Changes in strength, power, and steroid hormones during a professional rugby union competition

Argus, Christos K.; Gill, Nicholas D.; Keogh, Justin W. L.; Hopkins, Will G.; Beaven, C. Martyn

Published in:
Journal of Strength and Conditioning Research

DOI:
10.1519/JSC.0b013e3181a392d9

CHANGES IN STRENGTH, POWER AND STEROID HORMONES DURING A PROFESSIONAL RUGBY UNION COMPETITION

Christos K. Argus[1], Nicholas D. Gill[1], Justin W. L. Keogh[1], Will G. Hopkins[1],
C. Martyn Beaven[1, 2]
[1]*Institute of Sport and Recreation Research New Zealand, AUT University, Auckland NZ*
[2]*Health and Food Group, HortResearch, Hamilton NZ*

R# JSCR-08-64, Revision 2.

Running Head: Strength, power and hormones in rugby union.

Corresponding author
Christos Argus
Institute of Sport and Recreation Research New Zealand, Faculty of Health and Environmental Sciences, Auckland University of Technology,
Private Bag 92006,
Auckland 1020,
New Zealand.
Email: argy15@hotmail.com
Phone: +64 275527487
Facsimile: +64 92358885

CHANGES IN STRENGTH, POWER AND STEROID HORMONES DURING A PROFESSIONAL RUGBY UNION COMPETITION

ABSTRACT

The purpose of this investigation was to assess changes in strength, power and levels of testosterone and cortisol over a 13 week elite competitive rugby union season. Thirty two professional rugby union athletes from a Super 14 rugby team (age, 24.4 ± 2.7 years; height, 184.7 ± 6.2 cm; mass, 104.0 ± 11.2 kg; mean ± SD) were assessed for upper-body and lower-body strength (bench press and box squat respectively) and power (bench throw and jump squat respectively) up to five times throughout the competitive season. Salivary testosterone and cortisol samples, along with ratings of perceived soreness and tiredness, were also obtained prior to each power assessment. An effect size of 0.2 was interpreted as the smallest worthwhile change. A small increase in lower-body strength was observed over the study period (8.5%; 90% confidence limits ±7.2%), while upper-body strength was maintained (-1.2%; ±2.7%). Decreases in lower-body power (-3.3%; ±5.5%) and upper-body power (-3.4; ±4.9%) were small-trivial. There were moderate increases in testosterone (54%; ±27%) and cortisol (97%; ±51%) over the competitive season, and the testosterone/cortisol ratio showed a small decline (22%; ±25%), while changes in perceived soreness and tiredness were trivial. Individual differences over the competitive season for all measures were mostly trivial or inestimable. Some small to moderate relationships were observed between strength and power, however relationships between hormonal concentrations and performance were mainly trivial but unclear. Positive adaptation in strength and power may be primarily affected by cumulative training volume and stimulus over a competitive season. Greater than two resistance sessions per week may be needed to improve strength and power in elite rugby union athletes during a competitive season. **Key words:** ELITE ATHLETES, CORTISOL, RESISTANCE TRAINING, TESTOSTERONE

INTRODUCTION

Rugby union is a high contact, dynamic sport in which athletes require a combination of strength, power, speed, agility, endurance and sport-specific attributes. As such, rugby union athletes perform concurrent training in an attempt to elicit gains in the many physical attributes required. Traditionally, concurrent training has been discussed as performing training modes with contrasting physical adaptations during the same training phase, typically strength and endurance (26). However the term concurrent does not necessarily denote contrasting modes of training, rather concurrent is simply defined as existing or happening at the same time. Therefore concurrent training may be more accurately discussed as numerous aspects of physical preparation targeted at the same time during a training phase. Indeed team sport athletes predominately perform concurrent training to maximise adaptation in the many skill and physical aspects required. Similar to other athletes, physical conditioning plays a large role in the preparation and subsequent performance of rugby players.

