



LEEDS
BECKETT
UNIVERSITY

Citation:

Roe, G and Darrall-Jones, J and Till, K and Jones, BL (2016) Preseason changes in markers of lower body fatigue and performance in young professional rugby union players. *European Journal of Sport Science*, 16 (8). pp. 981-988. ISSN 1536-7290 DOI: <https://doi.org/10.1080/17461391.2016.1175510>

Link to Leeds Beckett Repository record:

<https://eprints.leedsbeckett.ac.uk/id/eprint/2687/>

Document Version:

Article (Accepted Version)

The aim of the Leeds Beckett Repository is to provide open access to our research, as required by funder policies and permitted by publishers and copyright law.

The Leeds Beckett repository holds a wide range of publications, each of which has been checked for copyright and the relevant embargo period has been applied by the Research Services team.

We operate on a standard take-down policy. If you are the author or publisher of an output and you would like it removed from the repository, please [contact us](#) and we will investigate on a case-by-case basis.

Each thesis in the repository has been cleared where necessary by the author for third party copyright. If you would like a thesis to be removed from the repository or believe there is an issue with copyright, please contact us on openaccess@leedsbeckett.ac.uk and we will investigate on a case-by-case basis.

Abstract

This study investigated the changes in measures of neuromuscular fatigue and physical performance in young professional rugby union players during a preseason training period. Fourteen young (age; 19.1 ± 1.2 years) professional rugby union players participated in the study.

Changes in measures of lower-body neuromuscular fatigue (countermovement jump (CMJ) mean power, mean force, flight time) and physical performance (lower-body strength, 40 m sprint velocity) were assessed during an 11-week preseason period using magnitude-based inferences. CMJ mean power was likely to very likely decreased during week 2 (-8.1 ± 5.5 to $-12.5 \pm 6.8\%$), and likely to almost certainly decreased from weeks 5 to 11 (-10 ± 4.3 to $-14.7 \pm 6.9\%$), while CMJ flight-time demonstrated likely to very likely decreases during weeks 2, and weeks 4 to 6 (-2.4 ± 1.0 to $-3.3 \pm 1.3\%$), and weeks 9 to 10 (-1.9 ± 0.9 to $-2.2 \pm 1.5\%$). Despite this, possible improvements in lower-body strength ($5.8 \pm 2.7\%$) and very likely improvements in 40 m velocity ($5.5 \pm 3.6\%$) were made. Relationships between changes in CMJ metrics and lower-body strength or 40 m sprint velocity were trivial or small (<0.22).

Increases in lower-body strength and 40 m velocity occurred over the course of an 11-week preseason despite the presence of neuromuscular fatigue (as measured by CMJ). The findings of this study question the usefulness of CMJ for monitoring fatigue in the context of strength and sprint velocity development. Future research is needed to ascertain the consequences of negative changes in CMJ in the context of rugby specific activities to determine the usefulness of this test as a measure of fatigue in this population.

Key Words: fatigue, recovery, performance.

Introduction

Rugby union is a collision sport in which players are required to possess high levels of strength, power, and endurance to compete at an elite level (Duthie, 2006). Therefore enhancement of such physical characteristics is important for the progression of young professional rugby union players towards senior status (Darrall-Jones, Jones, & Till, 2015). In particular, during the pre-season, the development of these physical characteristics is often prioritised with the aim of preparing players for the forthcoming competitive season (Argus, Gill, Keogh, Hopkins, & Beaven, 2010). A major challenge to coaching staff during the preseason is the prescription of appropriate training volumes that result in optimal physiological adaptation and skill development, without incurring negative effects of the high training loads (e.g. fatigue and injury) typically associated with pre-season training (Cross, Williams, Trewartha, Kemp, & Stokes, 2015).

Monitoring of athletes during such intensified training periods is commonly undertaken in order to maximise the physical development of players, while managing the development of fatigue (Halson, 2014). One particular facet of fatigue that is of interest to sports scientists and strength and conditioning practitioners is neuromuscular fatigue. Neuromuscular fatigue manifests as a reduction in the ability to produce force or power (Grassi, Rossiter, & Zoladz, 2015), and thus may compromise physical development and optimal sports performance (Taylor, Cronin, Chapman, Hopkins, & Newton, 2015).

