2002). Ground Reaction Forces During the Power Clean. *Journal of Strength & Conditioning Research*. 16(3): 423-427.

149. Stone, M.H. (1993). Literature Review: Explosive Exercises and Training. *NSCA Journal*. 15(3): 7-15.

150. Stone, M.H., D. Collins, S. Plisk, G. Haff, & M.E. Stone. (2000). Training Principles: Evaluation of Modes and Methods of Resistance Training. *Strength & Conditioning Journal*. 22(3). 65-76.

151. Stone, M.H., H.S. O'Bryant, R.L. Johnson, K.C. Pierce, D.G. Haff, A.J. Koch, & M. Stone. (1999). Periodisation: Effects of Manipulating Volume and Intensity: Part One. *Strength & Conditioning Journal*. 21(2): 56-62.

152. Stone, M.H., H.S. O'Bryant, L. McCoy, R. Coglianese, M. Lehmkuhl, & B. Schilling. (2003a). Power and Maximum Strength Relationships During Performance of Dynamic and Static Weighted Jumps. *Journal of Strength & Conditioning Research*. 17(1): 140-147.

153. Stone, M.H., K. Sandborn, H. O'Bryant, M. Hartman, M.E. Stone, C. Proulx, B. Ward, & J. Hruby. (2003b). Maximum Strength-Power-Performance Relationships in Collegiate Throwers. *Journal of Strength & Conditioning Research*. 17(4): 739-745.

154. Straub, W.F. (1968). Effect of Overload Procedures Upon Velocity and Accuracy of the Overarm Throw. *Research Quarterly*. 39(2): 370-379.

155. Tabata, I., K. Irisawa, M. Kouzaki, K. Nishimura, F. Ogita, & M. Miyachi. (1997). Metabolic Profile of High Intensity Intermittent Exercises. *Medicine & Science in Sports & Exercise*. 29(3): 390-395.

156. Tabata, I., K. Nishimura, M. Kouzaki, Y. Hirai, F. Ogita, & M. Miyachi. (1996). Effects of Moderate-Intensity Endurance and High-intensity Intermittent Training on Anaerobic Capacity and VO2max. *Medicine & Science in Sports & Exercise*. 28(10): 1327-1330.

157. Taylor, J. (2004). A Tactical Metabolic Training Model for Collegiate Basketball. *Strength & Conditioning Journal*. 26(5). 22-29.

158. Treadwell, P.J. (1988). Computer-aided Match Analysis of Selected Ball Games (Soccer & Rugby Union). In: Reilly, T, Lees, A, Davids, K, et al. Ed.s. Science and Football. pub. London: E & FN Spon.

159. Van Den Tillar, R. (2004). Effect of Different Training Programs on the Velocity of Overarm Throwing: A Brief Review. *Journal of Strength & Conditioning Research*. 18(2): 388-396.

160. Van Huss, W.D., L. Albrecht, R. Nelson, & R. Hagerman. (1962). Effect of Overload Warm-Up on the Velocity and Accuracy of Throwing. *Research Quarterly*. 33(3): 472-475.

161. Vossen, J.F., J.F. Kraemer, D.G. Burke, & D.P. Vossen. (2000). Comparison of Dynamic Push-Up Training and Plyometric Push-up

Training on Upper-Body Power and Strength. *Journal of Strength & Conditioning Research.* 14(3): 248-253.

162. Vuorimaa, T., & J. Karvonen. (1988). Recovery Time in Interval Training for Increasing Aerobic Capacity. *Annals of Sports Medicine.* 3(4): 215-219.

163. Wenger, H.A. & G.J. Bell. (1986). The Interaction of Intensity, Frequency and Duration of Exercise Training in Altering Cardiorespiratory Fitness. *Sports Medicine* 3: 346-356.

164. Wilder, N., R. Gilders, F. Hagerman, & R.G. Deivert. (2002). The Effects of a 10-Week, Periodised, Off-Season Resistance Training Program and Creatine Supplementation Among Collegiate Football Players. *Journal of Strength & Conditioning Research.* 16(3): 343-352.

165. Wilkins, H.A., S.R. Petersen, & H.A. Quinney. (1991). Time-Motion Analysis of and Heart Rate Responses to Amateur Ice Hockey Officiating. *Canadian Journal of Sports Sciences.* 16(4): 302-307.

166. Wilmore, J.H., & D.L. Costill. (1999a). Neuromuscular Adaptations to Resistance Training. In J.H. Wilmore & D.L. Costill (Eds). *Physiology of Sport and Exercise (2nd Ed).* (pp 82-111). Champaign, IL: Human Kinetics.

167. Wilmore, J.H. & D.L. Costill. (1999b). Metabolism and Basic Energy Systems. In J.H. Wilmore & D.L. Costill (Eds). *Physiology of Sport and Exercise (2nd Ed).* (pp 114-154). Champaign, IL: Human Kinetics.

168. Wilmore, J.H. & D.L. Costill. (1999c). Metabolic Adaptations to Training. In J.H. Wilmore & D.L. Costill (Eds). *Physiology of Sport and Exercise (2nd Ed).* (pp 184-203). Champaign, IL: Human Kinetics.

169. Wilson, B.D., K.L. Quarrie, P.D. Milburn, & D.J. Chalmers. (1999). The Nature and Circumstances of Tackle Injuries in Rugby Union. *Journal of Science & Medicine in Sport.* 2(2): 153-162.

170. Wilson, G.J., A.D. Lyttle, K.J. Ostrowski, & A.J. Murphy. (1995). Assessing Dynamic Performance: A Comparison of Rate of Force Development Tests. *Journal of Strength & Conditioning Research.* 9(3): 176-181.

171. Wilson, G.J., A.J. Murphy, & A. Giorgi. (1996). Weight and Plyometric

Training: Effects on Eccentric and Concentric Force Production. *Canadian Journal of Applied Physiology*. 21(4): 301-315.

172. Wilson, G.J., R.U. Newton, A.J. Murphy, & B.J. Humphries. (1993). The Optimal Training Load for the Development of Dynamic Athletic Performance. *Medicine & Science in Sports & Exercise*. 25(11): 1279-1286.

173. Woolford, S., & M. Angove. (1991). A Comparison of Training Techniques and Game Intensities for National Level Netball Players. *Sport Coach*. 14(4): 18-21.

174. Yamamoto, K., M. Miyachi, T. Saitoh, A. Yoshiaka, & S. Onodera. (2001). Effects of Endurance Training on Resting and Post-Exercise Cardiac Autonomic Control. *Medicine & Science in Sports & Exercise*. 33(9): 1496-1502.

175. Yessis, M. (1994). Training for Power Sports – Part 1. *Strength & Conditioning*. 16: 42-45.

176. Young, W., B. McLean, & J. Ardagna. (1995). Relationship Between Strength Qualities and Sprinting Performance. *Journal of Sports Medicine & Physical Fitness*. 35(1): 13-19.

177. Young, W.B., A. Jenner, & K. Griffiths. (1998). Acute Enhancement of Power Performance From Heavy Load Squats. *Journal of Strength & Conditioning Research*. 12(2); 82-84.

Journal of Strength and Conditioning Research, 2004, 18(3), 491–497

A SKILL-BASED CONDITIONING GAMES APPROACH TO METABOLIC CONDITIONING FOR ELITE RUGBY FOOTBALL PLAYERS

PAUL GAMBLE

London Irish Rugby Football Club, Sunbury-on-Thames, Middlesex, United Kingdom.

ABSTRACT. Gamble, P. A skill-based conditioning games approach to metabolic conditioning for elite rugby football players. *J. Strength Cond. Res. 18(3)491–497.*—The purpose of this study was to evaluate changes in endurance fitness of elite-level rugby union players ($n = 35$) undertaking skill-based conditioning games for a 9-week preseason training period. Metabolic conditioning was conducted exclusively in the form of skill-based conditioning games in conjunction with heart rate (HR) telemetry. Two markers of cardiorespiratory fitness were assessed at weekly intervals via the recording of HR responses to an intermittent multistage shuttle test. Significant differences post-training were observed for the percentage of maximal HR (% HRmax) reached during the final test stage and the percentage of HR recovery (% HR recovery) from the end of the final stage to the end of the final 1-minute rest period. Significant improvements were demonstrated for % HR recovery at week 7 ($p < 0.05$) and week 9 ($p < 0.01$), and % HRmax in the final test stage was significantly lower at weeks 4, 5, and 7 ($p < 0.05$) and week 9 ($p < 0.01$). Further improvements from mid-preseason to the end of the preseason training period were observed for % HR recovery scores in week 8 ($p < 0.01$) and week 9 ($p = 0.012$) and for % HRmax reached in the final test stage at week 9 ($p < 0.05$). These results indicate skill-based conditioning games were successful at improving markers of cardiorespiratory endurance for the duration of a 9-week training period in the elite-level professional rugby union players studied. The HR monitoring was demonstrated to be an effective and practical means of quantifying intensity in the conditioning games format and of tracking changes in cardiorespiratory fitness.

KEY WORDS. heart rate, training specificity, cardiorespiratory fitness, recovery score

INTRODUCTION

During the past 20 years, sport scientists have reached a consensus that the most effective mode of training for preparing athletes for competition is that which most closely replicates competitive performance conditions, which is the central tenet of "Specificity of Training" (2, 6, 28). This has led to growing interest in sport-specific methods to condition athletes for team sports. Conditioning drills that incorporate skills and movements specific to the sport are increasingly implemented, with the aim of simulating the movement patterns and metabolic conditions encountered during competition (15, 20). An extension of this is the Tactical Metabolic Training approach (23) whereby players perform set plays modeled on match-play scenarios, incorporating work-to-rest ratios derived from the tactical evaluation of real or "ideal" match sequences (22, 23).

One particular challenge for strength and conditioning coaches working in rugby football is providing metabolic conditioning in the limited time allowed by the concurrent high volumes of team practices and other forms of training—particularly resistance training—that players are required to complete. An approach that encompasses both movement and context specificity and one that is highly time-efficient involves the use of skill-based conditioning games. These comprise purpose-designed games featuring modified playing areas and rules, which are by definition less structured and conducted in a more open and random setting (8). As a result, skill-based conditioning games are more continuous than the discrete drills or modeled plays used under the tactical metabolic conditioning format. These methods are increasingly used as part of preseason and in-season metabolic conditioning, most notably in the professional rugby league (4, 5, 8). The skill and competition elements that are the key features of skill-based conditioning games are likely to promote enhanced effort and greater compliance in the athletes, which will in turn be manifested in increased training intensity (8). In view of this, it is hypothesized that the conditioning games training format offers superior improvements in cardiorespiratory fitness, compared to traditional team sports conditioning methods (i.e., running laps or shuttles).

Training that uses such an inherently unstructured format as conditioning games requires some objective marker to evaluate the work rates of individual players. Heart rate (HR) monitoring is extensively used as the most effective and practical means of objectively monitoring intensity during a training session (24) and quantifying training loads in the athlete's weekly training log (9). The HR monitoring therefore would appear to be a crucial adjunct to the skill-based conditioning games approach, as a tool to quantify intensity in the conditioning game setting. In addition, HR monitoring offers a basis on which to assess cardiorespiratory fitness, via the measurement of cardiorespiratory responses during and immediately following a standardized work bout (18, 28).

To assess the efficacy of skill-based conditioning methods, the preseason metabolic conditioning for an elite-level professional rugby union team was undertaken exclusively in the form of continuous conditioning games. Skill-based conditioning games were devised with rule modifications to ensure that players worked constantly for the duration of the work bout. For all players, HR was recorded in all conditioning sessions. Likewise, cardiorespiratory fitness was monitored via HR responses to a standardized interval work bout and assessed at weekly intervals throughout the 9 weeks of preseason training.

TABLE 1. Subject characteristics and HR parameters.*

Variable	Mean ± *SD*	Range
Age	27.61 ± 4.20	20.42–36.17
Height	185.42 ± 7.27	170–202
Body mass	98.61 ± 13.74	80–121
HRmax	190.37 ± 9.55	174–212
Resting HR	50.77 ± 6.41	40–65

* HR = heart rate.

METHODS

Experimental Approach to the Problem

All subjects were part of a single experimental group. The dependent variables selected were the percentage of HR elicited by a constant submaximal workload (% HRmax) and the percentage of HR recovery score (% HR recovery score). These are both established markers used to track progressions in training status. The study design is based on the assumption that the changes observed in dependent variables were due to the conditioning games intervention. This was deemed valid on the basis that this was the only form of metabolic conditioning undertaken and that no matches were played during this period.

Subjects

The subjects of this study were senior professional rugby union players ($n = 35$). All subjects represented the same English Premier league team and included current and former international players from the UK and South Africa. Subject characteristics are presented in Table 1. All players were familiar with all conditioning games and testing procedures.

Determination of HR Parameters

The majority of players (30 of the 35) had a database of HR files from the previous 12 months of training. The HRmax score was taken as the highest HR recorded during any session in this period and the duration of this study in these players. The HRmax of new players was taken as their individual peak HR registered in the 9 weeks of preseason training. For determining the resting HR, monitors were fitted to the athletes before the team meeting on conditioning days, and the minimum value from the resulting HR trace was noted. In this way, the resting HR was updated on a continual basis, i.e., when a new minimum HR was recorded for a given player. Similarly, the HR reserve (HRR) for each player was calculated as the deficit between the athlete's individual HRmax and resting HR (10). From these determinations, each player was assigned his individualized training zone (75–85% HRR), which was updated as necessary on an ongoing basis.

Monitoring Apparatus

The implementation of skill-based conditioning games was underpinned by the use of HR monitoring technology (Polar Team HR Monitoring System, Polar Electro, Kempele, Finland). This is a fully integrated 1-piece model that can be used independently of a watch device, with the HR files being stored and downloaded directly from the sensor strap. The HR trace for each conditioning session was downloaded, and the quality of the session was assessed based on the degree to which the player maintained his HR in his specific target zone. Printouts of each player's HR trace, with their individual HR parameters superimposed, were handed out in the following day's team meeting. Any additional feedback was given individually by the head coach as required.