Pre-season conditioning is considered crucial for athletes to develop the physical characteristics required for successful competitive performance (e.g. strength, power, speed, aerobic and anaerobic endurance) (35). Elite rugby athletes may sometimes train as many as four times per day during this phase of the season. During the competitive rugby season the main emphasis of the conditioning program is to maintain gains made in strength, power and lean body mass from pre-season training (2). This can be difficult however, as conditioning volume during the competitive season is reduced, and additional training goals are introduced alongside previous training goals (i.e. additional training sessions such as position-specific drills).

It is unclear whether it is possible to maintain or improve pre-season levels of physical performance throughout a competitive season that involves predominantly concurrent training. Indeed, research on other football codes has produced mixed findings (2, 10, 18, 19, 35). For example, Baker (2) found that bench press strength in college aged rugby league athletes increased by 4.9%, whereas professional athletes maintained bench press strength (-1.2%) during a competitive season. Additionally, both upper-body and lower-body power was maintained in both of these playing groups (2). Gabbett (19) reported similar findings in that amateur junior rugby league athletes were able to maintain lower-body muscular power (-0.7%) throughout a competitive season. In contrast, Gabbett (18) found that non-elite senior club level rugby league athletes had decreases in muscular lower-body power (-5.3%); while Schneider and colleagues (35) reported significant decreases in maximal upper-body strength (~8%) and lower-body power (~4.6%) in college aged American football athletes throughout a competitive season.

Although there are similarities between these football codes (rugby union, rugby league and American football), there are also many differences. For example duration of work periods, type of work (dynamic or static), work : rest ratios, differences in the time spent at maximal and sub-maximal intensities, distances covered throughout the game, and different rules and regulations (9, 13, 20, 30). These differences between codes and therefore training priorities may be partly responsible for the contrasting findings relating to the maintenance of strength and power previously reported in these football codes.

Another limitation of this literature is that there appears to be little research into the possible mechanisms contributing to the changes in strength and power across a competitive season of football. One such mediator might be the hormonal system. Testosterone and cortisol are steroid hormones with the testosterone to cortisol ratio (T:C ratio) reflecting the balance between anabolic and catabolic environments (16, 17). Higher levels of testosterone have been previously linked to performance in strength and power tasks (7), while diminished levels of testosterone and increased levels of cortisol have been linked to overtraining and reduced performance (24, 25, 36). A better understanding of the effects of a competitive season on these steroid hormones, and their relationship with strength and power may provide opportunity for enhanced programming strategies at an individual player level.

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

METHODS

Experimental Approach to the Problem

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

Although many physical attributes are required for successful performance in rugby union, only selected measures were monitored. This investigation was conducted using elite athletes in a professional environment, and therefore the researchers were limited as to what and how often they were able to test athletes. The researchers did not have the ability to test athletes during on-field training sessions, where attributes such as endurance, agility, speed and sport specific skills were trained and where these parameters would have been most easily assessed. The researchers' access to athletes was during off-field training sessions, i.e. gym sessions, in which they were able to assess levels of strength and power at the start of certain sessions.

Subjects

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

Procedures

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

Strength (Bench Press and Box Squat)

Maximal strength was assessed using the bench press and box squat exercises. Each athlete was required to perform three sets (50%, 70%, 90% effort, two-six repetitions) of sub-maximal bench press and box squat followed by one set to failure of one to four repetitions. Three minutes rest was allowed between each set. Each set to failure was used to predict the athletes' one repetition maximum (1RM) (27). For the bench press, athletes used a self-selected hand position, and were required to lower the bar to approximately 90° angle at the elbows and then pressed the bar in a vertical movement so that the arms were fully extended. The depth and hand position were kept consistent throughout all testing occasions. During the box squat, athletes used a self-selected foot position, and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each athlete to allow the top of the thighs to be parallel to the floor while in the seated position. The foot position selected was kept consistent throughout all testing occasions. Each repetition was performed irrespective of time.

