Title: To jump or cycle? Monitoring neuromuscular function in rugby union players.

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Purpose: The purpose of this study was to evaluate changes in performance of a 6-second cycle ergometer test (CET) and countermovement jump (CMJ) during a 6-week training block in professional rugby union players. **Methods:** Twelve young professional rugby union players performed two CET and CMJ on the first and fourth morning of every week prior to the commencement of daily training during a 6-week training block. Standardised changes in the highest score of two CET and CMJ efforts were assessed using linear mixed modelling and magnitude-based inferences. **Results:** Following increases in training load during weeks three to five, *moderate* decreases in CMJ peak and mean power, and *small* decreases in flight-time were observed during weeks five and six that were *very likely* to *almost certainly* greater than the smallest worthwhile change, suggesting neuromuscular fatigue. However, only *small* decreases, *possibly* greater than the smallest worthwhile change, were observed in CET peak power. Changes in CMJ peak and mean power, were *moderately* greater than in CET peak power during this period, while the difference between flight-time and CET peak power was *small*. **Conclusion:** The greater weekly changes in CMJ metrics in comparison to CET may indicate differences in the capacities of these tests to measure training induced lower-body neuromuscular fatigue in rugby union players. However, future research is needed to ascertain the specific modes of training that elicit changes in CMJ and CET in order to determine the efficacy of each test for monitoring neuromuscular function in rugby union players.

Key Words: countermovement jump, cycle ergometer test, fatigue, performance, team-sport.

INTRODUCTION

The high-intensity activities and impacts sustained during collision-sport match-play result in acute fatigue in the days following competition.[1-3] One of the most common manifestations of post-match fatigue is an acute reduction in neuromuscular function, represented by decrements in various countermovement jump (CMJ) variables that last between 24 and 72 hrs.[1-5] Common CMJ metrics that have shown sensitivity to match-induced fatigue include flight-time and power (mean and peak).[1-5] Such metrics have also shown sensitivity to increases in training load in collision-sport athletes during concentrated blocks of high-volume training.[6,7,8] Based on these findings, alongside the ease of implementation,[9] high reliability[10,11] and the minimal fatiguing effect of performance,[9] the regular monitoring of neuromuscular function using a CMJ has become common-place in high-performance sport.[12]

However, recently the cycle ergometer test (CET) has been proposed as an alternative to the CMJ for monitoring neuromuscular function in response to training and match-play.[13,14] The advantage of a CET, in contrast to the CMJ, is that it is a non-weight bearing activity that involves concentric-only muscle contraction.[15] Such a test may be favourable in the days post-match where players suffer from heightened muscle soreness[2,16] and may be reluctant to perform a maximal CMJ.[13] However, the ecological validity of measuring concentric only muscle actions versus stretch-shortening cycle (SSC) activities has been called into question when attempting to quantify locomotion-induced neuromuscular fatigue.[17] Nevertheless during accelerations over short distances, there is little SSC involvement, with propulsive forces coming primarily from concentric muscle actions.[18] Such short accelerations occur frequently during team-sport match-play,[19] and therefore the use of a concentric only test to assess neuromuscular function in such cohorts may be of use.

The sensitivity of a CET to post-match fatigue has been brought to light in a recent study by Wehbe et al.,[13] who examined changes in CET and CMJ in response to match-play in elite junior Australian Rules Football players. The authors observed substantial decreases in peak power during a 6-second maximal sprint test 1 hr and 24 hr following competition. Substantial decreases were also observed in CMJ peak power, mean power and flight-time at these time-points. However, although the CET appeared to be sensitive to fatigue in the first 24 hr post-match, substantial decrements in CMJ flight-time remained at 48 hr, beyond the recovery time of CET peak power. This would suggest that the CET failed to capture the full extent of post-match neuromuscular fatigue, or as the authors proposed, the CET was assessing a different component of neuromuscular function in comparison to the CMJ (i.e. concentric force production versus the stretch shortening cycle).[13]

Changes in a CET have also been reported over the course of a competitive season in division I collegiate soccer players using an inertial loading method.[13] McLean et al[14] observed small to large decreases in CET performance during the latter stages of the season in players who were subjected to greater training and match loads. However, a CMJ was not included in the study, preventing a comparison between the two measures to be made. Currently no study has compared the changes in CET and CMJ over an extended period of training (i.e., 6 weeks) in collision-sport athletes. Such research would provide an insight into the sensitivity of these measures for detecting neuromuscular fatigue during intensified or long periods of training. Therefore the aim of the present study was to compare the changes in CMJ and CET during a 6-week training period in professional rugby union players.