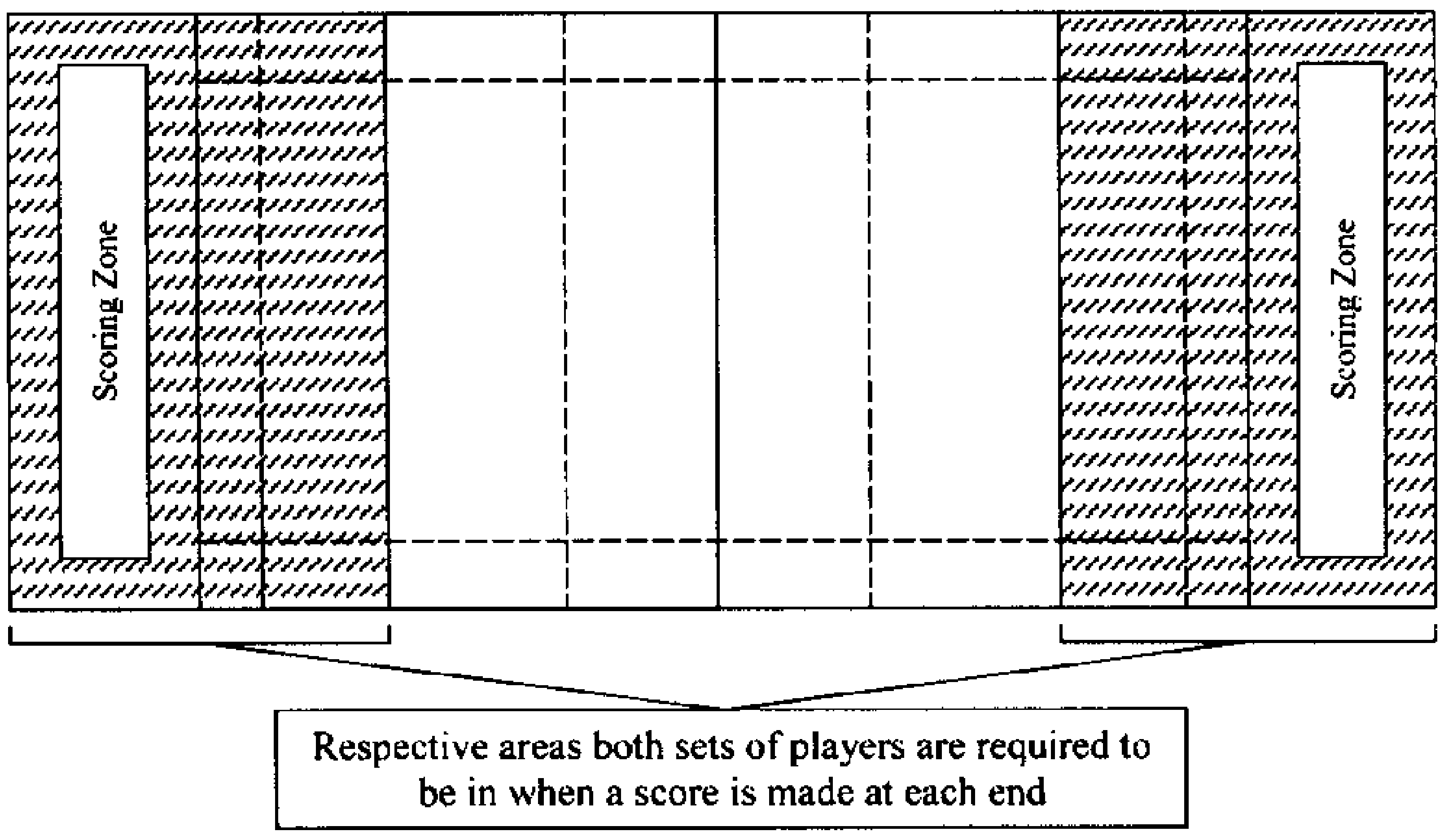


FIGURE 1. Skill-based conditioning game playing area.

Conditioning Game Design

Conditioning games were derived from elements of gridiron, netball, and soccer (the playing area for the gridiron conditioning game is depicted in Figure 1). Penalties were imposed if players were not keeping up with play (i.e., within a designated area in the vicinity of the scoring zone when a score was made). Penalties included disallowing the score if the penalized player was on the scoring side or awarding double scores if they were assigned to be opposition players. Alternatively, offending players were made to perform conditioning drills or sprints before rejoining play. Likewise, all players were punished with "down-and-ups" (dropping to a prone position on the ground before rapidly returning to an upright stance to resume play) when unforced errors were committed. Periodically, conditioning games were also filmed, and video analysis was undertaken for the session to generate performance stats for each player—specifically, the number of times each player touched the ball in each period of the conditioning game and the number of errors they made. In this way, the coaches were able to evaluate each player's involvement and error count objectively. This practice was adopted to guard against players staying on the periphery and doing the minimum necessary to keep up with play and avoid being penalized, without getting directly involved in play.

Testing

Cardiorespiratory fitness and, indirectly, autonomic nervous system (ANS) functioning were assessed on a weekly basis. These were based on the HR responses to a standardized interval work bout. The test consisted of four 2-minute stages, interspersed with 1-minute (passive) rest periods, during which subjects remained standing and assumed standardized stationary postures (static stretches) (Sports Science Institute, Cape Town, South Africa). The "beep" cadence—hence, shuttle velocity—within each 2-minute bout is constant, but the pace is increased with each successive stage. The first stage is an easy jog that equates to level 1 of the multistage shuttle "bleep" test (17). This progresses to rapid striding—analogous to bleep test level 8—in the final stage. The 2 intervening stages approximate to level 3 and level 6 of the bleep test and essentially serve to progressively prime the cardiorespiratory system—the $\dot{V}O_2$-"on" response—in readiness for the final stage.

High intraclass correlations have been reported for the 20-m multistage shuttle run test (16, 17, 25), from which the test protocol is derived. The effects of psychological arousal on HR are reported to be nullified during high-intensity exercise involving large muscle groups (1, 19). Even at the end of the training period, HR intensity during the final stage was 88.5 ± 3.6% of HRmax, which was considered sufficiently high to offset any interference effects that were caused by psychological arousal.

The test provides 2 indices of training status. The first is the HR—expressed as a percentage of the player's individual HRmax—reached at the end of the final stage. A well-established marker of progression in endurance training is that a given absolute power output elicits a lower percentage of $\dot{V}O_2$max—and hence, a lower percentage of the HRmax (7, 28). The second index of training status is the % HR recovery score. This is derived from the decline in HR from the end of the final stage to the end of the final 1-minute rest period, expressed as a percentage of the player's individual HRR. The HR recovery after a standardized work bout reflects autonomic nerve system function (11, 26). This index has likewise been shown to be sensitive to training status, with endurance-trained subjects exhibiting a more rapid HR recovery following maximal and submaximal work bouts (3, 11, 28, 29).

Statitistical Analyses

Group data were analyzed by a 1-way analysis of variance (ANOVA) with repeated measures. Simple and repeated within-subject contrasts were undertaken in the case of significant differences. Comparisons of data for new vs. existing players in the squad were undertaken via independent t-tests. Statistical significance was set at $p \leq 0.05$. Data analysis was completed with SPSS software (SPSS for Windows, version 10, SPSS Inc., Chicago, IL).

TABLE 2. Repeated within-subject contrasts.†

Weeks	p value % HRmax	 % HR recovery score
Week 1 vs. week 2	<0.01*	<0.01*
Week 2 vs. week 3	>0.05	>0.05
Week 3 vs. week 4	>0.05	=0.078
Week 4 vs. week 5	>0.05	>0.05
Week 5 vs. week 6	<0.01*	=0.76
Week 6 vs. week 7	<0.01*	<0.01*
Week 7 vs. week 9	>0.05	>0.05

* significant difference p < 0.01
† HR = heart rate.

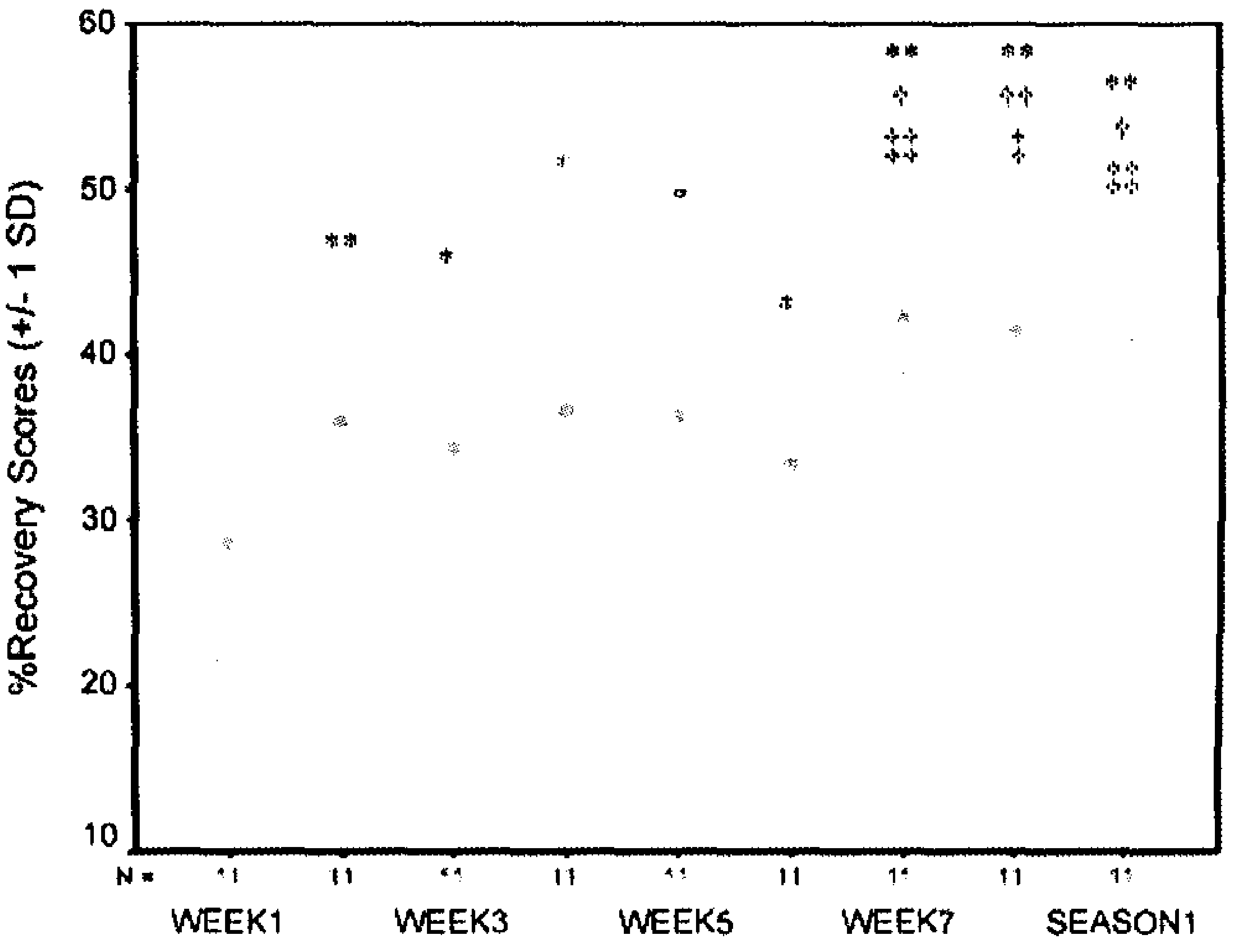


FIGURE 2. Group recovery scores. * Significantly higher than week 1 (<0.05). ** Significantly higher than week 1 (<0.01). † Significantly higher than week 2 (<0.05). †† Significantly higher than week 2 (<0.01). ‡ Significantly higher than week 5 (<0.05). ‡‡ Significantly higher than week 5 (<0.01).

RESULTS

Player characteristics and HR parameters are presented in Table 1. One player sustained long-term injury midway through the training period, which prevented this player from completing preseason training. As a result, this subject was excluded from statistical analyses. Testing using the multistage intermittent shuttle test was completed at the beginning of each week of preseason, with the exception of week 8, when players were away for a training camp.

A repeated-measures ANOVA showed significant differences in the % HR recovery score ($p < 0.01$) for pre- vs. post-training tests. The % HRmax at the end of the final stage of the test was also significantly lower ($p < 0.01$) at the end of preseason training. That said, repeated within-subject contrasts showed significant differences in both test measures from week 1 to week 2 ($p < 0.01$) and are presented in Table 2. In view of this, repeated-measures ANOVAs were rerun for both data sets using week 2 as the baseline. Simple within-subject contrasts with week 2 as the reference again showed that the % HR recovery was significantly improved at week 7 ($p < 0.05$) and week 9 ($p < 0.01$). Similarly, the % HRmax at the end of the final stage was shown to be significantly lower at weeks 4, 5, and 7 ($p < 0.05$) and week 9 ($p < 0.01$), relative to week 2.

Week 5 was selected as the baseline to evaluate changes from mid-preseason to the end of the training period. Significantly higher % HR recovery scores were observed in week 8 ($p < 0.01$) and week 9 ($p = 0.012$), and this persisted into the first week of the playing season ($p < 0.01$), as shown in Figure 2. The reductions in the % HRmax that were reached in the final test stage from mid-preseason (week 5) became significant at week 9 ($p < 0.05$), as shown in Figure 3.

During week 6, there was a significant depression in the % HR recovery scores and a significant elevation in the end-stage % HRmax (Figures 2 and 3). This was reflected in the repeated within-subject contrasts for week 6 vs. week 7 ($p < 0.01$) for the % HR recovery scores (Table 2) and was likewise apparent for the % HRmax, both for week 5 vs. week 6 ($p < 0.01$) and for week 6 vs. week 7 ($p < 0.01$), as shown in Table 2.