The following equation was used to predict bench press and box squat 1RM (27) and has been show to have a correlation between actual and predicted 1RM of r=0.993 and r=0.969 for bench press and box squat, respectively (28):

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

Soreness and Tiredness

On arrival at the training facility on the days which power was assessed, athletes rated their perceptions of soreness and tiredness on a ten point scale ranging from 0 = normal to 10 = extremely sore (soreness scale), or 0 = normal to 10 = extremely tired (tiredness scale) (8).

Salivary Hormones

Resting saliva samples were also obtained from each player prior to each power assessment. Salivary samples were obtained in this study as they are stress-free and non-invasive (37). Salivary samples also reflect the free (non-protein-bound) plasma fraction which represents the biological activity of the steroid hormone (37) which has been reported to be more physiologically relevant than total blood levels (32, 38). Athletes provided a ~2 mL sample by passive drool into polyethylene tubes which was stored at -20°C until assayed for testosterone and cortisol. Sugar free gum was used to stimulate saliva flow before collection. The athletes then rested for five minutes prior to the beginning of the training session.

Upper-body Power (Bench Throw)

Upper-body power was monitored over the competitive season using a bench throw exercise performed in a Smith machine. Athletes warmed up with two sets of four repetitions of bench press at 50% of their most recent predicted 1RM bench press. Athletes then completed two sets of four repetitions of the bench throw at 50% and 60% 1RM bench press as these loads have been previously shown to produce maximal upper-body power in well trained athletes (2). Athletes used a self selected hand position and lowered the bar to a self selected depth which was kept constant throughout all testing occasions. Athletes were then asked to throw the bar vertically and explosively as possible, trying to propel the bar to a maximal height (31). Three minutes rest was allowed between each set.

Lower-body Power (Jump Squat)

Lower-body power was monitored over the competitive season using a jump squat exercise performed in a Smith machine. Athletes warmed up with two sets of four repetitions lowering the bar to a 90° knee angle using a load of 55% of their most recent predicted 1RM box squat. Athletes then completed two sets of four repetitions of jump squat at 55% and 60% 1RM box squat as these loads have been previously shown to produce maximal lower-body power in well trained athletes (2). Athletes used a self selected foot position and lowered the bar to a self selected depth which was kept constant throughout all testing occasions. Athletes were then asked to jump as explosively as possible, to propel themselves and the bar off the ground. Three minutes rest was allowed between each set.

The power produced during each bench throw and jump squat repetition was quantified with a Gymaware™ optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) using the methods described elsewhere (11). Quantification of the power produced during the jump squat exercise included bodyweight and bar mass (system mass) in the calculation, whereas only the bar mass was included for bench throw (12).

Training Loads

Training loads for each session were recorded and calculated by randomly selecting five athletes to give the training session a rating of perceived exertion (RPE) using the Borg scale (6) (Table 1). This intensity was then averaged and multiplied by the duration of the training (minutes) to calculate a training load for the session.

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

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

Insert Table 1 about here

Specifically, during the pre-season, backs performed approximately 3.4 ± 1.3 resistance training sessions per week in comparison to 1.3 ± 0.6 resistance sessions per week during the in-season. Forwards performed approximately 5.0 ± 1.7 resistance sessions per week in the pre-season in comparison to 2.2 ± 0.7 resistance sessions during the in-season. Resistance training loads and duration are presented in Table 2.

Insert Table 2 about here

Saliva Analysis

Saliva samples were analysed in triplicate for testosterone and cortisol using radioimmunoassay (RIA) methods (5). Briefly, standards from serum diagnostic kits (Diagnostic Systems Laboratories, USA) were diluted in phosphate buffer saline (Sigma P4417) to cover the expected ranges of 0-18.56 and 0-1.73 nmol·L^{-1}, for cortisol and testosterone respectively. Saliva sample sizes of 50 and 100μl were used for cortisol and testosterone respectively. Antibodies were diluted with a phosphate buffered saline solution containing 0.05% bovine serum albumin. Kit standards were diluted so that ~50% binding was achieved with respect to the total counts. Detection limits for the assays were 0.4 and 0.004 nmol·L^{-1} for cortisol and testosterone respectively. The intra- and inter-assay CV were 1.58 and 16.48 % for cortisol, and 1.61 and 12.75 % for testosterone.