METHODS

Subjects

Twelve young professional rugby union players (age 19.8±1.1 years, body mass 96.8±13.1 kg, height 188.5±7.9 cm) were recruited from a professional rugby union club. Each subject was a member of the Senior Academy, a transitional squad from the Junior Academy (under-18's) to the senior squad, consisting of 18-23 year old players. Players typically engaged in 8 individual training sessions across 5 days per week, including resistance training, rugby skills and conditioning (see Table 1). Ethics approval was granted by the university ethics board and written informed consent was acquired from all subjects.

Design

A within-group repeated measures design was used to examine the magnitude of change in lower-body neuromuscular function using a CET and CMJ during an 6-week training cycle in young professional rugby union players. Subjects performed 2 maximal CMJ followed by 2 maximal CET sprints on the first and fourth morning of each week following a rest day (Table 1). The CMJ and CET were also measured following a week off (week 8), to assess the recovery of neuromuscular function.

INSERT TABLE 1 HERE

Countermovement Jump

CMJs were performed on a portable force plate (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) that measured ground reaction forces at 600Hz, which was attached to a laptop with appropriate software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia). It has been recommended that a minimum sampling frequency of 200Hz be used when measuring CMJ performance.[20] A standardised 2-minute warm-up consisting of dynamic stretching was performed prior to the test (walking lunges, squats, heel flicks, high knees, skipping, legs swings and 3 practice submaximal CMJs). Following the warm-up, subjects performed 2 maximal CMJs with 1-minute rest between each effort.[10] The highest score achieved from the 2 jumps was used in the final analysis.[9] Subjects began standing on the platform with knees extended and feet in a position of their choice. Subjects were instructed to keep their hands on their hips and jump as a high as possible. The depth of the countermovement was at the discretion of the subject, with no instruction on countermovement depth given. In order to compare with previous literature investigating neuromuscular fatigue, CMJ peak power, mean power and flight-time were included in the analysis. All metrics have shown acceptable reliability and sensitivity in this cohort (coefficient of variation [CV] < 5%, CV < SWC).[10]

Cycle Ergometer Test

The 6-second CET involved 2 maximal 6-second sprints on a Wattbike ergometer (Wattbike Pro, Nottingham UK). The resistance was set to 4 and 10 for the magnet- and air-braked resistance respectively.[13] Using a goniometer, each subject's saddle height was standardised using the manufacturer's recommendations to approximately 25° of knee bend when the crank was perpendicular to the seat post. Saddle heights were recorded for use on subsequent testing days. Handlebar height was set to the same height as the saddle, as recommended by the manufacturer's guidelines. When the subject was sitting comfortably on the bike, instructions were given to pedal as fast as possible until they were given a 'stop' command. Each test was initiated from a static position with the dominant leg initiating the first pedal stroke. The initiation of pedalling started a 6-second timer during which peak power was recorded by the Wattbike monitor. Following the test, peak power was read from the monitor screen and recorded by the tester. No verbal encouragement was given during the test. A total of 2 maximal sprints were performed with a 1-minute active recovery consisting of a self-selected 'gentle' cadence at resistance set to level 1.[13] The highest score achieved from the 2 sprints was used in the final analysis. Between-day reliability of the test for peak power was assessed during the first week of pre-season when training load was minimal. The best-of 2 sprints achieved a between-day CV of 3.7% and a SWC of 3.5%.