Scores for positional categories are presented in Figures 4 and 5. There was some indication of differences in the rate and magnitude of improvement between differ-

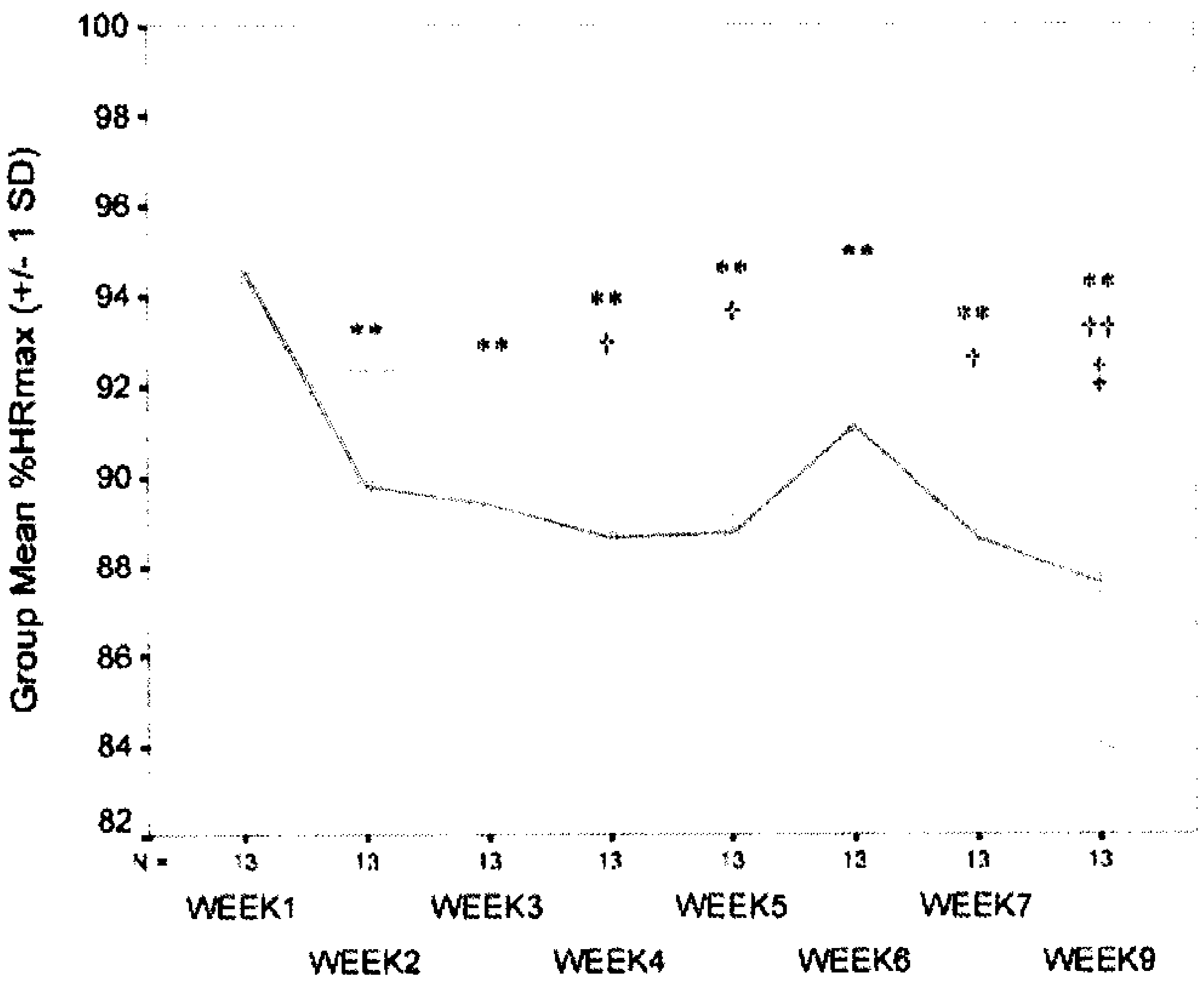


FIGURE 3. Group final-stage percentage of maximal heart rate (% HRmax). ** Significantly lower than week 1 (<0.01). † Significantly lower than week 2 (<0.05). †† Significantly lower than week 2 (<0.01). ‡ Significantly lower than week 5 (<0.05).

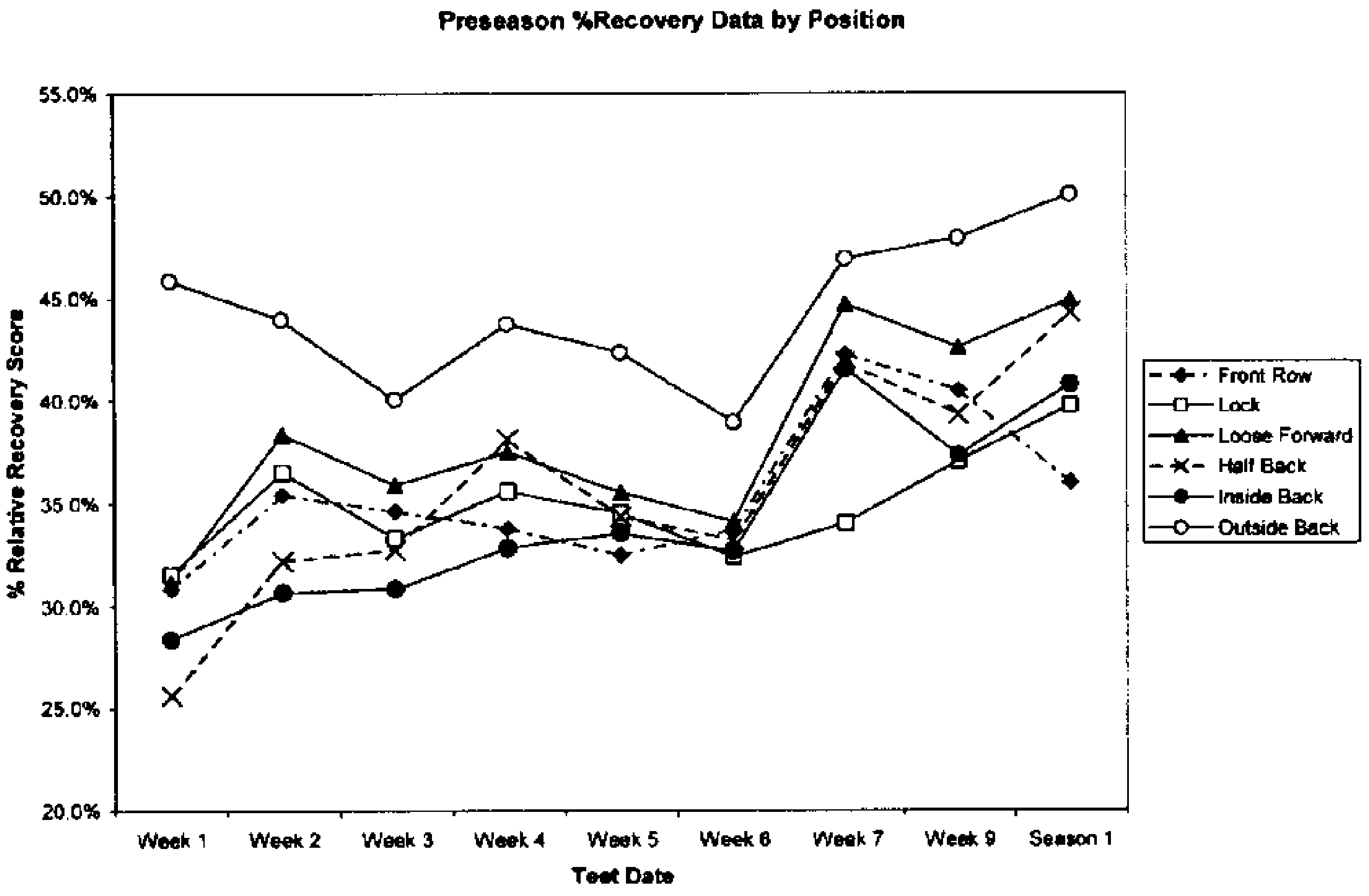


FIGURE 4. Recovery scores by position.

ent playing positions; however, there were insufficient numbers in each positional group to allow post hoc tests to assess any position effect. Any differences were negated when playing positions were merged into broader groupings.

To assess differences in training status at the beginning of preseason, the % HRmax scores were compared for existing players and players new to the squad, as shown in Figure 6. Independent *t*-tests were undertaken for week 1 and week 2 data. In week 1, the % HRmax scores (mean ± *SD*) for existing players were 94.9 ± 2.8% vs. the average scores for new players, which were 97.5 ± 1.1%, bordering on statistical significance ($p = 0.078$). The difference in week 2 was more marked—and reached significance ($p = 0.015$).

DISCUSSION

Rugby union is essentially the definitive intermittent sport, in the sense that patterns of activity during match play are highly variable, being dictated by a multitude of factors—including the game plan of the opposition and refereeing calls. As a consequence, practically speaking, it is very difficult to design drills to simulate the continuum of intensities and movement patterns encountered during match play. The solution described that circumvents the need for structured conditioning drills is skill-based conditioning games. The conditioning games are continuous and require players to operate in the upper range of the work-to-relief ratios encountered during match play; such games also evoke exercise intensities in the range required (~90–100% $\dot{V}O_2$max) for optimal gains in cardiorespiratory fitness (22, 23, 27). Skill-based conditioning games appear to offer far greater intrinsic motivation, simply because of the game-play element. It requires significant motivation to reproduce these high work rates on a consistent basis to obtain continued improvements. Practically speaking, most rugby union players are more likely to work at these higher intensities under competitive conditions than when they are engaged in more traditional conditioning (running laps or intervals) with no skill or competition element.

Crucially, this was borne out by the exercise test data. Both HR recovery and % HRmax for the final stage showed the expected trends indicative of advances in training status. A significant improvement was seen post-training for both of these markers of endurance fitness. These significant effects persisted when week 2 was substituted as the baseline to correct for the effects on the submaximal HR of the hypervolemia (increase in blood plasma volume) that occur during the early stages of training (12), demonstrated in the significant differences from week 1 to week 2 (Table 2). Further, continued improvements were observed from mid-preseason to the end of the preseason. It should be stated that these gains were elicited in already fit players, the majority of whom had been trained using conditioning games for the previous 12 months, and were coming off the back of the most successful season in the club's history. The scope for physiological adaptation is finite, and the superior early preseason fitness of existing players in the squad suggests these players had already fulfilled a good portion of their window of adaptation for cardiorespiratory fitness. This being the case, these players would be at a stage of physical development whereby diminishing returns would be expected (10)—thus rendering the fact that gains were made throughout preseason training all the more significant.

To my knowledge, this is the first published study to quantify changes in cardiorespiratory fitness in response to a preseason training program in elite rugby union players. The lack of previous studies thus makes a comparison of the current findings to existing data impossible. Given this, and from an overall scientific perspective, the ideal would therefore have been to match subjects for playing position and randomly assign players to a parallel control group. However, the reality is that it would be untenable to disrupt the preparation of a professional team to this extent in view of the financial rewards and consequences of failure (i.e., relegation) contingent on the team's performance in the subsequent season. Likewise, players would be opposed to having their chances of selection jeopardized on the basis that they may have been as-

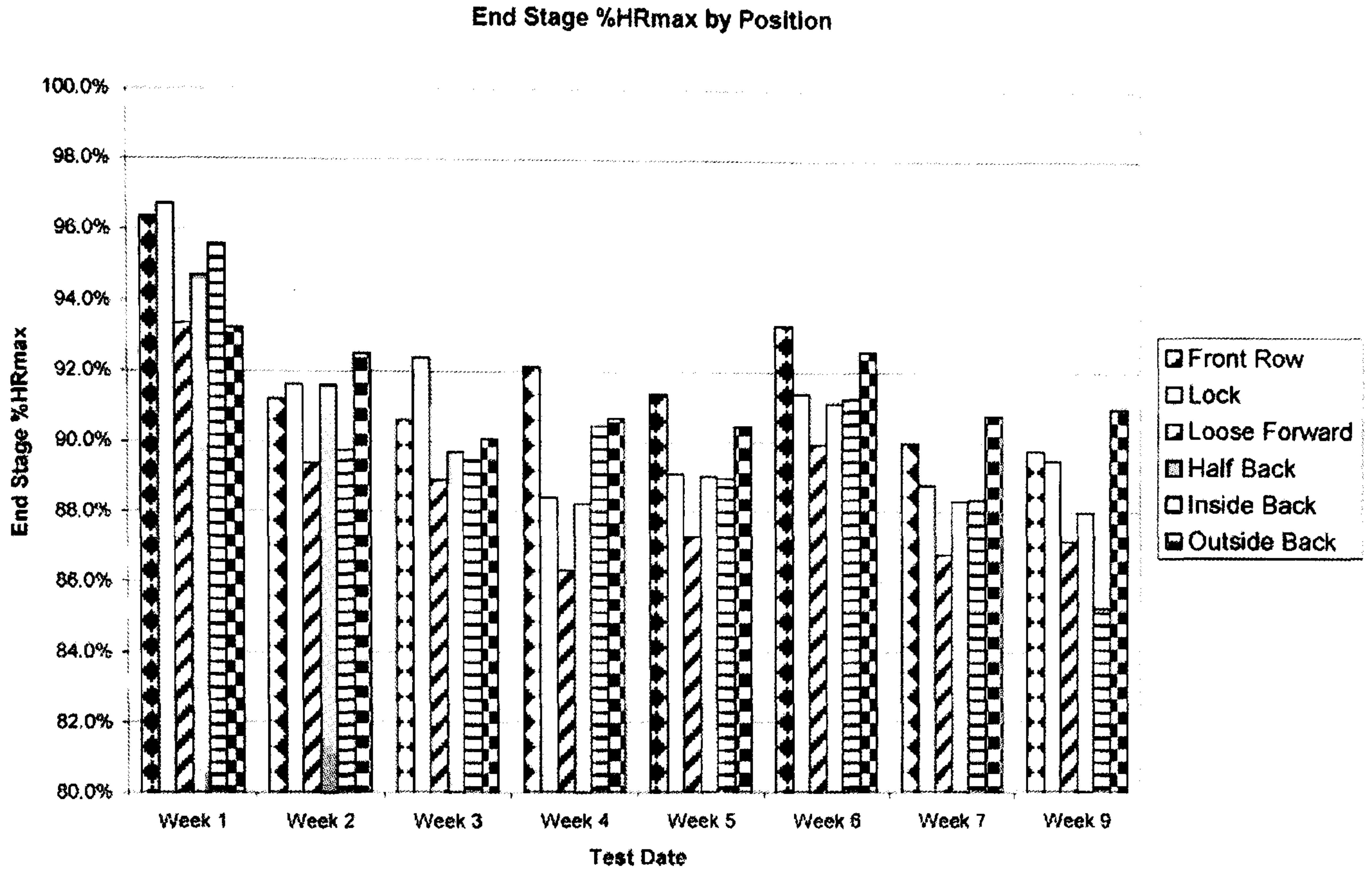


FIGURE 5. Final-stage percentage of maximal heart rate (% HRmax) by position.