Statistical Analyses

The analysis was performed in three stages. First, the values of all measures were characterised via a straightforward reliability model, which consisted of a fixed effect for the mean value at each assessment and random effects to characterize typical variation within an athlete from assessment to assessment and between athletes in any one assessment (Table 3). Secondly, to show changes in mean values, a straight line was fitted to each athlete's values with assessment date as the predictor measure; the model provided the predicted change between the first and last assessment dates averaged over all athletes (Table 4). Finally, to investigate the ability of each measure to predict changes in performance, a similar model was used with each measure as the predictor measure (Table 5). All analyses were performed using the mixed procedure (Proc Mixed) in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC).

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

Standardised changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-athlete standard deviation. Standardised changes of <0.20, <0.60, <1.2, <2.0 and >2.0 were interpreted as trivial, small, moderate, large and very large effects, respectively. To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

The interclass correlation (ICC) and coefficient of variation (CV) for bench throw and jump squat activities were 0.900 and 5.0%, and 0.904 and 4.8% respectively. Validity of the Gymaware™ optical encoder has been previously reported elsewhere (11).

RESULTS

Throughout the competitive season the overall mean score for bench press and box squat 1RM strength was 141 kg and 194 kg respectively (Table 3). A trivial decrease was observed in bench press strength (-1.7 kg), while a small increase in box squat strength (16.0 kg) was observed from the start to the end of the 13 week competitive season (Table 4).

Overall mean scores for bench throw and jump squat were 1150 watts (W) and 5190 W respectively (Table 3). A trivial decrease was observed in bench throw power (-40 W), while a small decrease in jump squat power (-175 W) occurred over the competitive season (Table 4).

The overall means for resting testosterone, cortisol and the testosterone to cortisol ratio (T/C ratio) for the competitive season were 99 $pg \cdot mL^{-1}$, 2.0 $ng \cdot mL^{-1}$, and 50 (units) respectively (Table 3). Moderate increases in testosterone and cortisol were observed over the 13 weeks, while a small decrease occurred in the T/C ratio (Table 4). Trivial changes in ratings of perceived soreness and tiredness were also observed from the start to the end of the competition (Table 4). Individual differences over the competitive season were mostly trivial or inestimable and therefore not reported in Table 4.

Insert Table 3 about here

Insert Table 4 about here

The analysis of the relationship between predictor and dependent measures revealed mostly trivial but unclear findings (Table 5). However, some small to moderate relationships were observed. When examining relationships one must note the (two) large within standard deviations necessary to allow for the performance enhancement in the dependent measure e.g. to improve jump squat strength by 2.3% an athlete would need to increase T/C ratio by 320%.

Insert Table 5 about here

DISCUSSION

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

Similar to previous studies, strength was maintained (-1.7 kg; -1.2%) in the upper-body, and improved (16.0 kg; 8.5%) in the lower-body throughout the competitive season even with a reduction of resistance training volume (2, 10, 35). Numerous factors are reported to influence strength adaptations to resistance training (2, 26, 34). Baker (2) reported that upper-body strength in college aged athletes could be increased (4.9%), but only maintained in professional athletes during a competitive season. It has been suggested that lack of strength gains in professional athletes is likely due to their greater strength training background, which may reduce the scope for further strength improvements (2, 4). It is also likely that the variation in training modality that occurs in football codes influences adaptation. Specifically, the athletes in this study performed combinations of skill, tactical, strength, power, speed and aerobic training sessions. As a result of this wide variety of different training stimuli performed and the need for recovery, some of these physical qualities may only be trained once a week during some points of the in-season phase. Such combinations of training stimuli may also produce numerous challenges to the body's adaptive processes (26).