Training Load

Training load was quantified using the session rating of perceived exertion method (sRPE)[21] on a modified Borg scale within 15-30 minutes of the end of each session. This rating was then multiplied by training duration to give a training load in arbitrary units (AU).[21] Training sessions were categorised into resistance training, off-feet conditioning and field training. Resistance training consisted of a concurrent programme of power (3 set of 4-6 reps; squat jump, power clean, push-press, speed bench) strength (3-6 sets of 3-6 RM) and hypertrophy (3-6 sets of 6-12 RM) exercises (squat, deadlift, split-squat, bench press, bench row, overhead press, chin-up). Off-feet conditioning consisted of cycle ergometer interval training (Wattbike Pro, Nottingham UK) based on subjects' average speed achieved during a 3-minute test. Field training consisted of rugby conditioned-games interspersed with intermittent running based on subjects' individual 30-15 intermittent fitness test score. Training loads were summated to provide an overall weekly training load.

Statistical Analyses

Data were analysed using mixed linear modelling in SPSS (version 22). Each dependent variable was log transformed to reduce non-uniformity of error that is typically associated with athletic performance measures.[22] In the current study, 'day' and 'week' were treated as fixed effects while subjects were treated as random effects. As the effect of 'day; was *likely* to *very likely* trivial for all variables (ES < 0.2), only the effect of 'week' was included in the final analysis, which averaged both 'day' values per week. Weekly changes in CET peak power and CMJ variables, and differences in weekly changes between CET peak power and CMJ variables were assessed using effect sizes and standardised differences respectively. These were rated as *trivial* (<0.2), *small* (0.2-0.59), *medium* (0.6-0.19) or *large* (1.2-1.99).[22] Magnitude based-inferences were used to assess for practical significance.[22] The threshold for a change to be considered practically important (the smallest worthwhile change; SWC) was set at 0.2 x between subject standard deviation (SD), based on Cohen's d effect size (ES) principle. The probability that the magnitude of change was greater than the SWC was rated as <0.5%, *almost certainly not*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost certainly*.[22] Where the 90% Confidence Interval (CI) crossed both the upper and lower boundaries of the SWC (ES±0.2), the magnitude of change was described as unclear.[22]

RESULTS

Total and weekly distribution of training loads across each training category (i.e., resistance training, off-feet conditioning and field training), are presented in Figure 1. The mean weekly training load was 1891±519 AU. The greatest mean weekly training loads came from weight training (859±159 AU) and field training (806±393 AU) while the lowest mean weekly training load was accumulated during off-feet conditioning (231±191 AU).

INSERT FIGURE 1 HERE

Weekly changes in CET peak power and CMJ variables are presented in Figure 2. Average baseline CET peak power was 1423 ± 141 W. CET peak power (raw change ±90% confidence intervals, *effect size*) was *very likely* decreased during week 2 (-55~~.52~~ ±29~~.49~~ W, *small*), while only *possibly* decreased during weeks 3 (-26~~.85~~ ±28~~.66~~ W, *small*), 4 (-21~~.64~~ ±28~~.85~~ W, *trivial*), 5 (-22~~.76~~ ±28~~.66~~ W, *small*) and 6 (-24~~.88~~ ±30~~.82~~ W, *small*). Average baseline CMJ peak power was 5395 ± 823 W. Decreases in CMJ peak power were *very likely* during week 2 (-760 ±405 W, *moderate*), *likely* and *very likely* during weeks 3 (-389 ±394 W, *small*) and 4 (-455 ±397 W, *small*), *almost certainly* during week 5 (-1035 ±394 W, *moderate*) and 6 (-1007 ±423 W, *moderate*), while *very likely* during week 8 (-891 ±460 W, *moderate*). Decreases in CMJ mean power from an average baseline of 1455 ± 193 W were *very likely* during week 2 (-148±94 W, *moderate*), *possibly* decreased during weeks 3 (-49 ±91 W, *small*) and 4 (-68 ±92 W, *small*) and *very likely* to *almost certainly* decreased during week 5 (-222 ±91 W, *moderate*), 6 (-194 ±98 W, *moderate*) and 8 (-160 ±109 W, *moderate*). CMJ flight-time average baseline was 0.596 ± 0.038 s. CMJ flight-time was *very likely* decreased during weeks 2 (-0.015 ±0.007 s, small), 4 (-0.017 ±0.007 s, *small*), 5 (-0.021 ±0.007 s, *small*) and 6 (-0.020 ±0.007 s, *small*), while *possibly* decreased during weeks 3 (-0.009 ±0.007 s, *small*) and 8 (-0.009 ±0.008 s, *small*).