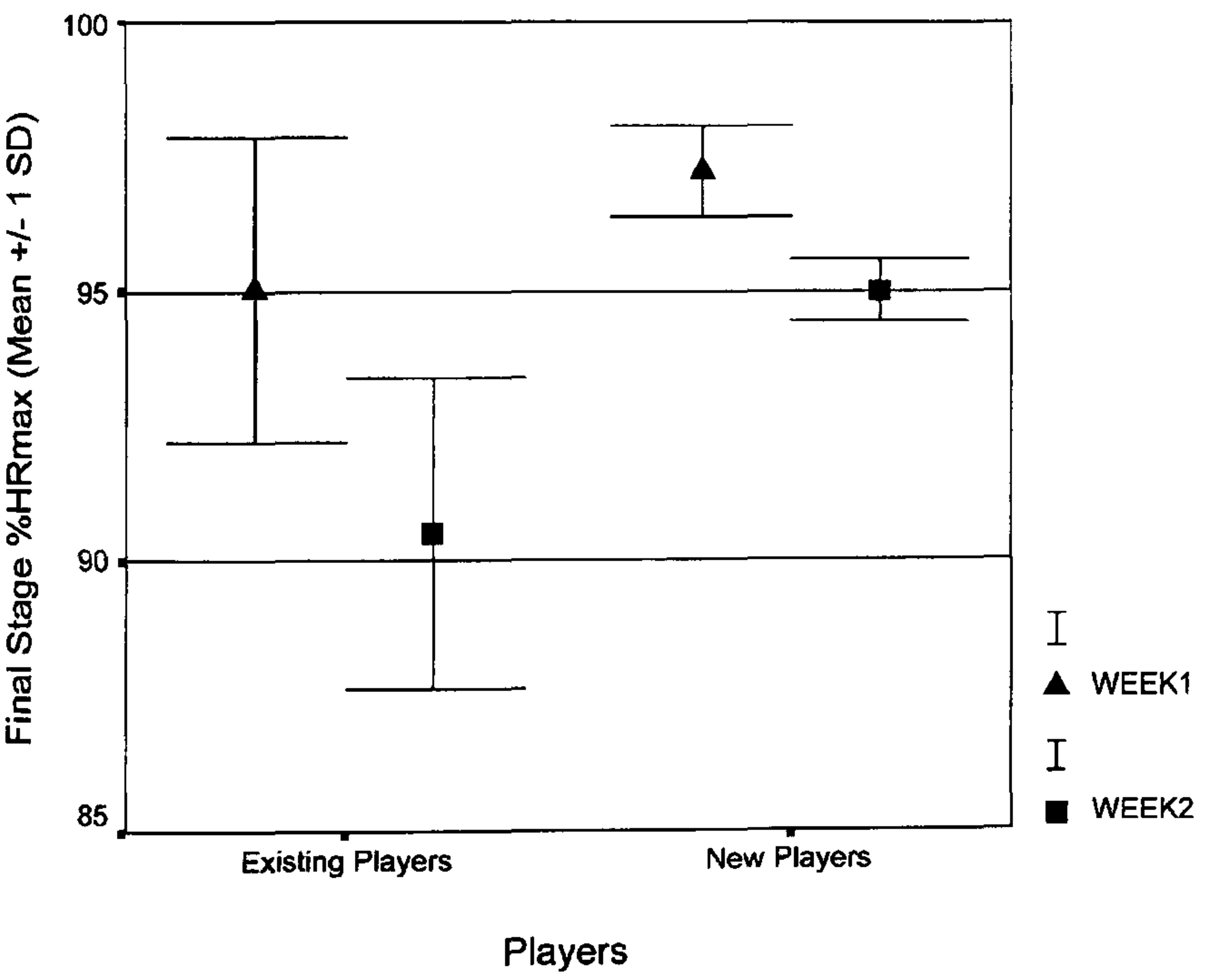


FIGURE 6. Week 1 and week 2 final-stage percentage of maximal heart rate (% HRmax): new vs. existing players.

signed to the "wrong" experimental group, and their physical preparation was not to the same standard as other players in their position as a result.

The study thus rests on the assumption that the observed improvement in markers of cardiorespiratory fitness resulted from the skill-based conditioning games training intervention. The only other mode of training undertaken during this period that could conceivably have had a metabolic conditioning effect was team tactical practices. However, HR traces from these sessions showed the average work intensity to be considerably lower than that elicited by conditioning games (unpublished data). Similarly, by definition, these practice sessions were not continuous: they featured frequent and often extended pauses for fault correction and coaching input. Further, the tactical practice sessions were introduced in the latter stages of the preseason training period, by which time significant gains in cardiorespiratory fitness were already evident.

Indirect evidence for the superiority of conditioning games as a training mode for athletes in rugby union is alluded to by the deficit in early preseason test scores of new players in the squad, compared to the existing players' average scores (Figure 5). Differences in training status are indicated by the fact that new players required a greater percentage of their individual HRmax in completing the final test stage. This would suggest that the conditioning they were exposed to at previous clubs was less successful, certainly in terms of maintaining endurance during in-season play.

The skill-based conditioning games approach emphasizes movement specificity to a greater extent than do traditional conditioning methods. This is significant, as the more specific an activity is to the training mode in which endurance gains are made, the greater the degree to which these gains are expressed (6, 28). The games format requires players to react to the movement of both teammates and opponents as well as to the movement of the ball. In this way, the conditioning games mode of training incorporates the changes in direction and velocity and the "utility" movements (lateral and backward locomotion) that are features of match play. A key parameter contributing to endurance performance is exercise economy (12). Running efficiency has been identified as the major avenue for advancing performance in highly trained endurance athletes (2). Exercise economy is postulated to be closely related to patterns of motor unit recruitment, and as such, improvements are highly specific to the speeds and power outputs at which athletes habitually train (12). It follows that the skill-based conditioning games training format should similarly enhance economy for the range of sport-specific modes of locomotion and continuum of velocities that are features of match play. Indeed, conditioning games may be the optimal training mode available to promote these adaptations. This sport-specific movement efficiency factor is likely to be underestimated by the 20-m shuttle test format, which requires only straight-line running and 180° turns.

Regardless of the apparent effectiveness of the conditioning games training mode, it is unlikely that coaches would be receptive to the use of skill-based conditioning games without being able to substantiate that each player in the squad is working sufficiently hard in the conditioning game setting for consistent gains in cardiorespiratory fitness. In view of this, HR monitoring technology is a critical element in the skill-based conditioning games approach. As a physiological marker of cardiorespiratory intensity, HR has been proven to be a more accurate index of exercise intensity during an acute exercise bout than are perceptual cues, such as central or peripheral ratings of perceived exertion (24). Likewise, HR provides a basis for prescribing the intensity that is sensitive to environmental conditions (heat and humidity) and the changes in training status (28). This offers an objective means of verifying that players are working at or above their individually determined threshold to ensure a training effect, enabling the coaching staff to take appropriate steps if a player is not working at the required intensity. Similarly, on a longitudinal basis, HR records of training sessions allow training load and volume to be logged far more reliably, compared to self reports of intensity for daily training sessions (9). In this way, the HR offers a basis for training loads to be manipulated with a greater degree of accuracy as part of the players' long-term periodized training plan.

Characteristic changes occur in cardiac ANS modulation with advances in endurance training status. Reduced resting sympathetic input and greater vagal (parasympathetic) tonic activity are reflected in relative bradycardia (lowered HR) at rest following a period of endurance training (11, 28). The HR recovery immediately postexercise is likewise sensitive to endurance training status, with endurance-trained individuals exhibiting an accelerated return to resting levels following the termination of exercise (3, 11, 28, 29). This is attributed predominantly to enhanced vagal (parasympathetic) reactivation. Practically, it is difficult to separate psychological factors to obtain a true measure of the resting HR on a consistent basis. The measurement of resting HR is therefore too unreliable to be used as the primary marker for tracking changes in cardiac ANS modulation. In contrast, the HR recovery assessed using the intermittent shuttle test proved to be an easily implemented and time-efficient test that could be conducted with large numbers of athletes.

The HR recovery after a standardized work bout likewise provides insight into ANS functioning. This is significant, as the disruption of ANS function is the primary characteristic of acute overreaching and the chronic state of overtraining (13, 28). Any marked decrease in a player's recovery score may indicate sleep disturbance, acute fatigue due to alterations in training (acute "overreaching"), residual fatigue from the previous week's training, or other daily stressors. These precursors of overtraining, if not addressed, can render the player susceptible to the chronically overtrained state. This was evident late in the preseason, when there was a depression in recovery scores evident in some playing positions during week 5 that became particularly marked for the group as a whole during week 6. Paradoxically, this appeared to be provoked by a decrease in training volume. Preceding the week 5 and week 6 tests, players were given Fridays off instead of training, which entailed 3 days away from training—as opposed to the 2-day weekend rest to which they were accustomed. Many players reported the following Monday that they were feeling tired—which was corroborated by the decline in recovery test scores. It appears the active rest provided by the Friday training session actually served to enhance sleep quality and recovery. Accordingly, when the squad returned to the normal weekly training plan (i.e., with Friday training sessions), recovery scores continued their previous upward trend, which persisted into the first week of the playing season.

With the high volumes of team practices and other training required in rugby football, metabolic conditioning must be as time-efficient as possible to maximize gains in the limited training time allowed. Skill-based conditioning games enable players to simultaneously develop an awareness of space and the ability to execute game skills and decision-making under pressure and to practice effective communication with teammates in a simulated competitive environment. Collectively, these elements have been termed "game sense" in rugby league coaching circles (4, 5). Because skill-based conditioning games offer players the opportunity to develop game skills and communication, coaches are able to continue metabolic conditioning even late in the preseason, when the training emphasis shifts to skills practice and game strategy sessions. A noticeable plateau in endurance performance measures was observed toward the end of the training period, concurrent with the shift in emphasis to greater strategy and tactical work, and correspondingly less time was engaged in metabolic conditioning. If metabolic conditioning using less time-efficient training conditioning activities were undertaken, this shift away from metabolic conditioning work would likely occur earlier and to a greater extent. In this case, reduced total conditioning time would likely elicit fewer net gains in cardiorespiratory fitness at the end of the preseason training period. Similarly, the skill element allows conditioning work to be continued during the playing season, which in turn allows cardiorespiratory endurance to be maintained to a far greater extent during in-season play.

The skill-based games approach to metabolic conditioning may offer the ancillary benefit of lower injury incidence rates, compared to traditional conditioning activities without a ball (8). Injury rates were adjusted for the time engaged in a particular mode of training for the duration of a rugby league season. The majority of injuries were sustained during traditional conditioning work without a ball or skill element, in contrast to the low incidence of injury when participating in skill-based conditioning games (8). The underlying reasons for the apparent decreased occurrence of injury associated with conditioning games remains to be clarified. There are indications that skill sports athletes exhibit enhanced agility when holding the implement of their sport (14). Similarly, it may be that an underlying factor leading to decreased injury is improved motor control when performing sports movements, as opposed to running without a ball. Improved neuromuscular control is identified as helping guard against "noncontact" injuries (21). Whatever the mechanism, the benefits of less time away from the training pitch due to injury will be readily obvious to the coach and athlete.

PRACTICAL APPLICATIONS

To my knowledge, this study provides the first quantitative data to support the efficacy of skill-based conditioning games as the primary mode of metabolic conditioning for elite-level rugby union players. This substantiates the proposed theoretical advantages of conditioning games with regard to specificity of training. These results, together with the findings of a previous investigation that indicated lower injury incidence rates associated with skill-based conditioning games, suggest the conditioning games approach to metabolic conditioning for rugby football players actually offers superior benefits to traditional training activities without a skill or competition element. Further research quantifying changes in cardiorespiratory fitness for a preseason training period that uses traditional conditioning methods in a similar group of athletes that would also allow a direct comparison with the present findings is required for a definitive answer on this point.

The HR monitoring has been demonstrated to be a practical means of quantifying training intensity in the conditioning games format, providing an objective basis to validate this mode of training. Coaches can thus implement conditioning games as part of their team's metabolic conditioning, secure in the knowledge that they can verify each player's work rate in any given training session and, in so doing, gain insight into the work ethic of individuals in their playing squad. This study further indicates that the HR recovery index described has potential use as an index for the coaching staff to identify players exhibiting disruptions in ANS function indicative of acute fatigue that may be precursors of overtraining.

These findings have the most relevance for coaches in rugby unions and rugby leagues. However, this approach to metabolic conditioning may also be applied to other team sports of an intermittent nature.

REFERENCES

1. BANGSBO, J. The physiology of soccer—With special reference to intense intermittent exercise. *Acta Physiol. Scand.* 151(Suppl.):619. 1994.
2. DANIELS, J. Aerobic capacity for endurance. In: *High-Performance Sports Conditioning.* B. Foran, ed. Champaign, IL: Human Kinetics, 2001. pp. 193–212.
3. DARR, K.C., D.R. BASSETT, B.J. MORGAN, AND D.P. THOMAS. Effect of age and training status of heart rate recovery after peak exercise. *Am. J. Physiol.* 254:H340–H343. 1988.
4. DEN DUYN, N. Game sense. *Sports Coach* 19(3):6–9. 1996.
5. DEN DUYN, N. Game sense: It's time to play. *Sports Coach* 19(4):9–11. 1997.
6. DURSTINE, J.L., AND P.G. DAVIS. Specificity of training and testing. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th ed.). J.L. Roitman, ed. Philadelphia: Lippincott Williams & Wilkins, 2001. pp. 484–491.
7. FRANKLIN, B.A., AND J.L. ROITMAN. Cardiorespiratory adaptations to exercise. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th ed.). J.L. Roitman, ed. Philadelphia: Lippincott Williams & Wilkins, 2001. pp. 160–166.
8. GABBETT, T.J. Training injuries in rugby league: An evaluation of skill-based conditioning games. *J. Strength Cond. Res.* 16: 236–241. 2002.
9. GILMAN, M.B., AND C.L. WELLS. The use of heart rates to monitor exercise intensity in relation to metabolic variables. *J. Sports Med.* 14:339–344. 1993.
10. HOLLY, R.G., AND J.D. SHAFFRATH. Cardiorespiratory endurance. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th ed.). J.L. Roitman, ed. Philadelphia: Lippincott Williams & Wilkins, 2001. pp. 449–459.
11. IMAI, K., H. SATO, M. HORI, H. KUSUOKA, H. OZAKI, H. YOKOYAMA, H. TAKEDA, M. INOUE, AND T. KAMADA. Vagally mediated heart rate recovery after exercise is accelerated in athletes but blunted in patients with chronic heart failure. *J. Am. Coll. Cardiol.* 24:1529–1535. 1994.
12. JONES, A.M., AND H. CARTER. The effect of endurance training on parameters of aerobic fitness. *Sports Med.* 29:373–386. 2000.
13. KRAEMER, W.J. Physiological adaptations to anaerobic and aerobic endurance training programs. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 137–168.
14. KRAEMER, W.J., AND A.L. GOMEZ. Establishing a solid fitness base. In: *High-Performance Sports Conditioning.* B. Foran, ed. Champaign, IL: Human Kinetics, 2001. pp. 3–17.
15. LAWSON, E. Incorporating sport-specific drills into conditioning. In: *High-Performance Sports Conditioning.* B. Foran, ed. Champaign, IL: Human Kinetics, 2001. pp. 215–266.
16. LEGER, L., AND C. GADOURY. Validity of the 20m shuttle run test with 1min stages to predict VO2max in adults. *Can. J. Sports Sci.* 14:21-26. 1989.
17. LEGER, L.A., D. MERCIER, C. GADOURY, AND J. LAMBERT. The multistage 20-metre shuttle run test for aerobic fitness. *J. Sports Sci.* 6:93–101. 1988.
18. MCCONNELL, T.R. Cardiorespiratory assessment of apparently healthy individuals. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th ed.). J.L. Roitman, ed. Philadelphia: Lippincott Williams & Wilkins, 2001. pp. 361–366.
19. MCINNES, S.E., J.S. CARLSON, C.J. JONES, AND M.J. MCKENNA. The physiological load imposed on basketball players during competition. *J. Sports Sci.* 13:387–397. 1995.
20. MEIR, R., P. COLLA, AND C. MILLIGAN. Impact of the 10-meter rule change on professional rugby league: Implications for training. *Strength Cond. J.* 23(6):42–46. 2001.
21. PETTITT, R.W., AND E.R. BRYSON. Training for women's basketball: A biomechanical emphasis for preventing anterior cruciate ligament injury. *Strength Cond. J.* 24(5):20–29. 2002.
22. PLISK, S.S. Speed, agility, and speed-endurance development. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 471–491.
23. PLISK, S.S., AND V. GAMBETTA. Tactical metabolic training: Part 1. *Strength Cond.* 19(2):44–53. 1997.
24. POTTEIGER, J.A., AND B.W. EVANS. Using heart rate and ratings of perceived exertion to monitor intensity in runners. *J. Sports Med. Phys. Fitness* 35:181–186. 1995.
25. RAMSBOTTOM, R., J. BREWER, AND C. WILLIAMS. A progressive shuttle run test to estimate maximal oxygen uptake. *Br. J. Sports Med.* 22:141–144. 1988.
26. SAVIN, W.M., D.M. DAVIDSON, AND W.L. HASKELL. Autonomic contribution to heart rate recovery from exercise in humans. *J. Appl. Physiol.* 53:1572–1575. 1982.
27. WENGER, H.A., AND G.J. BELL. The interaction of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. *Sports Med.* 3:346–356. 1986.
28. WILMORE, J.H., AND D.L. COSTILL. *Physiology of Sport and Exercise* (2nd ed.). Champaign, IL: Human Kinetics, 1999.
29. YAMAMOTO, K., M. MIYACHI, T. SAITOH, A. YOSHIAKA, AND S. ONODERA. Effects of endurance training on resting and post-exercise cardiac autonomic control. *Med. Sci. Sports Exerc.* 33: 1496–1502. 2001.