In the present study the lack of improvement in upper-body strength (-1.2%) throughout the competitive season may have been due to a decreased resistance training volume (1.3 and 2.2 sessions per week, Backs and Forwards respectively). Indeed a meta-analytic review of strength training protocols (34) concluded that trained athletes can improve strength by performing a strength training session of eight sets per muscle group two times per week. This supports findings from the current study as although the forwards did perform on average 2.2 resistance sessions per week in the competitive season, only one of these sessions had a specific upper-body strength focus, thus preventing athletes from achieving the possible training volume required to increase upper-body strength.

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

The results of the present study are consistent with previous literature in that a small decrease in lower-body power (-175 W; -3.3%) was observed throughout a competitive season, while power in the upper-body was maintained (-40 W; -3.4%) (2, 18, 19, 35). Unfortunately, limited data exists that quantify changes in power in elite athletes over the course of a training or competition phase. Similar to the data reported earlier on strength, the changes observed for power may be due to numerous factors including training volume and stimulus, inadequate recovery, and training status (2, 4, 18, 26).

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

Decreases in power may also be due to a compromised physical development caused by residual fatigue induced by limited recovery time between successive matches and training sessions (18). Repeated residual fatigue caused by weekly competition and training stress without adequate recovery, may lead to athletes being in an ‘over-reached’ state resulting in a short-term decrement in performance (22).

It has been previously shown that performance gains are reduced in elite athletes with a high training status (2, 4). For example, Baker and Newton (4) assessed power in sub-elite rugby league athletes over a four year period and reported that initial increases in power diminished as athletes became stronger (and progressed to an elite level). This was eventually followed by a cessation of power improvements by the end of the second year. The lack of improvement may suggest that elite level athletes need a greater volume of training and/or perhaps a more specific stimulus to enhance power production. Therefore the lack of improvement in upper-body and lower-body power may have been due to a combined effect of 1) inadequate recovery between matches, 2) insufficient training stimulus (intensity and frequency) and, 3) athlete training status.

There was large within-subject variation in hormonal data over the competitive season (Table 3). However moderate increases in testosterone (54%) and cortisol (94%) were observed throughout the season. A small reduction (22%) in the testosterone to cortisol ratio (T/C ratio) also occurred due to the larger increase in cortisol over the competitive season. There is a limited body of knowledge regarding hormonal changes in athletes over competitive seasons. Nonetheless, potential mechanisms for the increase in testosterone and cortisol observed may include such factors as deflated pre-test values, training volume, recovery, and psychological variables (14, 15, 25, 29, 36).

Increases in testosterone observed throughout the season may have been due to a diminished resting level of testosterone on the first testing occasion. During periods of heavy or high volume training, levels of testosterone can be significantly reduced (25, 36). It may be possible in the current study that during the initial testing session athletes may have been experiencing a reduced testosterone level as a result of the prior intense seven week pre-season training phase.

The increase in testosterone throughout the 13 week season may also be due to a ‘recovery’ of the endocrine system caused by the reduction of training load throughout the season (for training loads see Table 1). Increases in testosterone have previously been reported following an 11 week competitive soccer season (25). Kraemer and colleagues (25) suggested that the recovery / increase in testosterone reflected the dramatic reduction of training stress throughout the season. Additionally, increases observed in testosterone may also be in part due to psycho-physiological mechanisms. The participants in the current study lost their first five games of the season, but then went on to win seven of their final eight games. Etias (15) reported that humans undergo specific endocrine changes in response to victory or defeat and that the victor responds with a greater increase in testosterone than the loser.

Periods of intense training have previously been reported to increase levels of cortisol (24, 25). In contrast to testosterone, one may speculate that the large volume of training performed in the pre-season in the current study may have lead to an increased cortisol level at the initial testing session. Interestingly, there was a continual increase in cortisol throughout the competitive season even though there was a reduction in training volume. Although somewhat speculative, this may have been caused by the difference in training intensity between the pre-season and competitive season phases. By reducing the training volume throughout the competitive season athletes may be less effected by fatigue and are able to train at a higher intensities (for shorter periods). The greater intensities of training during the competitive season may place additional physical stress on the athlete in comparison to the high volume, moderate intensity pre-season training. Furthermore, when comparing pre-season and competitive season phases, there was a greater amount of physical impact and contact throughout the competitive season in comparison to the pre-season training. This higher intensity of training coupled with the added volume of physical impact may have added to the increase in cortisol observed.