INSERT FIGURE 2

Weekly differences between CET peak power and CMJ variables are presented in Figure 3. Differences in CMJ peak power were *possibly* greater (ES=0.31-0.35, *small*) during week 2 and 4, and *very likely* greater (ES=0.89-1.07, *moderate*) during weeks 5, 6 and 8 than CET peak power. Differences in CMJ mean power were *unclear* between weeks 2 to 4, while *likely* to *very likely* decreased to a greater extent (ES=0.72-0.87, *moderate*) than CET peak power during weeks 5, 6 and 8. Decreases in CMJ flight-time were *unclear during weeks 2 and 3, while possibly* greater (ES=0.22-0.33, *small*) during weeks 4, 5, 6 and 8.

INSERT FIGURE 3

Weekly differences between CMJ variables are presented in Figure 4. Differences between CMJ peak and mean power were *unclear* for all time-points. In comparison to CMJ flight-time, CMJ peak and mean power demonstrated *likely* greater changes during week 2 (ES = 0.46 ±0.47 and 0.34 ±0.48 respectively, *small*), unclear differences during weeks 3 and 4 and *likely* greater differences during weeks 5 (ES = 0.61 ±0.46, *moderate* and 0.54 ±0.47, *small* respectively) and 6 (ES = 0.6 ±0.49, *moderate* and 0.43 ±0.5, *small* respectively). During week 8 changes in CMJ peak power were *very likely* greater than flight-time (ES = 0.74 ±0.54, *moderate*) while changes between CMJ mean power were *likely* greater (ES = 0.54 ±0.56, *small*).

INSERT FIGURE 4 HERE

DISCUSSION

This study examined the magnitude of changes in, and compared the difference in changes between CET peak power and CMJ variables during a 6-week training block in professional rugby union players. *Moderate* decreases that were *very likely* to *almost certainly* greater than the SWC were observed in CMJ peak and mean power in the latter weeks suggesting neuromuscular fatigue. However, only *small* decreases, *possibly* greater than the SWC were observed in CET. During this training period, decreases in CMJ were *moderately* larger than in CET, which may indicate differences in the capacities of these tests to measure training induced lower-body neuromuscular fatigue in rugby union players.

The mean training load observed in the current study (1891±519 AU) was lower than the training load reported during preseason in other UK professional rugby union clubs for senior players (2175±380 AU).[23] This is likely the result of the difference in training content between a 'senior academy' and 'first team' squad. Although subjects in this study engaged in some first team field sessions, the overall training exposure was determined as appropriate for young professional rugby union players by the coaching team. Nevertheless, the findings demonstrate that all CMJ metrics decreased following the period during which players were exposed to the highest training volumes (weeks 3-5; 2253±507, 2318±482, 2016±386 AU) which were more reflective of the training load reported by Cross et al.[23] The decreases in CMJ metrics observed following this period (weeks 5 and 6) would suggest that the subjects began to exhibit substantial lower-body neuromuscular fatigue, although this may have been an intention of the coaching staff to overreach players during this training period. Interestingly, during this period (weeks 5 and 6), the largest differences were observed between the CET and the CMJ, suggesting the inability of the CET peak power to detect neuromuscular fatigue following high training loads. The differences between CET peak power and CMJ metrics are shown in Figure 2, where is can be seen that both CMJ peak power and mean power had *moderately* greater decreases during this period when compared to CET peak power.