Address correspondence to Mr. Paul Gamble, paulg2000@ukonline.co.uk.

© National Strength and Conditioning Association
Volume 26, Number 4, pages 10–23

Keywords: rugby football; metabolic conditioning; strength training; injury prevention; periodization

Physical Preparation for Elite-Level Rugby Union Football

Paul Gamble, CSCS
London Irish Rugby Football Club, Middlesex, United Kingdom

summary

The manuscript features a brief discussion of the specific physical demands characteristic of rugby union football. This is followed by a rationale and description of the elements comprising the strength and conditioning program for rugby union football players at the elite level. Finally, a sample periodized strength training macrocycle for the training year is included.

Introduction

Like American football, rugby football is an intermittent collision sport. As such, a crucial part of strength and conditioning is developing the levels of strength and hypertrophy of muscle and connective tissue in order to equip players to cope with the physical rigors involved (6, 30). Maximal strength and explosive power are major program goals common to both American football and rugby football.

Where the sports differ is that both league and union codes of rugby football are far more continuous in nature than American football. Unlike American football, play continues after the player is tackled, only stopping when the ball goes out of play, a technical infringement is made, or a penalty is committed. Rugby union features considerably higher work:rest ratios (8) than American football and therefore has a much greater demand for metabolic conditioning for the oxidative and glycolytic energy systems.

As a result, strength and conditioning coaches working with rugby football players face 2 additional challenges. The first challenge is to provide appropriate metabolic conditioning in the most time-efficient manner. The second challenge is to develop and maintain high levels of strength and power while athletes are concurrently performing high volumes of metabolic training and team practices.

Strength Training Program Design

From a performance perspective, program design is driven by a desire to develop athleticism via the use of coordinated whole-body training movements (16). Similarly, exercises are selected to maximize carry-over of strength and power gains from the gym to the playing field (17). (Specific examples will be given later in the text.) Accordingly, strength training emphasizes sport-specific actions, rather than simply training single muscle groups in isolation (15, 16).

Needs analyses of individual roles of players within a rugby union team reveal that the different playing positions lie on various points on the maximum strength/speed-strength continuum. Positional roles are divided into 2 broad categories: forwards and backs. The main distinction between the roles is that the forwards are required to contest possession at the restart phases, i.e., scrum and lineout. Rugby union has a greater emphasis on restart set-pieces than the league version of rugby football, and as a result there is a greater disparity between the roles and physical demands of forward and back positions in this version of the game (37). Further, rugby union requires players to secure or contest possession of the ball at each tackle. Due to the emphasis on set-pieces and contesting at the tackle area, rugby union forwards have a greater reliance on maximal strength than their counterparts in rugby league.

Given that set-piece phases distinguish the roles and demands placed upon the forward positions from those of the backs, a brief description of the physical work involved is necessary. In a scrum each set of forwards combines to form a single unit that engages with the opposing pack of forwards to contest a ball rolled into the gap between the 2 opposing forward packs (29). Rugby union rules stipulate that the ball must be rolled along a line perpendicular to and equidistant from the front rows of opposing forward packs. As a result there is a greater effort to contest for the ball by physically shoving the opposition pack of forwards off the ball as it is fed into the scrum (29).

The lineout is unique to rugby union and serves to restart the game after the ball goes out of play. This phase of play essentially involves jumpers being lifted by teammates to contest possession of a ball thrown in from the sideline. The lineout is a highly evolved process, with forward positions increasingly being used interchangeably as lifters or jumpers to disguise where the ball is being thrown.

Based upon qualitative assessment of the physical work involved in these aspects of rugby, the predominant biomechanical action is the simultaneous triple extension of hips, knees, and ankles, often transmitting force through the shoulders as the point of contact during collisions with other players. This triple extension likewise characterizes the high-force activities involved in contesting and retaining possession in open play and the high-power (high force/fast movement speed) dynamic actions associated with jumping and tackling. The primary goal of the strength training program therefore is to enhance strength and power for this triple-extension movement. The forward positions particularly have a need for both strength (heavy load) training and explosive power training that emphasizes this specific action.

The resistance training activities selected are primarily "closed kinetic chain" (feet planted) multi-joint movements. Players train exclusively with free weights, using dumbbells in preference to barbells where appropriate (16). The principle lifts for all phases of the periodized strength training program are the high-force power lifts—squat, deadlift, and bench press—and the explosive Olympic-style lifts. Unilateral support resistance exercises, such as lunge, step-up, and split squat, are core exercises that are performed throughout the training year (16, 27). Additional exercises to develop the muscle groups that assist the prime mover musculature are included to develop active joint stability. Likewise, resistance training sessions are incorporated to address areas typically prone to injury position and to remedy any preexisting muscular imbalances or sites of previous injury (1).

Later in the periodized training plan, specific resisted movements are introduced with the aim of translating strength and power gains developed in the gym to game-related actions involved in contact phases on the pitch (18). Bungee ropes and harnesses are used to provide resistance for specific rugby movements. These include the engage on the scrum machine and simulating clearing opposing players from the tackle area by hitting a rucking shield and tackling by hitting tackle pads or teammates in armored contact suits.

All strength training is conducted in a circuit format to reduce the time taken between exercises. This is a reflection of both the need to train large numbers of players in a restricted time and the high local muscular endurance demands of rugby match play. Rest periods between consecutive exercises for similar muscle groups are manipulated according to the goal of the training cycle.

It has been established that strength, power, and muscle mass gains are compromised by performing high-intensity endurance training earlier in the day before strength training (24). These interference effects of concurrent strength and endurance training are associated with conflicting hormonal responses to the 2 forms of training (24). Therefore, strength training is performed first in the day, before metabolic conditioning or team practice sessions.

Injury Profiles of Match Play

There is a lack of recent comprehensive injury studies in elite-level rugby union since the advent of professionalism, which appears to have engendered an increase in injury (2). Differences have been identified in injury rates and the prevalence of different types of injury between lower playing grade and higher standard competition (2, 35). Hence, data from amateur rugby has limited application to the professional game in England (26).

The majority of injuries arise from collision phases, termed tackle injuries (2, 12, 43). These injuries are distributed fairly evenly between the tacklers and the players being tackled (12, 43). The majority of injuries occur during head-on tackles, as a consequence of the higher collision forces involved (2, 12, 43).

Rugby league play shares the characteristics of open play phases in rugby union (i.e., carrying the ball and tackling). Data taken from rugby league identify injuries in open play as predominantly occurring to the lower body (13), with upper-limb (arm/shoulder) and head/neck injuries being the next most common. The added elements of contesting at the tackle area (rucks and mauls) and scrummaging demanded of the forward positions pose an increased hypothetical risk of head and neck injuries (36). Data from international rugby union players show the data from rugby league to be fairly representative in terms of site of injury, with lower-limb injuries being the most common,

Table 1a
Off-season Cycle #1

Frequency: 4 x per week: 1 whole body; 1 upper body; 1 lower body; 1 assistance
Intensity: 8–12RM (all lifts)
Volume: 3–5 full load sets (exercises performed in circuit format)
Rest: Short rest (<60 seconds) between exercises; core stability work (~2 minutes) between sets
Other Training: No other formal training performed in this period

Monday	**Tuesday**
8RM, 3 sets	**8RM, 3–4 sets**
Parallel back squat Dumbbell lunge Back extensions Dumbbell step-ups Split squat Single-leg calf raise	Bench press One-arm dumbbell row Bicep curls Standing dumbbell shoulder press Bent-over barbell row Dumbbell upright row
Thursday	**Friday**
10RM, 3–4 sets	**12RM, 3–4 sets**
Deadlift Incline dumbbell bench press Dumbbell lunge Bent-over barbell row Dips Dumbbell step ups Dumbbell upright row	Bent-over dumbbell raises EZ Bar (straight-arm) pull-overs Lateral dumbbell raises Dumbbell bicep curls EZ bar tricep extensions Dumbbell front raises Elastic tubing shoulder rotations

followed by head and neck injuries, with upper-limb injuries the least common (2). However, it appears that when upper-limb injury does occur, it is more likely to be severe (2). The most common injuries classified as severe in terms of weeks missed subsequent to injury are injuries to the knee (2).

Of particular concern in rugby union is the incidence of hyperflexion of the cervical spine as the head is pushed downwards into the ground under the weight of teammates and/or opponents, forcing the chin down into the chest, as in the case of a collapsed scrum, ruck, or maul (36). This is the typical mechanism of potentially the most debilitating or even fatal injuries to which rugby union players are exposed (36).

Previous injury is shown to predispose players at all levels to subsequent injury in season (26, 35). This observation underlines the importance of rehabilitation and addressing previous injuries in players' physical preparation.

Injury Prevention/"Prehabilitation": Exercise Selection

Lower Extremity

Injury prevention exercises include stability ball work to train the hamstrings and hip extensors, which are particularly prone to injury in running-intensive sports. This training modality develops strength, balance, and motor control in a way that replicates the horizontal forces and range of motion featured in running (32, 39).

Ankle stability exercises to develop proprioceptive sense and balance are also included. Exercise selection aims to target the peroneal muscles, which provide active joint stability for the ankle complex (3). Exercises include calf raises holding dumbbells as part of the player's strength training program in the gym and supplementary functional training using specialized apparatus, such as ankle disks (3, 5).

Upper Body

As a consequence of its high degree of mobility, the shoulder joint is reliant on dynamic (i.e., muscular) stability (31). This factor is of critical importance, as the shoulder is the main point of contact in all collision phases. Specifically, during tackles, ruck cleans, and the engage at scrum-time, the shoulders are subjected to high-impact forces. Thus, injury prevention for the upper body mainly addresses the muscles of the rotator cuff and the stabilizer muscles around the scapula (41). A minimum of 1 workout a week is dedicated solely to single-joint auxiliary exercises to maintain the structural integrity of the shoulder complex. These exercises comprise mainly raises in various planes. Dumbbells, free weights, curl bars, and resistance tubing are used for resistance.

Neck

There is a commercially available harness that allows free weights to be hung from the head to allow specific training of the neck musculature. Both isometric (static hold) and dynamic actions are performed. This helps to develop the capacity to resist forces acting to hyperflex the cervical spine (36).

Metabolic Conditioning

A key feature that separates rugby football from American football is the lack of pause between each play, thereby involving considerably greater energetic demand, particularly in terms of oxidative and glycolytic energy systems. Specifically, the fact that play continues after a tackle is made in rugby union

Table 1b
Off-season Cycle #2

Frequency: 5 x per week: 2 upper body; 2 lower body; 1 assistance

Intensity: 8–12RM (all lifts)

Volume: 3–5 full load sets (exercises performed in circuit format)

Rest: Short rest (<60 seconds) between exercises; core stability work (~2 minutes) between sets

Other Training: No other formal training performed in this period

Monday	**Tuesday**	**Wednesday**
8RM, 3 sets	**8RM, 3 sets**	**10RM, 3–4 sets**
Parallel back squat Dumbbell lunge Romanian deadlift Back extensions Split squat Single-leg calf raise	Bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Bench dips Dumbbell upright row	Bent-over dumbbell raises EZ bar pull-overs Dumbbell front raises Dumbbell bicep curls EZ Bar tricep extensions Lateral dumbbell raises Elastic tubing shoulder rotations
Thursday	**Friday**	
12RM, 3 sets	**12RM, 3 sets**	
Deadlift Dumbbell lunge Back extensions Dumbbell step-ups Split squat Single-leg calf raise	Incline dumbbell bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Dips Dumbbell upright row	

leads to multiple consecutive phases of play, requiring a high level of metabolic conditioning.

Conditioning drills that incorporate skills and movements specific to the sport are often used (25, 28, 33), with the aim of simulating the movement patterns and metabolic conditions encountered during a rugby game. However, practically it is very difficult to design drills to simulate the continuum of intensities and movement patterns encountered during rugby match play. The pace of the game and the amount of ball-in-play time is directly influenced during any given match by the environmental conditions and game plan of the opposition. For example, in wet conditions and playing against conservative opposition, there will inevitably be greater emphasis on the tactic of kicking the ball out of play to gain territorial advantage with a view to contesting possession at the subsequent lineout; hence, there are far more stoppages and less time with the ball in play. Therefore, it is often spurious to model conditioning on time-motion studies undertaken on rugby union, given the variability inherent in any given game and the competition studied.

A solution that circumvents the need for structured conditioning drills is the use of skill-based conditioning games. Conditioning games are derived from elements of American football, netball, soccer, and rugby league and are played on customized playing areas with rule modifications to ensure that players must work continuously. Hereby, the conditioning games are continuous and require players to operate in the upper range of work:relief ratios encountered during match play. These are used in conjunction with heart rate telemetry to assess each player's work-rate. Players are assigned their own target heart rate (HR) range (75–85% heart rate reserve) and are instructed to operate in the upper range of this zone. My observation and experience is that conditioning games elicit intensity equivalent or superior to traditional conditioning activities and provide considerably greater total work time.