Increases in cortisol following a single game of rugby union have been previously reported (14). The authors concluded that a minimum of five days rest (or light training) was needed to adequately recover from the demands of the game (14, 21). The participants in the current study were generally performing intense and physically demanding training by the second or third day following the game. Therefore based on the findings from Elloumi and colleagues (14), the participants may not have recovered fully. This inadequate recovery following games in addition to the training demands and successive weekly competition may have caused a gradual increase in cortisol levels over the competitive season.

Psychological factors may also add to the increased level of cortisol. Previous investigations have reported a statistically larger increase in cortisol following competition than in simulated competition or training (23, 33) Additionally, increased cortisol levels have been reported prior to competition in instances where the perceived importance of the outcome is greater (29). Due to the professional nature of the sport the perceived importance of the outcome is regularly high. Athletes also have additional pressure to perform, as poor performance can lead to non-selection, which can ultimately lead to a loss of employment. This additional pressure to perform can increase the level of stress. Stressful situations have been reported to be one of the best known triggers for a increase in cortisol levels (1).

The statistical analysis used in the current investigation allowed for a better understanding of not cause and effect, but rather *change* and effect between measures. It should be noted that strength and power measures were not measured at the same time (24-48 hours apart) due to structure of the training week. The results from the present investigation indicated that upper-body power may be improved by increasing upper-body strength. The relationship supports the contention that increases in power can be attained through increased strength (3). However similar findings were not reciprocated in the lower-body in which a trivial relationship between changes in box squat and jump squat was observed. The differences between the relationships of the upper-body and lower-body may be due to the differences in the kinematics of the movements. The bench press and bench throw both employ the stretch shortening cycle (SSC); only the jump squat exercise uses the SSC in the lower-body exercises assessed. The box squat differs in that at the end of the eccentric phase there is a pause (sitting on the box) before the commencement of the concentric phase, minimising or eliminating the SSC. These differences may potentially explain the disparity in the relationships observed between the upper-body and lower-body. Findings from the present study also suggest that increases in strength can be obtained through increasing power output, albeit to a much lesser extent. Caution should be taken when interpreting these findings, as although some small to moderate relationships were observed, the actual observed change in performance measures over the competitive season were much smaller than the within standard deviations needed to obtain the predicted changes in performance. Therefore many of the relationships would be near unobtainable in elite athletes over a competitive season. For example to increase jump squat power by 2.6% you would need to increase box squat strength by 18%, whereas the observed change in box squat over the competitive season was only 8.5%.