It must be noted that CMJ flight-time did not appear as sensitive to the increase in training load in comparison to CMJ peak or mean power. From Figure 3 it can be seen that flight-time differed by only a *small* magnitude to CET peak power during weeks 5, 6 and 8, while *moderate* differences were observed between CMJ power measures and CET peak power. Furthermore, Figure 4 demonstrates *small* to *moderate* differences between CMJ flight-time and CMJ power measures during these weeks. Similarly, McLean et al [24] observed differences in changes in CMJ metrics when monitoring professional rugby league players during the in-season. The authors observed acute changes in CMJ flight-time 24 hours post-match, while reductions in CMJ relative power were more pronounced during between-match microcycles with high training volumes. It has been suggested that the outcomes of a CMJ, the flight-time and height, are the result of many neuromuscular factors,[11] some of which may alter to a greater extent than the CMJ outcome itself in the presence of fatigue.[24] In this case it would appear that both peak and mean power were more sensitive to increased training loads than the CMJ outcome measure of flight-time, and thus may represent more sensitive metrics for monitoring lower-body neuromuscular fatigue in this cohort. However, future research is needed to clarify this.

The difference in the magnitude of change between CET peak power and CMJ peak power and mean power may be explained by the particular muscle actions performed in each test, and the specificity of each test to the particular locomotive demands of rugby union. The CET relies primarily on concentric muscle action[13,15] whereas the CMJ involves a SSC.[25] The locomotive demands of rugby union training and match-play primarily consist of walking, jogging or striding,[26] all of which utilise the SSC.[17,27] As previously mentioned, increases in training volume during weeks 3 to 5 in the present study led to greater decreases in CMJ metrics than in CET peak power. From Figure 1 it can be seen that the primary contributor to the increase in training volume during this period was field-based training. It is therefore possible that the specificity of the CMJ was greater in detecting locomotive-induced neuromuscular fatigue than CET peak power.

It has previously been argued that a concentric-only test of neuromuscular function may have application for monitoring neuromuscular fatigue in team-sport athletes.[13] This is because such sports involve repetitive short accelerations, which rely primarily on concentric muscle performance.[18] However, Wehbe et al[13] observed substantial decreases in CMJ-flight time that outlasted CET peak power in elite academy AFL players in response to a competitive match. Although flight-time also demonstrated greater changes than CET peak power in the present study, in contrast to the work by Wehbe et al (2015), CMJ peak and mean power demonstrated greater reductions than CMJ flight-time. This may be the result of the difference in study design as Wehbe et al (2015) observed acute changes in response to a competitive match, while observations in the present study were made over the course of a 6-week training cycle. Unlike Australian Rules football players, flight-time appears less sensitive to post-match fatigue in rugby union players.[1] The differences may also be due to the fact that Australian rules players have different anthropometry, physical characteristics, are exposed to different training regimes[28] and activity patterns during match play.[29] Nevertheless, collectively these results demonstrate that CMJ metrics may be more useful for monitoring lower-body neuromuscular function than CET peak power, although the sensitivity of particular CMJ metrics may be population specific. Further research is needed to clarify this point.

In addition to the greater changes in CMJ in comparison to the CET, performance in short sprint distances (0-10 m) has also been shown to recover more quickly than CMJ performance following field-based training.[24] Unfortunately a short distant sprint was not included in the current study. Therefore future research is needed to investigate if changes in such a performance test are similar to those of the CET. Nonetheless, these findings, along with the findings of the present study suggest that performance measures primarily involving concentric-only muscle actions may not be as sensitive to field-sport locomotion-induced neuromuscular fatigue in comparison to a test the involves an SSC.[17,24]

In the present study, subjects received a rest week following 6 weeks of training. Following the rest week, CET had recovered to base-line levels (Figure 1). In contrast, CMJ peak and mean power still demonstrated *moderate* decreases that were *very likely* greater than the SWC (Figure 2), and *moderately* lower than the CET (Figure 3). According to the fitness fatigue model, it is only when the fatigue-inducing training stimulus has been removed or reduced, that improvements in fitness can be observed.[30] It is possible that the rest week during week 7 was not long enough to dissipate the training-induced fatigue and restore CMJ peak and mean power, thus explaining the suppression of these CMJ metrics following the rest week. In contrast, as CET demonstrated only *small* decreases that were *possibly* greater than the SWC prior to the rest week, one week of rest was sufficient to restore CET performance. It is unclear from the findings of this study what time period is required to fully restore neuromuscular function, although this one week period appeared insufficient, which should be a consideration for practitioners working with similar cohorts of athletes.