The games format requires players to react to the movement of both teammates and opponents, as well as following the ball. In this way, the conditioning games training mode incorporates

Table 2
Hypertrophy #1 Cycle

Frequency: 4 x per week: 2(1) upper body; 1(2) lower body; 1 assistance
Intensity: 8–12RM (all lifts)
Volume: 3–5 full load sets (exercises performed in circuit format)
Rest: Short rest (<60 seconds) between exercises; abdominal work (~2 minutes) between sets
Other Training: Metabolic conditioning performed five days a week
Strength training performed in the morning before conditioning or practice sessions

Week 1	
Monday	**Tuesday**
8RM, 5 sets	**8RM, 5 sets**
Bench press	Parallel back squat
Bent-over barbell row	Dumbbell lunge
Standing dumbbell shoulder press	Romanian deadlift
One-arm dumbbell row	Back extensions
Bicep curls	Dumbbell step-ups
Dumbbell upright row	Split squat
	Single-leg calf raise
Thursday	**Friday**
12RM, 4 sets	**10RM, 3 sets**
Bent-over dumbbell raises	Incline dumbbell bench press
Lateral dumbbell raises	Bent-over barbell row
Dumbbell bicep curls	Standing dumbbell shoulder press
Dumbbell front raises	One-arm dumbbell row
EZ bar tricep raises	Dips
Elastic tubing shoulder rotations	Dumbbell upright row
Week 2	
Monday	**Tuesday**
8RM, 5 sets	**8RM, 5 sets**
Parallel back squat	Bench press
Dumbbell lunge	One-arm dumbbell row
Romanian deadlift	Bicep curls
Back extensions	Standing dumbbell shoulder press
Dumbbell step-ups	Bent-over barbell row
Single-leg calf raise	Dips
	Dumbbell upright row
Thursday	**Friday**
10RM, 3 sets	**12RM, 4 sets**
Deadlift	Bent-over dumbbell raises
Dumbbell lunge	EZ bar (straight-arm) pull-overs
Back extensions	Lateral dumbbell raises
Dumbbell step-ups	Dumbbell bicep curls
Split squat	Dumbbell front raises
Single-leg calf raise	EZ bar tricep raises
	Elastic tubing shoulder rotations

Note: Week 2 frequency in parentheses.

the changes in direction and velocity and the "utility" movements (lateral and backwards locomotion) that are featured in match play. Exercise economy is closely related to patterns of motor unit recruitment, and, as such, improvements are highly specific to the speeds and power outputs at which athletes habitually train (22). It follows that the skill-based conditioning games training format should similarly enhance economy for the range of sport-specific modes of locomotion and the continuum of velocities that are featured in match play. Conditioning games may be the optimal training mode available to promote these adaptations.

As a result of the high degree of similarity between conditioning games and rugby match play, cardiorespiratory fitness gains made in this training mode are more likely to be reflected in terms of "match fitness" (9, 42). By training this way in-season, reserve players are able to maintain a level of match fitness despite a lack of game time.

From a coaching standpoint there is also a mental conditioning element. The conditioning games encourage players to adopt good habits, such as remaining involved in play and keeping unforced errors to a minimum while fatigued. The capacity of individual players to maintain high work rates during conditioning games has great relevance for the coaches, in terms of criteria for selection. If the HR records for a player show that he persistently fails to motivate himself to work sufficiently hard during conditioning game sessions despite repeated feedback, the coach will likely not risk playing him in a match on the grounds of poor work ethic. This is particularly the case for the work-rate–oriented forward positions, who are primarily responsible for securing or contesting possession at each tackle.

A reduced relative incidence of injury has been reported among rugby league players when performing conditioning games, in comparison to traditional conditioning activities (e.g., running without a ball) (11). Injury rates adjusted for the time engaged in a particular mode of training for the duration of a rugby league season revealed that the majority of injuries were sustained during traditional conditioning work without a ball or skill element (11). In contrast, there is a low incidence of injury reported when participating in skill-based conditioning games. The underlying reasons for the apparent decreased occurrence of injury associated with conditioning games remains to be clarified. It may be that a mediating factor in this decreased incidence of injury is improved motor control when performing sports movements, as opposed to running without a ball. Improved neuromuscular control is identified as helping to guard against noncontact injuries (32). Whatever the mechanism, the benefits of less time away from the training pitch due to injury will be readily obvious to the coach and athlete.

Plyometric Training

Plyometric training is introduced during preseason on non–weight-training days. Depth jumping is approached with caution for players weighing more than 100 kg, which tends to be the case with forwards, particularly in rugby union. It has therefore been recommended that these players not exceed a depth jump drop height of 18 inches (46 cm) (34). As training macrocycles progress, plyometric exercises are introduced into gym sessions prior to weight training. The in-season progression involves plyometric drills being "complexed," or alternated, with heavy whole body powerlifts and Olympic-style lifts. Jumping to intercept balls thrown into the air is incorporated to increase context specificity. The use of a mechanical jump-and-reach measurement device to gauge height jumped for instant feedback is helpful when performing jumps and depth jumps to help maintain motivation and effort.

Table 3
Strength #1 Cycle

Frequency: 4x per week; 2(1) upper body; 1(2) lower body; 1 assistance

Intensity: 5–8RM multi-joint lifts; 8RM assistance lifts

Volume: 3–5 full load sets (exercises performed in circuit format),

Rest: Multi-joint lifts 2–3 minutes; assistance lifts 60 seconds; core work (~2 minutes) between sets

Other Training: Metabolic conditioning performed 4–5 days per week

Moderate intensity plyometrics and agility and quickness drills performed three days/week

Week 1	
Monday	**Tuesday**
6RM, 4–5 sets	**8RM, 4–5 sets**
Bench press Barbell bench row Bicep curls Standing dumbbell shoulder press One-arm dumbbell row Dumbbell upright row	Bent-over dumbbell raises EZ bar (straight-arm) pull-overs Lateral dumbbell raises Dumbbell bicep curls EZ bar tricep raises Dumbbell front raises Elastic tubing shoulder rotations
Thursday	**Friday**
6RM, 4–5 sets	**8RM, 4–5 sets**
Push press Parallel back squat Dumbbell lunge Romanian deadlift Back extensions Dumbbell step-ups Single-leg calf raise	Incline dumbbell bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Dips Dumbbell upright row
Week 2	
Monday	**Tuesday**
5RM, 4–5 sets	**8RM, 4 sets**
Clean pull Parallel back squat Dumbbell lunge Romanian deadlift Back extensions Single-leg calf raise	Bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Bicep curls Dumbbell upright row
Thursday	**Friday**
5RM, 5 sets	**8RM, 4 sets**
Split jerk Deadlift Dumbbell step-ups Back extensions Split squat Single-leg calf raise	Bent-over dumbbell raises EZ bar (straight-arm) pull-overs Lateral dumbbell raises Dumbbell bicep curls EZ bar tricep raises Dumbbell front raises Elastic tubing shoulder rotations

Note: Week 2 frequency in parentheses.

Table 4
Hypertrophy #2 Cycle (Preseason Weeks 5–6)

Frequency: 5 x per week: 2 upper body; 2 lower body; 1 assistance

Intensity: 8–10RM (all lifts)

Volume: 3–5 full load sets (exercises performed in circuit format)

Rest: Short rest (<60 seconds) between exercises; core stability work (~2 minutes) between sets

Other Training:

Metabolic conditioning reduced to three days per week

Moderate intensity plyometrics and agility and quickness drills performed 2 days per week

Strength training performed in the morning before conditioning or practice sessions

Monday	**Tuesday**	**Wednesday**
Week 1, 8RM **Week 2, 6RM** **5 sets**	**Week 1, 8RM** **Week 2, 6RM** **5 sets**	**Week 1, 10RM** **Week 2, 8RM** **4 sets**
Clean pull Parallel back squat Dumbbell lunge Back extensions Split squat Single-leg calf raise	Bench press Barbell bench row Standing dumbbell shoulder press One-arm dumbbell row Dips Dumbbell upright row	Bent-over dumbbell raises EZ bar pull-overs Lateral dumbbell raises Dumbbell bicep curls Dumbbell front raises EZ bar tricep extensions Elastic tubing shoulder rotations
Thursday	**Friday**	
Week 1, 10RM **Week 2, 8RM** **3–5 sets**	**Week 1, 10RM** **Week 2, 8RM** **3–5 sets**	
Deadlift Split squat Romanian deadlift Back extensions Dumbbell step-ups Single-leg calf raise	Incline dumbbell bench press One-arm dumbbell row Dumbbell bicep curls Standing dumbbell shoulder press Bent-over barbell row Bench dips Dumbbell upright row	

Sprint Work

In the early phases of the periodized plan (early to mid-preseason), technique drills are performed to develop efficient running mechanics. Likewise, bounding (a variety of explosive cyclic stepping and hopping actions) is implemented at progressively increasing intensities, in association with plyometric training. Towards the end of the preseason phase, resisted (sprinting uphill, towing sleds, or running attached to bungee ropes) and assisted (downhill running or towed running) methods are introduced to develop stride length and stride frequency, respectively (7).

Core Stability

Rugby football requires a strong core and good motor control to stabilize the trunk and to maintain upright posture while changing direction at speed. This aspect is also important when being lifted to contest possession at lineouts and kickoffs. Strong core and lumbo-pelvic stability are necessary for efficient transfer of force from the ground up during collision phases (tackling, cleaning rucks, and scrummaging). These elements are similarly important for guarding against injury (4, 32). The focus is on Swiss ball work, using medicine balls for added resistance as necessary. This provides a labile surface, which demands a coordinated response from the core musculature to stabilize the athlete (40). When performing abdominal work, there is a tendency for anterior bias (i.e., focusing on the muscle groups that can be seen in the mirror). To counter this bias, there is a particular emphasis on exercises for the transversus abdominus, obliques, and lumbo-pelvic musculature. Exercises include curls on the ball, bridging exercises, and lumbo-pelvic support exercises.

Agility Training

There is a focus on ladder drills and low hurdle work for developing quick feet. This also has direct application for movement in the lineout for the forward positions. Slalom pole drills are implemented to practice the skill of spinning out of collisions to evade tacklers. All drills feature a ball and defenders where possible and appropriate to enhance context specificity (21). As training advances, these drills are supplemented by one-on-one attacker/defender work with a tether joined by Velcro or popper fasteners. The goal of the attacker is to "wrong-foot" his opponent and thus break the tether bond; the defender aims to shadow his partner to keep the tether intact. This develops motor control for the close quarter reactive movements involved in evading tacklers and puts the athlete into an optimal position to make a tackle when defending.

Warm-up and Stretching

General warm-up (low-intensity aerobic activity) should precede all training sessions, as well as matches. For practice sessions on the training pitch, this warm-up will be in the form of submaximal running, generally including a ball-handling element to maintain the players' interest. For gym sessions, ergometers such as rowing machines, climbers, or Nordic skiers are ideal, as they provide whole body activities. The rationale for this general warm-up is that it raises core and muscle temperature to decrease muscle viscosity, which guards against muscle-tendon injury (14, 20).

Table 5

Strength #2 Cycle (Preseason Weeks 7–8)

Frequency: 4 x per week: 1 whole body; 1 upper body; 1 lower body; 1 assistance

Intensity: 4–6RM multi-joint lifts; 8RM assistance lifts

Volume: 3–5 full load sets (exercises performed in circuit format)

Rest: Multi-joint lifts 2–3 minutes, assistance lifts 60 seconds; abdominal work (~2 minutes) between sets

Other Training: Metabolic conditioning two days per week to allow for more tactical practice sessions

Moderate–high intensity plyometrics and agility and quickness drills performed 2 days per week before gym sessions

Resisted and assisted sprint training drills introduced

Rugby-specific resistance training exercises introduced

Strength training performed in the morning before conditioning or practice sessions

Monday	**Tuesday**
Week 1, 5RM **Week 2, 4RM** **4–5 sets**	**6RM** **5 sets**
Clean pull Overhead full squat Split jerk Parallel back squat Lunge Romanian deadlift	Incline dumbbell bench press Bent-over barbell row Standing dumbbell shoulder press Back extensions with barbell Dumbbell upright row Single-leg calf raise
Thursday	**Friday**
Week 1, 5RM **Week 2, 4RM** **4–5 sets**	**8RM** **5 sets**
Power clean Bench press Push press Deadlift One-arm dumbbell row	Bent-over dumbbell raises EZ bar pull-overs Lateral dumbbell raises Dumbbell bicep curls Dumbbell front raises EZ bar tricep raises Elastic tubing shoulder rotations

Ballistic stretching is now largely avoided, on the grounds that it can cause musculotendinous damage and because it evokes stretch reflexes and therefore does not allow the muscle to relax (20). Furthermore, there is growing evidence that static stretching may be counterproductive prior to matches and high-intensity training sessions with a high muscular power requirement. Similarly, there is increasing data indicating that static stretching leads to short-term impairment of dynamic strength and power output (44), and the injury prevention effect that is supposed to occur with static stretching appears to be absent. Likewise, there is recent evidence that proprioceptive neuromuscular facilitation (PNF) stretching also has a negative effect on dynamic performance

Table 6
Power Cycle (Preseason Weeks 9–11)

Frequency: 3 x per week

Intensity: 3–5RM (all lifts)

Volume: 3–5 full load sets (exercises performed in circuit format)

Rest: 3–4 minutes between exercises; core stability work (~2 minutes) between sets

Other Training: Strength training performed in the morning before conditioning or practice sessions

Monday	**Wednesday**	**Friday**
Week 1, 4RM **Week 2–3, 3RM** **4–5 sets**	**80% Week 1, 4RM** **80% Week 2&3, 3RM** **3–5 sets**	**90% Week 1, 4RM** **90% Week 2&3, 3RM** **4–5 sets**
Clean pull Push press Bench press Deadlift Barbell bench row	Split jerk Parallel back squat Romanian deadlift Ballistic push-ups One-arm dumbbell row	Power clean Overhead full squat Ballistic push-up Resisted hip/knee drive Alternate box hops

capabilities, as evident from short-term reductions in vertical jump height (44).

Given this, it appears prudent to avoid both static and PNF stretching prior to matches and training sessions that have an emphasis on speed or power, as will be the case for most training for rugby. This would include sprint work, agility and quickness drills, and plyometric training, as well as explosive power training (Olympic-style lifts or ballistic resistance exercises) in the gym.

Static and PNF stretching does still have its place in terms of flexibility training for long term increases in joint range of motion. These stretches are implemented after strength training gym sessions and during warm-down postmatch and after training and practices. In addition, gastrocnemius and soleus stretches are incorporated for injury prevention, particularly for players presenting with calf stiffness or plantar fasciitis (38), as is common among athletes in running- and jumping-intensive sports.

Dynamic stretches, such as walking lunges, sprint technique drills, and rehearsals of sport-related actions at low to moderate intensity are all advocated as alternative specific warm-up modes to prepare the athlete for competition and speed/power training in a way that does not hinder subsequent performance or risk injury (10, 14). These stretches are performed with increasing intensity as warm-up advances, by way of progressively warming up the athlete in readiness for the match or training session.