Lower-body neuromuscular fatigue has been shown to occur in the first 24-72 hr post-match in collisions sport athletes, as demonstrated by transient reductions in countermovement jump (CMJ) metrics (e.g. power, flight-time) (McLellan & Lovell, 2012; Shearer et al., 2015; Twist, Waldron, Highton, Burt, & Daniels, 2012; West et al., 2014). Based on these findings, it has been proposed that the CMJ is a practical and valid measure of lower-body neuromuscular fatigue in this population (Shearer et al., 2015; Twist & Highton, 2013; Twist et al., 2012; West et al., 2014). Furthermore, it has been suggested that CMJ performance prior to the commencement of training may be a useful tool for regulating training volume in order to optimise training adaptation while minimising fatigue (Claudino et al., 2012).

Currently however, no study has investigated the relationship between changes in measures of neuromuscular fatigue and physical performance in this

1
2
3
4
5
6 population during the preseason. Studies documenting the preseason in rugby players
7 have either reported changes in performance measures (Argus et al., 2010; Bradley et
8 al., 2015; Coutts, Reaburn, Piva, & Murphy, 2007) or neuromuscular fatigue only
9 (Gathercole, Sporer, & Stellingwerff, 2015). Such research would give an insight into
10 the potential usefulness of the CMJ for monitoring neuromuscular fatigue during the
11 preseason period. Therefore the aim of the present study was to describe the changes
12 in measures of lower-body neuromuscular fatigue (CMJ) and physical performance
13 (i.e., lower-body strength and 40 m sprint velocity) during a preseason in young
14 professional rugby union players, and to investigate if any relationships exist between
15 such changes.
16
17
18
19
20
21

22 **Methods**

23 *Subjects*

24
25
26
27
28
29
30 Fourteen young professional rugby union players (age 19.1 ± 1.2 years, body
31 mass 96.2 ± 13.2 kg, height 186.5 ± 8.2 cm) were recruited from a professional rugby
32 union club. Each player was a member of the Senior Academy, a transitional squad
33 from the Junior Academy (under-18's) to the senior squad, consisting of 18-23 year
34 old players. Players typically engaged in 8 individual training sessions across 5 days
35 per week, including resistance training, rugby skills and conditioning. Ethics approval
36 was granted by Leeds Beckett University ethics board and written informed consent
37 was acquired from all subjects.
38
39
40
41
42

43 *Design*

44
45
46 A within-group repeated measures design was used to examine the magnitude
47 of change in lower-body neuromuscular fatigue (CMJ), and physical performance
48 (lower-body strength and 40 m sprint velocity), and the relationships that exist
49 between such changes, during an 11-week preseason period. The CMJ was assessed
50 on the first and fourth morning of each week following a rest day. Lower-body
51 strength and 40 m sprint velocity were assessed at the beginning and end of
52 preseason.
53
54
55
56
57
58
59
60

Lower-body Neuromuscular Fatigue

A CMJ was used to measure lower-body neuromuscular fatigue. It has been recommended that a minimum sampling frequency of 200Hz be used when measuring CMJ performance (Hori et al., 2009). Therefore the CMJ was performed on a portable force plate (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) that was attached to a laptop with software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that measured ground reaction forces at 600Hz, as previously used in similar studies (Cormack, Mooney, Morgan, & McGuigan, 2013; Cormack, Newton, McGuigan, & Cormie, 2008). 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, players performed 2 maximal CMJs with 1-minute rest between each effort (Roe et al., 2015). Players began standing on the force 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 high as possible. The depth of the countermovement was at the discretion of the subject (Cormack, Newton, McGuigan, & Doyle, 2008). Mean power, mean force and flight-time were analysed based on the previous between-day reliability (Coefficient of variance (CV) = 3.1%, 1.0% and 2.6% respectively) of these metrics published in this cohort (Roe et al., 2015). The start time for concentric mean power and mean force was when the velocity was equal to zero (Linthorne, 2001).

Lower-Body Performance

To determine changes in a player's maximal velocity, 40 m sprint testing was undertaken on the same day of the week, at the same time of day and on the same surface (3G pitch) during week 1 and week 10 of pre-season. Players performed a standardised warm-up followed by 3 maximal 40 m sprints with 3 minutes of rest between each effort (Darrall-Jones et al., 2015). Each player wore a 10 Hz GPS unit (Catapult Optimeye S5), which have previously been shown reliable in sprint testing (Varley, Fairweather, & Aughey, 2012). The highest velocity achieved was used in the final analysis.