A limitation of the present study is the lack of objective measures of training load. Therefore it was not possible to examine the effect of different modes of training (e.g. field training, resistance training) on changes in CET and CMJ metrics. Consequently, future research is needed to investigate the effects of different modes of training on changes in CET and CMJ metrics in this population to ascertain the potential causes of these changes. Such research would develop an understanding of the appropriateness and specificity of the CET and CMJ for monitoring neuromuscular function in response to different training modes.

PRACTICAL APPLICATIONS

The results from the present study suggest that CMJ metrics peak and mean power may be more sensitive to increases in training load than CET peak power in professional rugby union players. Given the high reliability of these metrics, along with ease of implementation and minimal fatiguing effect, the CMJ may be preferred over CET for monitoring lower-body neuromuscular function in this cohort.

CONCLUSION

In conclusion, this study examined changes in CET peak power and CMJ metrics during a training block in professional rugby union players. During the latter stages of the training block when training load increased, moderately greater decreases in CMJ peak and mean power were observed when compared to CET peak power. The findings suggest that a CMJ was more sensitive to increases in training load than a CET in rugby union players. However, future research is needed to ascertain the specific modes of training that elicit changes in

CMJ and CET in order to determine the efficacy of each test for monitoring neuromuscular function in rugby union players.

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Table 1: Weekly training schedule during the 8-week preseason period. CMJ = countermovement jump

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Monitoring	CMJ			CMJ			
a.m.	Upper-body resistance training (50-60 min)	Lower-body resistance training (50-60 min)	OFF	Lower-Body resistance training (50-60min)	Upper-body resistance training (50-60min)	Speed / rugby skills / conditioned games (30-45 min)	OFF
p.m.	Rugby conditioned-games / running conditioning (45-60 min)	Off-feet conditioning (30-45 min)		Rugby conditioned games (30 min) Off-feet conditioning (30 min)			