Sample Periodized Plan

The example given is based on the English Premiership rugby union season schedule. The competition calendar runs from September to May, with formal preseason training starting at the beginning of July. The plan can be modified for application to rugby league (which has a summer playing season) by adjusting the timing of the respective training cycles.

There are several disparate training goals—specifically hypertrophy, strength and explosive power, and injury prevention—all of which must be addressed in the course of the training plan. This is achieved by planned variations in the training program that systematically shift the emphasis to promote different training effects at different phases of the training period. In addition, varying the training at regular intervals prevents plateaus in training adaptations.

All strength training is conducted in a circuit format to address muscular endurance needs. Rest periods between consecutive exercises for similar muscle groups are manipulated according to the goal of the training cycle. Intensity guidelines are given as the repetition maximum (RM) for the specified number of repetitions. Volume recommendations are made for full load sets. However, all gym sessions should be preceded by a warm-up circuit with 75–80% resistance of the prescribed RM load for each lift. Strength training is performed first in the day, before metabolic conditioning or other training (24)

Active Rest

This phase encompasses the 2 weeks following the final match of the season. Players are encouraged to refrain from formal strength training and metabolic conditioning for the duration of the 2-week period, with the exception of recreational activities and light resistance work.

Table 7a

5-week schedule September–October

Tuesday	Wednesday	Friday
Weeks 1–2, 6RM **Weeks 3–4, 5RM** **Week 5, 4RM** **3 sets**	**Weeks 1–2, 6RM** **Weeks 3–4, 5RM** **Week 5, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–5, 6RM** **2–3 sets**
Clean pull Push press Parallel back squat Lunge Romanian deadlift	Bench press Barbell bench row Standing dumbbell shoulder press One-arm dumbbell row Dumbbell bicep curls	Power clean (<6 reps) Ballistic push-up Resisted hip/knee drive Incline dumbbell bench press Dumbbell front raises Resistance tubing shoulder rotations Single-leg calf raise

Table 7b

5-week schedule October–November

Tuesday	Wednesday	Friday
Weeks 1–2, 6RM **Weeks 3–4, 5RM** **Week 5, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–4, 6RM** **Week 5, 5RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–5, 6RM** **2–3 sets**
Power clean Resisted hip/knee drive Push press Deadlift Back extensions with barbell Dumbbell step up	Incline dumbbell bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Dips Dumbbell upright row	Split jerk Bench press Overhead full squat Bent-over dumbbell raises Resistance tubing shoulder rotations Dumbbell bicep curl

Table 7c

5-week schedule November–December

Tuesday	Wednesday	Thursday
Weeks 1–2, 5RM **Weeks 3–4, 4RM** **Week 5, 3RM** **3 sets**	**Weeks 1–2, 6RM** **Weeks 3–4, 5RM** **Week 5, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–5, 6RM** **2–3 sets**
Clean pull Overhead squat Split jerk Parallel back squat Split squat Romanian deadlift	Bench press Barbell bench row Standing dumbbell shoulder press One-arm dumbbell row Dumbbell bicep curl Dumbbell upright row	Push press Ballistic push-up Bent-over barbell row EZ bar pull-overs Dumbbell lateral raise Resistance tubing shoulder rotations Single-leg calf raise

Table 8a

6-week schedule January–February

Tuesday	Wednesday	Friday
Weeks 1–2, 6RM **Weeks 3–4, 5RM** **Weeks 5–6, 4RM** **3 sets**	**Weeks 1–2, 6RM** **Weeks 3–4, 5RM** **Weeks 5–6, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3-6, 6RM** **2–3 sets**
Clean pull Push press Parallel back squat Alternate box hops Romanian deadlift	Bench press Barbell bench row Standing dumbbell shoulder press One-arm dumbbell row Dumbbell bicep curls	Power clean (<6 repetitions) Ballistic push-up Resisted hip/knee drive Dumbbell front raises Resistance tubing shoulder rotations Single-leg calf raise

Table 8b

6-week schedule October–November

Tuesday	Wednesday	Friday
Weeks 1–2, 6RM **Weeks 3–4, 5RM** **Weeks 5–6, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–4, 6RM** **Weeks 5–6, 5RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–6, 6RM** **2–3 sets**
Power clean Resisted hip/knee drive Push press Deadlift Back extensions with barbell Dumbbell step up	Incline dumbbell bench press Bent-over barbell row Standing dumbbell shoulder press One-arm dumbbell row Dips Dumbbell upright row	Split jerk Bench press Overhead full squat Bent-over dumbbell raises Resistance tubing shoulder rotations Dumbbell bicep curl

Table 8c

6-week schedule November–December

Tuesday	Wednesday	Friday
Weeks 1–2, 5RM **Weeks 3–4, 4RM** **Weeks 5–6, 3RM** **3 sets**	**Weeks 1–2, 6RM** **Weeks 3–4, 5RM** **Weeks 5–6, 4RM** **3 sets**	**Weeks 1–2, 8RM** **Weeks 3–6, 6RM** **2-3 sets**
Clean pull Overhead squat Split jerk Resisted hip/knee drive Parallel back squat Romanian deadlift	Ballistic push-up Bench press One-arm dumbbell row Standing dumbbell shoulder press Dumbbell upright row	Push press Incline dumbbell bench press Dumbbell lateral raise EZ bar pull-overs Dumbbell bicep curl Resistance tubing shoulder rotations Single-leg calf raise

Table 9
Inseason—Play-offs (May)

Tuesday	Thursday
3–5 RM, 2–3 sets	**4-6RM, 2–3 sets**
Clean pull Overhead squat Push press Bench press One-arm dumbbell row	Power clean Ballistic push-up Split jerk Romanian deadlift

Off-season Cycle

The length of the off-season is dictated by the team's progress in the end-of-season play-offs and participation in European cup competition semi-finals and finals. Thus, the off-season may last anywhere from 2 weeks (if involved in a play-off championship final) to 5 weeks (if the team failed to qualify for either championship or wild card play-offs and is not involved in the final stages of European competitions).

The off-season is a key opportunity for strength training without the constraints and possible interference effects of concurrent metabolic conditioning and team practices. Injuries and existing muscular imbalances are likewise addressed in this period.

Off-season strength training consists of 2 microcycles: an initial 4 d/wk microcycle (Table 1a) and a 5 d/wk microcycle (Table 1b) implemented in the 2 weeks leading up to the beginning of preseason practice. No other formal training is performed in this period.

Hypertrophy #1 Cycle (Preseason Weeks 1–2)

High training volume (3–5 full load sets) is combined with moderate loads (8–12RM) and short rest periods (<60 seconds between exercises). Exercises are performed as a circuit to reduce the time taken between consecutive exercises. Core stability work is performed between each circuit to allow some active recovery. The combination of load scheme and elevated lactic acid levels resulting from the short rest intervals is designed to promote optimal testosterone and growth hormone responses for lean muscle growth, or hypertrophy (23).

Four sessions are performed in each of the 2 weekly microcycles based around an upper/lower body split routine, supplemented by an assistance lifts (arms and shoulder complex) workout (Table 2). Metabolic conditioning is performed 5 days a week in this period. As in the remainder of the preseason, strength training is performed in the morning before conditioning or practice sessions.

Strength #1 Cycle (Preseason Weeks 3–4)

High volume (4–5 full load sets) is maintained in this phase; the specific number is at the discretion of the strength coach on each training day. Greater weight (5–8RM multi-joint lifts) is lifted to promote greater strength gains. Players continue to train in a circuit format, but rest periods are extended to allow 2 to 3 minutes between consecutive exercises with similar muscle groups in multi-joint lift sessions. The provision of more complete recovery is designed to enable higher loads to be lifted in later sets.

Four sessions per week are performed, incorporating a split routine similar to the previous phase, again including 1 workout dedicated to assistance lifts (Table 3). Moderate intensity plyometrics and agility and quickness drills are introduced 3 days per week before gym sessions. Metabolic conditioning is performed 4 or 5 days a week. Strength training is performed in the morning before conditioning or practice sessions.

Hypertrophy #2 Cycle (Preseason Weeks 5–6)

This cycle includes the highest volumes used in the preseason training period, with 5 strength training sessions performed each week (Table 4). A loading scheme of 6RM (heavy days) and 8RM (light days) is used for multi-joint lifts (8RM for assistance lifts) in a circuit format with minimal rest (<60 seconds) between consecutive exercises.

The duration of metabolic conditioning is tapered slightly. Likewise, plyometrics and agility and quickness drills are limited in intensity and restricted to 2 days per week on lower-body strength training days to accommodate the high volumes of strength training.

Strength #2 Cycle (Preseason Weeks 7–8)

Four training sessions are completed each week in this phase: 1 combined whole-body workout; 1 upper-body workout; 1 lower-body workout; and 1 assistance workout (Table 5). Intensity increases to 4–5RM for multi-joint lifts (8RM for assistance lifts), reflecting a shift towards gains in maximum strength. Exercises continue to be performed in circuit format, with rest intervals manipulated to provide 2 to 3 minutes between consecutive exercises with similar muscle groups for multi-joint lifts.

Less metabolic conditioning is performed to accommodate a greater number of tactical practice sessions. Resisted and assisted sprint training drills are introduced. Similarly, rugby-specific resistance training exercises are introduced, using bungee ropes for resistance. Moderate- to high-intensity plyometrics and agility drills are performed 2 days per week before gym sessions.

Power Cycle (Preseason Weeks 9–11)

This phase features the highest loads used in the training cycle. There is a focus on explosive lifts; these are performed first in the workout when the player is still fresh.

Three sessions are undertaken per week (Table 6). Intensity is raised to 3–4RM for all lifts, with players completing 4–5 full load sets at the discretion of the strength coach each day. Assistance lift days are eliminated during this phase. Rest periods are extended to allow 3 to 4 minutes between exercises, with core work (approximately 2 minutes duration) performed between sets.

High-intensity plyometrics training is implemented twice weekly (Monday and Friday) prior to gym sessions. Strength training continues to be performed in the morning before conditioning or practice sessions.

In-season/Regular Season (September–April)

It is vital that resistance training is maintained in season to prevent significant losses in strength and power. High loads (≥80%1RM or ≥8RM) are implemented 2 d/wk for multi-joint lifts. This loading scheme has been shown to maintain, or even increase, strength levels in the multi-joint lifts throughout the playing season in American Football (19).

15-Week Schedule September–December. Loads are varied according to an undulating nonlinear periodized plan to allow high weight to be lifted without overloading the player. This phase consists of three 5-week macrocycles, each comprising microcycles of progressively increasing intensity (Table 7a–c).

Late December. One week active rest is given, comprising unstructured recreational games and workouts.

18-Week Schedule January–April. An undulating nonlinear periodized plan is again used, working to a format similar to the early season mesocycle. There is some manipulation of selection and order of exercises to offer variation in the training stimulus (Table 8a–c).

Inseason/Play-offs (May). A peaking cycle is implemented for the period leading up to major competitions at the end of the season. This cycle features very high loads (3–6RM) and low volume (2–3 sets). There is a focus on multi-joint lifts, with assistance exercises being eliminated (Table 9). ♦

References

1. Baechle T.R., R.W. Earle, and D. Wathen. Resistance training. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 395–425.
2. Bathgate, A., J.P. Best, G. Craig, and M. Jamieson. A prospective study of injuries to elite Australian rugby union players. *Br. J. Sports Med.* 36:265–269. 2002.
3. Bellew, J.W., and S. Dunn. Ankle rehabilitation: A reintroduction of the peroneus longus. *Strength Cond. J.* 24(4):61–63. 2002.
4. Cissik, J.M. Programming abdominal training, part 1. *Strength Cond. J.* 24(1):9–15. 2002.
5. Cohen, S.B. Implementation of balance training in a gymnast's conditioning program. *Strength Cond. J.* 24(2): 60–67. 2002.
6. Conroy, B., and R.W. Earle. Bone, muscle, and connective tissue adaptations to physical activity. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 57–72.
7. Delecluse, C. Influence of strength training on sprint running performance. *Sports Med.* 24(3):147–156. 1997.
8. Deutsch, M.U., G.J. Maw, D. Jenkins, and P. Reaburn. Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *J. Sports Sci.* 16:561–570. 1998.
9. Durstine, J.L., and P.G. Davis. Specificity of training and testing. In: *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (4th Ed). J.L. Roitmanm ed. Lippincott Williams & Wilkins, 2001. pp 484–491.
10. Fredrick, G.A., and D.J. Szymanski. Baseball (part 1): Dynamic flexibility. *Strength Cond. J.* 23(1):21–30. 2001.
11. Gabbett, T.J. Training injuries in rugby league: An evaluation of skill-based conditioning games. *J. Strength Cond. Res.* 16(2):236–241. 2002.
12. Garraway, W.M., A.J. Lee, D.A.D. Macleod, J.W. Telfer, I.J. Deary, and G.D. Murray. Factors influencing tackle injuries in rugby union football. *Br. J. Sports Med.* 33:37–41. 1999.
13. Gissane, C., D. Jennings, K. Kerr, and J.A. White. A pooled data analysis of injury incidence in rugby league football. *Sports Med.* 32(3):211–216. 2002.
14. Hedrick, A. Dynamic flexibility training. *Strength Cond. J.* 22(5):33–38. 2000.
15. Hedrick, A. Training for high-performance collegiate ice hockey. *Strength Cond. J.* 24(2):42–52. 2002.
16. Hedrick, A. Manipulating strength and conditioning programs to improve athleticism. *Strength Cond. J.* 24(4): 71–74. 2002.
17. Hedrick, A. Designing resistance training programs: A practical example. *Strength Cond. J.* 24(6):7–15. 2002.
18. Hoffman, J., and E. Hamilton. Wall-mounted sled training and testing for football players. *Strength Cond. J.* 24(4):9–13. 2002.
19. Hoffman, J.R., and J. Kang. Strength changes during an in-season resistance-training program for football. *J. Strength Cond. Res.* 17(1):109–114. 2003.
20. Holcomb, W.R. Stretching and warm-up. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 321–342.
21. Ives, J.C., and G.A. Shelley. Psychophysics in functional strength and power training: Review and implementation framework. *J. Strength Cond. Res.* 17(1):177–186. 2003.