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

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

PRACTICAL APPLICATIONS

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

REFERENCES

1. ANDREWS, J, WADIWALLA, M, JUSTER, RP, LORD, C, LUPIEN, SJ, and PRUESSNER, JC. Effects of manipulating the amount of social-evaluative threat on the cortisol stress response in young healthy men. *Behav Neurosci* 121:871-876. 2007.
2. BAKER, D. The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *J Strength Cond Res* 15:172-177. 2001.
3. BAKER, D and NEWTON, RU. Methods to increase the effectiveness of maximal power training for the upper body. *Strength Cond J* 27:24. 2005.
4. BAKER, DG and NEWTON, RU. Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes. *J Strength Cond Res* 20:541-546. 2006.
5. BEAVEN, CM, HOPKINS, WG, HANSEN, KT, WOOD, MR, CRONIN, JB, and LOWE, TE. Dose effect of caffeine on testosterone and cortisol responses to resistance exercise. *Int J Sport Nutr Exerc Metabol* 18:131-141. 2008.
6. BORG, G. A category scale with ratio properties for intermodal and interindividual comparisons. In: H.G. Geissler and P. Petzold, eds. *Psychophysical judgement and the process of perception*. Berlin: VEB Deutscher Verlag der Wissenschaften, 1982. pp. 25-34.
7. CARDINALE, M and STONE, MH. Is testosterone influencing explosive performance? *J Strength Cond Res* 20:103-107. 2006.
8. CLEAK, MJ and ESTON, RG. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *Brit J Sport Med* 26:267-272. 1992.
9. DEUTSCH, MU, KEARNEY, GA, and REHRER, NJ. Time motion analysis of professional rugby union players during match-play. *J Sport Sci* 25:461-472. 2007.
10. DOS REMEDIOS, KA, DOS REMEDIOS, RL, LOY, SF, HOLLAND, GJ, VINCENT, WJ, CONELY, LM, and HING, M. Physiological and field test performance changes of community college football players over a season. *J Strength Cond Res* 9:211-215. 1995.
11. DRINKWATER, EJ, GALNA, B, MCKENNA, MJ, HUNT, PH, and PYNE, DB. Validation of an optical encoder during free weight resistance movements and analysis of bench press sticking point power during fatigue. *J Strength Cond Res* 21:510-517. 2007.

12. DUGAN, EL, DOYLE, TLA, HUMPHRIES, B, HASSON, CJ, and NEWTON, RU. Determining the optimal load for jump squats: A review of methods and calculations. *J Strength Cond Res* 18:668-674. 2004.
13. DUTHIE, G, PYNE, D, and HOOPER, S. Applied physiology and game analysis of rugby union. *Sport Med* 33:973-991. 2003.
14. ELLOUMI, M, MASO, F, MICHAUX, O, ROBERT, A, and LAC, G. Behaviour of saliva cortisol [C], testosterone [T] and the T/C ratio during a rugby match and during the post-competition recovery days. *Eur J Appl Physiol* 90:23-28. 2003.
15. ETIAS, M. Serum cortisol, testosterone, and testosterone-binding globulin responses to competitive fighting in human males. *Aggressive Behav* 7:215-224. 1981.
16. FLORINI, JR. Effects of testosterone on qualitative pattern of protein synthesis in skeletal muscle. *Biochemistry* 9:909-912. 1970.
17. FLORINI, JR. Hormonal control of muscle cell growth. *J Anim Sci* 61:21-37. 1985.
18. GABBETT, TJ. Changes in physiological and anthropometric characteristics of rugby league players during a competitive season
J Strength Cond Res 19:400-408. 2005.
19. GABBETT, TJ. Physiological and anthropometric characteristics of junior rugby league players over a competitive season. *J Strength Cond Res* 19:764-771. 2005.
20. GABBETT, TJ. Science of rugby league football: A review. *J Sport Sci* 23:961-976. 2005.
21. GILL, ND, BEAVEN, CM, and COOK, C. Effectiveness of post-match recovery strategies in rugby players. *Brit J Sport Med* 40:260-263. 2006.
22. HALSON, SL and JEUKENDRUP, AE. Does overtraining exist?: An analysis of overreaching and overtraining research. *Sport Med* 34:967-981. 2004.
23. HANEISHI, K, FRY, AC, MOORE, CA, SCHILLING, BK, YUHUA, L, and FRY, MD. Cortisol and stress responses during a game and practice in female collegiate soccer players. *J Strength Cond Res* 21:583-588. 2007.
24. KIRWAN, JP, COSTILL, DL, FLYNN, MG, MITCHELL, JB, FINK, WJ, NEUFER, PD, and HOUMARD, JA. Physiological responses to successive days of intense training in competitive swimmers. *Med Sci Sports Exerc* 20:255-259. 1988.
25. KRAEMER, WJ, FRENCH, DN, PAXTON, NJ, HÃKKINEN, K, VOLEK, JS, SEBASTIANELLI, WJ, PUTUKIAN, M, NEWTON, RU, RUBIN, MR, GÃMEZ, AL, VESCOVI, JD, RATAMESS, NA, FLECK, SJ, LYNCH, JM, and KNUTTGEN, HG. Changes in exercise performance and hormonal concentrations over a big ten soccer season in starters and nonstarters. *J Strength Cond Res* 18:121-128. 2004.
26. KRAEMER, WJ, PATTON, JF, GORDON, SE, HARMAN, EA, DESCHENES, MR, REYNOLDS, K, NEWTON, RU, TRIPLETT, NT, and DZIADOS, JE. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J Appl Physiol* 78:976-989. 1995.
27. LANDER, J. Maximums based on reps. *Natl Str Cond Assoc* 6:60-61. 1985.
28. LESUER, DA, MCCORMICK, JH, MAYHEW, JL, WASSERSTEIN, RL, and ARNOLD, MD. The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. *J Strength Cond Res* 11:211-213. 1997.
29. MCKAY, JM, SELIG, SE, CARLSON, JS, and MORRIS, T. Psychophysiological stress in elite golfers during practice and competition. *Aust J Sci Med Sport* 29:55-61. 1997.