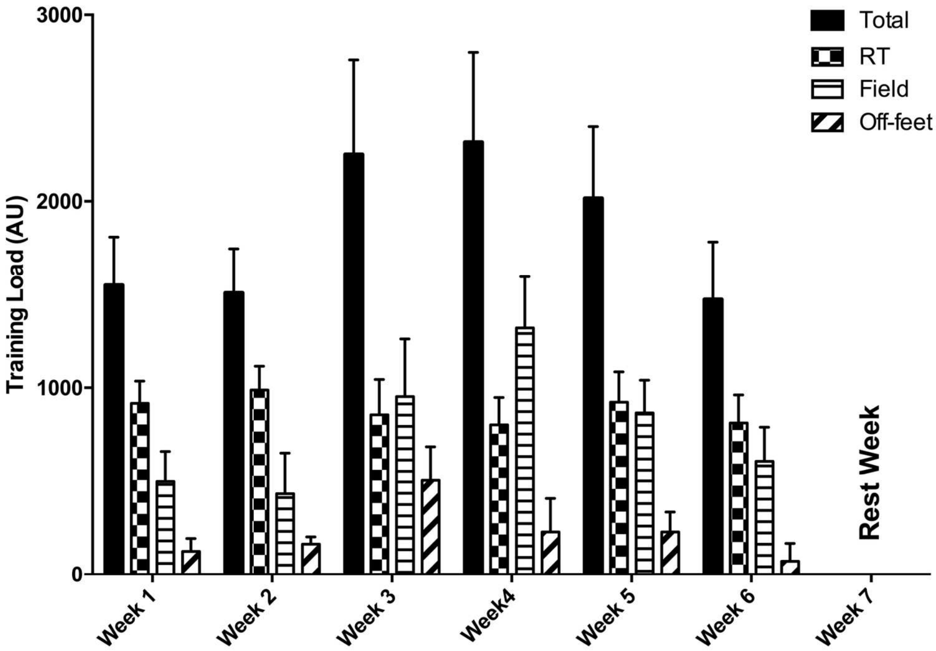

Figure 1: Mean (± SD bars) total weekly training loads and weekly distributions of training loads across each training category. RT = resistance training, Field = field training, Off-feet= off-feet conditioning, Total = total weekly training load.

150x108mm (300 x 300 DPI)

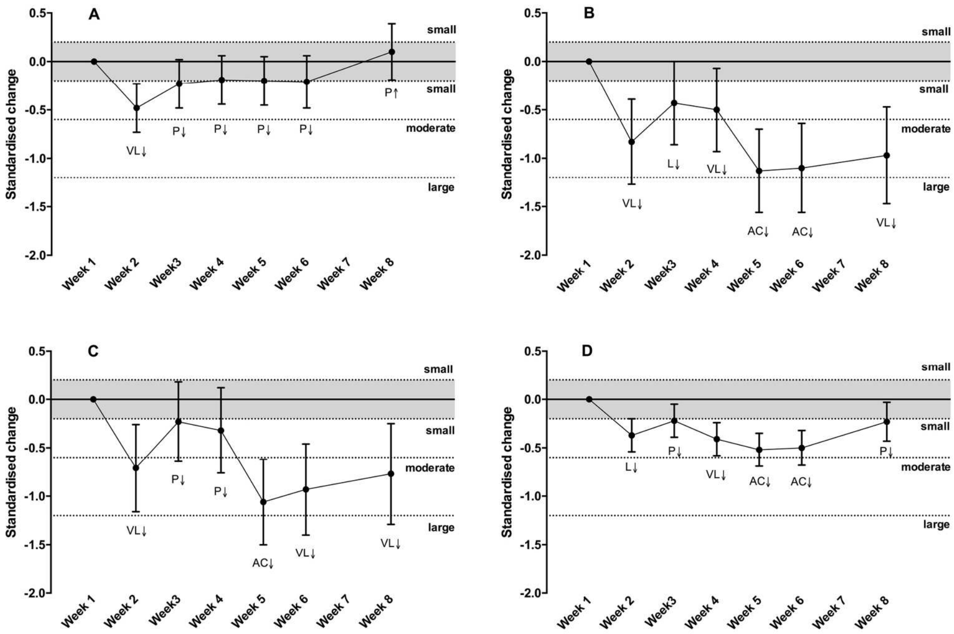

Figure 2: Changes in CET peak power (A), CMJ peak power (B), mean power (C) and flight-time (D). Change data are standardised changes with 90% confidence interval bars and the shaded area representing the smallest worthwhile change. P = possibly, L = likely, VL = very likely, A = almost certainly, ↑ = increase, ↓ = decrease.

164x110mm (300 x 300 DPI)