22. Jones, A.M., and H. Carter. The effect of endurance training on parameters of aerobic fitness. *Sports Med.* 29(6): 373–386. 2000.
23. Kraemer, W.J. Endocrine responses to resistance exercise. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 91–114.
24. Kraemer, W.J., J.F Patton, S.E. Gordon, E.A. Harman, M.R. Deschenes, K. Reynolds, R.U. Newton, N.T. Triplett, and J.E. Dziados. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J. Appl. Physiol.* 78(3):976–989. 1995.
25. Lawson, E. Incorporating sport-specific drills into conditioning. In: *High-Performance Sports Conditioning.* B. Foran, ed. Champaign, IL: Human Kinetics, 2001. pp 215–266.
26. Lee, A.J., W.M. Garraway, and D.W. Arneil. Influence of preseason training, fitness, and existing injury on subsequent rugby injury. *Br. J. Sports Med.* 35:412–417. 2001.
27. McCurdy, K., and C. Conner. Unilateral support training incorporating the hip and knee. *Strength Cond. J.* 25(2): 45–51. 2003.
28. Meir, R., P. Colla, and C. Milligan. Impact of the 10-meter rule change on professional rugby league: Implications for training. *Strength Cond. J.* 23(6): 42–46. 2001.
29. Milburn, P.D. Biomechanics of rugby union scrummaging. *Sports Med.* 16(3):168–179. 1993.
30. Murlatsis, Z., and J. Langley. In-season resistance training for high school football. *Strength Cond. J.* 24(4):65–68. 2002.
31. Newton, R.U., J. Jones, W.J. Kraemer, and H. Wardle. Strength and power training in Australian Olympic swimmers. *Strength Cond. J.* 24(3):7–15. 2002.
34. Pettit, R.W., and E.R. Bryson. Training for women's basketball: A biomechanical emphasis for preventing anterior cruciate ligament injury. *Strength Cond. J.* 24(5):20–29. 2002.
35. Plisk, S.S., and V. Gambetta. Tactical metabolic training: Part 1. *Strength Cond.* 19(2):44–53. 1997.
36. Potach, D.H., and D.A. Chu. Plyometric training. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 427–470.
37. Quarrie, K.L., J.C. Alsop, A.E. Waller, Y.N. Bird, S.W. Marshall, and D.J. Chalmers. The New Zealand rugby injury and performance project. VI. A prospective cohort study of risk factors for injury in rugby union football. *Br. J. Sports Med.* 35:157–166. 2001.
38. Quarrie, K.L., R.C. Cantu, and D.J. Chalmers. Rugby union injuries to the cervical spine and spinal cord. *Sports Med.* 32(10):633–653. 2002.
39. Quarrie, K.L., P. Handcock, A.E. Waller, D.J. Chalmers, M.J. Toomey, and B.D. Wilson. The New Zealand rugby injury and performance project. III. Anthropometric and physical performance characteristics of players. *Br. J. Sports Med.* 29(4):263–270. 1995.
40. Ross, M.D. Gastrocnemius and soleus muscle stretching for athletes with plantar fasciitis. *Strength Cond. J.* 24(6):71–72. 2002.
41. Santana, J.C. Hamstrings of steel: Preventing the pull, part II—Training the "triple threat." *Strength Cond. J.* 23(1):18–20. 2001.
42. Vera-Garcia, F.J., S.G. Grenier, and S.M. McGill. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys. Ther.* 80(6): 565–569. 2000.
43. Wagner, P. A comprehensive approach to shoulder complex maintenance. *Strength Cond. J.* 25(3):65–70. 2003.
44. Wilmore, J.H., and D.L Costill. *Physiology of Sport and Exercise* (2nd ed.). Champaign, IL: Human Kinetics, 1999.
45. Wilson, B.D., K.L. Quarrie, P.D. Milburn, and D.J. Chalmers. The nature and circumstances of tackle injuries in rugby union. *J. Sci. Med. in Sport.* 2(2):153–162. 1999.
46. Young, W., and D.G. Behm. Should static stretching be used during a warm-up for strength and power activities. *Strength Cond. J.* 24(6):33–37. 2002.

Gamble

Paul Gamble is currently completing a PhD in Exercise Physiology at Brunel University, West London and is the Strength and Conditioning Coach for London Irish RFC.

shouldn't be too surprised that their training needs are also different. On this basis, elite performers need to be treated as a special population.

It is increasingly common these days for training guidelines to make distinctions based on individual training status and experience. An extensive analysis of the strength training literature (covering 140 studies in total) identified a continuum of optimal training variables for maximal strength gains, depending on individual training status and experience.(4)

Training intensity

Maximal strength gains are demonstrated in untrained individuals when training at an average intensity of 60% 1RM (repetition maximum) and in strength-trained individuals when training at 80% 1RM. Competitive athletes appear to inhabit a territory still further along this continuum; and, in recognition of their specific needs, the American College of Sports Medicine (ACSM) recently updated its guidelines to include training prescriptions specifically for elite lifters.(2) However, attempts to treat competitive athletes as a special case are bedevilled by a lack of relevant data – particularly on team sports athletes – on which training prescriptions can be based.

There is an inevitable trade-off between obtaining access to these athletes as subjects and imposing the kind of scientific rigour that generates valid results. Counterbalanced study design requires a control group to act as a baseline for comparison with a 'treatment' group. But the problem is that the more beneficial a 'treatment' is perceived to be, the harder it is to accept no treatment or a placebo in its place.

As the demands and profile of competitive sport continue to increase and the financial stakes continue to rise, there is a proportionately increased emphasis on athletes' physical preparation, including strength training and conditioning. In this climate, no coach to a professional team would agree to having half the squad perform entirely different training, or even no training at all, to satisfy experimental protocol. Similarly, players would naturally be averse to having their chances for selection – and ultimately winning a contract – jeopardised by receiving inferior physical preparation as a result of being randomly assigned to the 'wrong' experimental group.

But in view of the doubts about the applicability of findings from studies on non-athletes and the lack of objective data relating to athletes, there is a critical need to gather information about this group. Until this can be done, strength and conditioning coaches in the majority of team sports will be without a quantitative basis for strength training prescription for their sport.

Given the time constraints imposed by extended playing seasons and the high volumes of concurrent training and team practices common to all professional team sports, the effectiveness of physical preparation is paramount. This data vacuum is therefore a critical issue. In the absence of specific objective data relating to their sport, coaches will continue to use their own observations and training experience as the basis for designing training programmes, and athletes' physical preparation will continue to be adversely affected as a result.

However, from the data that *is* available, some suggestions for the kind of training volumes, frequency and intensity relevant to competitive athletes can be derived. A mean training intensity of 85% 1RM has been found to have the greatest effect in competitive athletes in the majority of relevant studies. This equates to 6RM – *ie* the greatest weight that can be lifted for six repetitions when lifting to failure. It is also in general agreement with the recent finding that loads greater than 80% 1RM were necessary to maintain or improve strength throughout the playing season in American college football players.(5)

This requirement for greater average intensity appears to be a common theme for athletes as a special population. Training studies featuring protocols in which the athlete subject group lifted to failure report greater average strength gains. Accordingly, there is a need for strength training regimes for competitive athletes that stipulate the athlete must lift to failure at the specified load, as training at lesser intensities has been shown to elicit minimal improvements.

‘No coach to a professional team would agree to having half the squad perform entirely different training to satisfy experimental protocol’

Training frequency

In terms of frequency of strength training, recommendations are based on the number of times per week individual muscle groups should be trained. Data from athletes has shown that it is similarly effective to train a particular muscle group on two or three days a week. How many strength training sessions per week this equates to will depend on the design of the workout. It could mean two workouts per week if both workouts involved whole-body sessions. On the other hand, if a 'split routine' format is used to work on particular muscle groups independently, it could equate to four or more strength training sessions per week. Given the time constraints imposed by many team sports, the whole-body format is likely to be more time-efficient.

Strength training volume recommendations for competitive athletes are also made for individual muscle groups. A mean number of eight sets per muscle group per week have been found to maximise strength gains in groups of athletes. By contrast, most studies on non-athletes (both strength-trained and untrained) have found four sets per muscle group per week to be effective in evoking maximal strength gains. These observations reinforce the specific needs of athletes as a special population.

As far as training mode is concerned, exercise selection must be addressed on an individual basis, based on a 'needs analysis' for the particular sport and the individual athlete. This should include biomechanical analysis of the movements involved in match play and profiles of injury risk for that specific sport, as well as the biomechanical peculiarities and injury record of the athlete.

In conclusion, data from studies on competitive athletes reveal demonstrable differences between their strength training needs and those identified for non-athletes. Some strength training guidelines for competitive athletes have been suggested in this article, based on the limited data available.

Further research, which directly assesses the training responses of competitive athletes, is required in order to firm up and develop these guidelines. This is critical to providing coaches in professional sports with an objective basis for their strength training programmes and thus, ultimately, to optimising performance in these sports.

It is well recognised that randomised controlled scientific studies are the best route to valid results but, where professional athletes are concerned, some compromises on experimental design are likely to be needed.

Paul Gamble

References

1. *Medicine and Science in Sports & Exercise 1998; 30: 975-991*
2. *Medicine & Science in Sports and Exercise 2002; 34(2): 364-380*
3. *Journal of Strength & Conditioning Research 2004; 18(2): 377-382*
4. *Medicine & Science in Sports and Exercise 2003; 35: 456-464*
5. *Journal of Strength & Conditioning Research 2003; 17(1): 109-114*

STRENGTH TRAINING 2

Why women avoid weight training – and how coaches can change their minds

Female athletes are less likely to perceive weight training as beneficial to their sport than their male counterparts, according to a recent study. This may not seem like much of a problem, but weight training is a significant aid to female athletes, not just because it helps improve sporting performance but also because it helps ward off osteoporosis by enhancing bone mineral density (BMD).

Coaches and athletes need to be aware of these benefits as well as the social/cultural barriers that may discourage women from participating in weight training. This article will begin to address these issues as well as offering practical advice on training.

The study referred to above involved 139 male and 165 female student athletes from four US colleges.(1) The students, who participated in a total of 11 different sports, including soccer, athletics, lacrosse and basketball, completed two questionnaires:

- The Training Information Survey (TIS), including questions on weight training practice and perception, as well as other sports training and conditioning;
- The Sport Orientation Questionnaire (SOQ), which measures competitiveness, win orientation (where the performer is focused on an objective outcome, *eg* a race result) and goal orientation (focus on personal achievement).(2)

The authors were seeking to identify gender differences in weight training perception as well as differences between more competitive and less competitive athletes.

The key findings were as follows:

- Female athletes perceived weight training to be less important than their male counterparts, while their coaches considered weight training to be less essential for women than for men;
- The athletes who participated most in weight training activities were those who considered it essential to their sport. Participation was not linked with competitiveness, goal or win orientation;
- Female athletes were less confident about weight training than male athletes;
- The SOQ confirmed previous research that male athletes were more competitive and win orientated than women while female athletes were more goal orientated than men;
- In both groups of athletes, those who were goal orientated and competitive considered weight training equally important for male and female athletes, while those who were win orientated thought weight training was a masculine activity, important only for male athletes.

Leaving aside for the moment the differences between competitive, goal and win orientated athletes, the three main issues highlighted by this study were the perception of weight training as a masculine activity, the finding that participation in weight training is linked to the perception of sport specific relevance and the fact that female athletes are less confident about weight training than males.

Unfortunately, coaches did not appear to be helping matters. And the researchers conclude that coaches need specific education and support in order to promote weight training appropriately to female athletes.

Sportswomen seem to have an adverse perception of weight training, perhaps because

References
1. Noakes MD Lore of Running (4th edition) 157, 159 and 163 Human Kinetics 2002
2. Medicine and Science in Sports and Exercise, 30(5), 1998
3. Sports Med. 2003; 33(1): 59-73

(4 x 2,000m) to establish the relationship between running speed and blood lactate levels. Basically, the researchers wanted to discover how fast the runners needed to run to be able to stay within comfortable – for achieving fast half-marathon times – lactate levels.

Speeds used in the field test ranged from 4.2 to 5.8 metres per second, with a progression of 0.4m/s each step. Following each loading level, blood samples were taken and analysed. At first it seemed that the step tests were valuable predictors of half-marathon times, with test speeds corresponding to lactate concentrations of between 3.0 and 5.5mmol, reflecting half-marathon speed. Even higher correlations were found at lactate levels of 4.5, 5.0 and 5.5mmol running speeds.

However, when the athletes actually raced, these strong correlations fell apart; 70% of the athletes' final competition times fell outside the level of prediction based on the lactate levels of 4.5-5.5mmol achieved during the supposedly predictive step testing.

Predictive limitations

In an attempt to further explain lactate levels and LT's shortfalls when it comes to endurance event performance, Noakes writes: 'Lactate is a natural product of carbohydrate metabolism during exercise. As the rate of energy production rises, so more carbohydrate is used and as a result, more lactate appears in the bloodstream. Hence a rising blood lactate level only indicates that more carbohydrate is being burned. It does not mean that the muscle's work is becoming more anaerobic.' (1)

Thus attempts to correlate event performance with a notional lactate threshold are ultimately doomed to failure. Noakes suggests that better predictors of endurance performance are time trials, race results at shorter distances and self-analysis (for suitably experienced athletes).

By now some of your misconceptions surrounding lactate should have been cleared up. The reality is that lactate (or lactic acid) is neither a bad guy nor a waste product, but a key ingredient in energy production and sustainability.

So now, when you experience the pain of a highly beneficial lactate stacker workout, you should not curse lactic acid but rather pat it on the back for the attempt it *has* been making at keeping your muscles working and the contribution it *will* be making to your post-workout recovery.

Lactate only blots its newfound copybook when used to specifically predict endurance performance.

John Shepherd

STRENGTH TRAINING 1

When it comes to strength training, athletes need to be treated as a 'special population'

Sport scientists, coaches and trainers are becoming increasingly aware of a worryingly wide gap between the findings of strength training studies, as reported in the scientific journals, and what is applicable in the field. More specifically, there is a need for studies that investigate the training responses of competitive athletes directly rather than making inferences based on studies of non-athletes.

Findings from strength training studies have been generalised in order to establish guidelines for the frequency, volume and intensity of strength training likely to produce the greatest gains in trained and untrained subjects respectively.(1,2) However, such 'dose-response' relationships have not been identified in competitive athletes until recently.

A study published last year set out to investigate the relevance of the strength training literature to competitive athletes.(3) The authors conducted a meta-analysis (review of pooled data) of 37 individual studies involving competitive athletes from a range of sports and athletic backgrounds. Their aim was to identify the 'doses' of training frequency, volume and intensity that produced the greatest measured strength gains and to generalise the dose-response relationship from these findings.

Their key finding was that the training parameters found to optimise strength gains in competitive athletes differed markedly from those identified by similar studies on *non*-athletes. Specifically, the training volume (sets per muscle group), training frequency (days per week for each muscle group) and training intensity (resistance load) found to be most effective in a range of studies were very different for athletes from those applying to non-athletes – even those experienced in strength training.

The researchers concluded, quite naturally, that competitive athletes appear to exhibit different training responses from even recreationally trained non-athletes. Given this divergence, it would seem unwise – unsafe even – to generalise from findings about non-athletes, as has happened in the past.

The performance pressures on competitive athletes are vastly different from those on recreationally trained individuals. So perhaps we