30. MEIR, R, COLLA, P, and MILLIGAN, C. Impact of the 10-meter rule change on professional rugby league: Implications for training. *Strength Cond J* 23:42-46. 2001.
31. NEWTON, RU, KRAEMER, WJ, HAKKINEN, K, HUMPHRIES, BJ, and MURPHY, AJ. Kinematics, kinetics, and muscle activation during explosive upper body movements. *J Appl Biomech* 12:31-43. 1996.
32. OBMINSKI, Z and STUPNICKI, R. Comparison of the testosterone-to-cortisol ratio values obtained from hormonal assays in saliva and serum. *J Sports Med Phys Fit* 37:50-55. 1997.
33. PASSELERGUE, P, ROBERT, A, and LAC, G. Salivary cortisol and testosterone variations during an official and a simulated weight-lifting competition. *Int J Sport Med* 16:298-303. 1995.
34. PETERSON, MD, RHEA, MR, and ALVAR, BA. Applications of the dose-response for muscular strength development: A review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res* 19:950-958. 2005.
35. SCHNEIDER, V, ARNOLD, B, MARTIN, K, BELL, D, and CROCKER, P. Detraining effects in college football players during the competitive season. *J Strength Cond Res* 12:42-45. 1998.
36. VERVOORN, C, QUIST, AM, VERMULST, LJ, ERICH, WB, DE VRIES, WR, and THIJSSEN, JH. The behaviour of the plasma free testosterone/cortisol ratio during a season of elite rowing training. *Int J Sport Med* 12:257-263. 1991.
37. VINING, RF and MCGINLEY, RA. The measurement of hormones in saliva: possibilities and pitfalls. *J Steriod Biochem* 27:81-94. 1987.
38. VINING, RF, MCGINLEY, RA, and SYMONS, RG. Hormones in saliva: Mode of entry and consequent implications for clinical interpretation. *Clinical Chemistry* 29:1752-1756. 1983.

ACKNOWLEDGEMENTS

This study was funded by the Waikato Rugby Union and the Tertiary Education Commission.

The results of the present study do not constitute endorsement by the NSCA.

TABLE 1. An example training week during a competition training phase in professional rugby union athletes.

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

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

Team Conditioning / Recovery: Pattern work and games.

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

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

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

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

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

Power: Jump squat, power clean, push press, bench throw

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

TABLE 2. Average weekly training load and training duration (mean ± SD) of elite rugby union athletes during the pre-season and in-season competitive phases.

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

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

TABLE 3. Values of performance, hormonal and psychological measures for all testing sessions over a 13 week competitive season of concurrent training in elite level rugby union athletes.

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

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

TABLE 4. Linearised changes in performance, hormonal and psychological measures over a competitive season of concurrent training in elite level rugby union athletes.

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

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

TABLE 5. Change in a dependent measure associated on average with two within-subject SD of change in a predictor measure in well trained elite rugby union athletes over a competitive season.

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

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