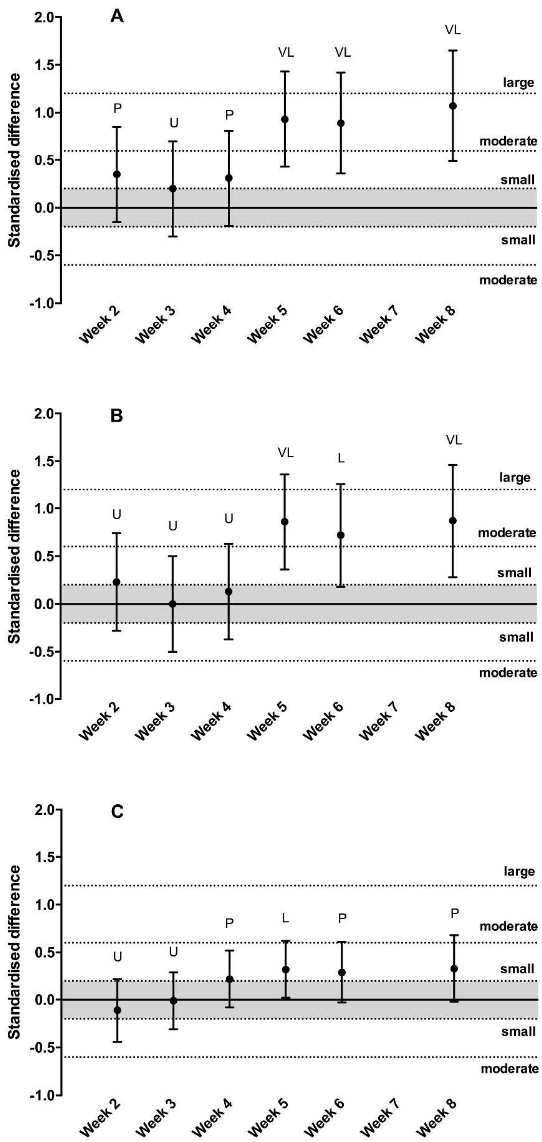

Figure 3: Differences between changes in CET peak power and CMJ peak power (A), CET peak power and CMJ mean power (B), CET peak power and CMJ flight-time (C). Change data are standardised changes with 90% confidence interval bars and the shaded area representing the smallest worthwhile change. P = possibly, L = likely, VL = very likely, A = almost certainly, ↑ = increase, ↓ = decrease.

244x505mm (300 x 300 DPI)

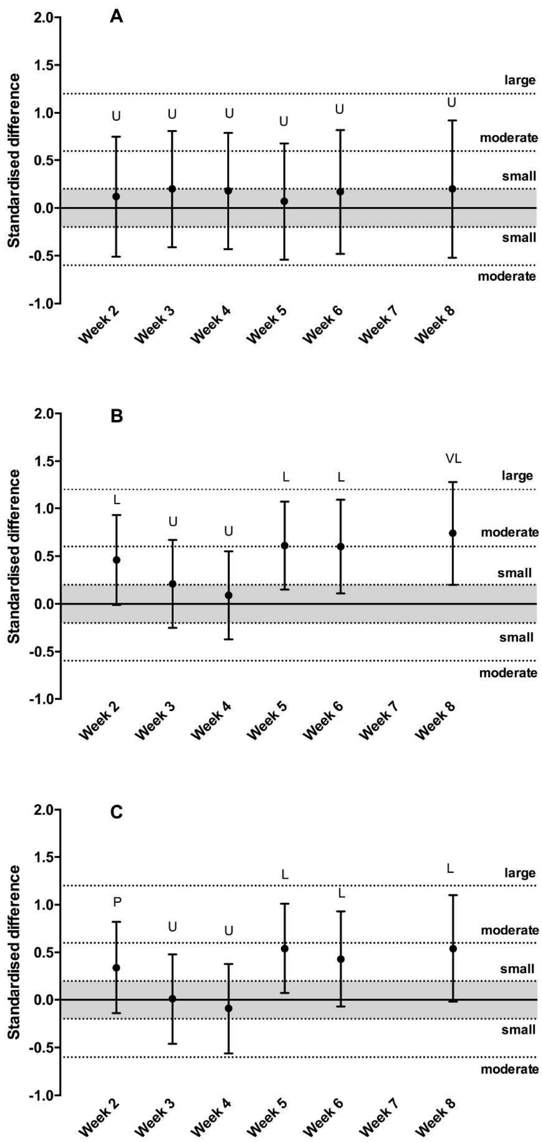

Figure 4: Differences between changes in CMJ peak power and CMJ mean power (A), CMJ peak power and CMJ flight-time (B), CMJ mean power and CMJ flight-time (C). Change data are standardised changes with 90% confidence interval bars and the shaded area representing the smallest worthwhile change. P = possibly, L = likely, VL = very likely, A = almost certainly, ↑ = increase, ↓ = decrease.

244x504mm (300 x 300 DPI)