1
2
3
4
5
6 To determine lower-body strength, front squat 3-repetition max (3RM) was
7 assessed on the same day of the week and at the same time of day during week 1 and
8 week 10. Players performed a standardised warm-up that included 1 set of 8
9 repetitions with the bar, 2 sets of 5, and 2 sets of 3 repetitions with submaximal loads
10 incrementally approaching their previous 3RM (Darrall-Jones et al., 2015). Players
11 then had 5 attempts to achieve a new 3RM, with 3 minutes of rest between each
12 attempt (Darrall-Jones et al., 2015).
13
14
15
16

17 *Training Load*

18
19
20
21 Training load was quantified using the session rating of perceived exertion
22 method (sRPE) (Foster et al., 2001) within 15-30 minutes of each session finishing,
23 on a modified Borg scale. This rating was then multiplied by the time spent training to
24 give a training load in arbitrary units (AU) (Foster et al., 2001). Training sessions
25 were categorised into resistance training, off-feet conditioning and field training. Off-
26 feet conditioning consisted of cycle ergometer interval training (Wattbike Pro,
27 Nottingham UK) based on players' average speed achieved during a 3-minute test. .
28 Field training consisted of rugby conditioned-games interspersed with intermittent
29 running based on players' individual 30-15 intermittent fitness test score. Training
30 loads were summated to provide an overall weekly training load.
31
32
33
34
35
36

37 *Statistical Analysis*

38
39
40 All data were log transformed to reduce bias as a result of non-uniformity
41 error. Data were all analysed for practical significance using magnitude-based
42 inferences (Hopkins, Marshall, Batterham, & Hanin, 2009). The threshold for a
43 change to be considered practically important (the smallest worthwhile change; SWC)
44 was set at 0.2 x between subject standard deviation (SD), based on Cohen's d effect
45 size (ES) principle. The probability that the magnitude of change was greater than the
46 SWC was rated as <0.5%, almost certainly not; 0.5-5%, very unlikely; 5-25%,
47 unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, almost
48 certainly (Hopkins et al., 2009). Where the 90% Confidence Interval (CI) crossed
49 both the upper and lower boundaries of the SWC ($ES \pm 0.2$), the magnitude of change
50 was described as unclear (Hopkins et al., 2009).
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 In order to analyse the relationship between neuromuscular fatigue and
7 changes in physical performance, data were tested for normality using Shapiro-Wilk's
8 test. Neuromuscular fatigue was deemed present on a given testing day if the
9 magnitude of change in a player's CMJ was below the summation of the SWC and the
10 CV (Hopkins, 2004). The relationships between the number of time-points a player
11 demonstrated neuromuscular fatigue (in each CMJ metric) and the percentage change
12 in both 40 m sprint velocity and lower-body strength were examined using Pearson's
13 product-moment correlation coefficient using SPSS for Mac (version 21). The
14 correlation coefficient was ranked as trivial (<0.1), small (0.1-0.29), moderate (0.3-
15 0.49), large (0.5-0.69), very large (0.7-0.89) and nearly perfect (0.9-0.99) (Hopkins et
16 al., 2009).
17
18
19
20
21
22

23 Results

24
25
26 Total and weekly distribution of training loads across each training category
27 (i.e., resistance training, off-feet conditioning and field training), are presented in
28 Figure 1. The average weekly training load was 1810 ± 339 AU. The weekly training
29 schedule is presented in Table 1.
30
31
32

33
34 INSERT FIGURE 1 HERE

35
36
37 INSERT TABLE 1

38
39
40 Changes in measures of neuromuscular performance and fatigue, alongside the
41 total training load are presented in Figure 2. Figure 2b shows that CMJ mean power
42 was likely to very likely decreased during week 2 (-8.1 ± 5.5 to $-12.5 \pm 6.8\%$), and
43 likely to almost certainly decreased from weeks 5 to 11 (-10 ± 4.3 to $-14.7 \pm 6.9\%$).
44 Figure 2c depicts decreases in flight-time that were likely to very likely during week 2
45 and weeks 4 to 6 ($-2.4 \pm 1.$ to $-3.3 \pm 1.3\%$), and during weeks 9 to 10 (-1.9 ± 0.9 to
46 $-2.2 \pm 1.5\%$). Changes in CMJ mean force were likely to almost certainly trivial at the
47 majority of time-points (Figure 2d).
48
49
50

51
52 Possible improvements in lower-body strength ($5.8 \pm 2.7\%$) were made from
53 week 1 to week 10, while very likely improvements in 40 m sprint velocity
54 ($5.5 \pm 3.6\%$) occurred between week 1 and week 10 (Figure 2a).
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

INSERT FIGURE 2

The relationships between the number of times a player demonstrated neuromuscular fatigue in CMJ flight-time and percentage change in 40 m sprint velocity and lower-body strength were trivial ($r = 0.09$) and small ($r = 0.19$) respectively. The relationships between the number of times a player demonstrated neuromuscular fatigue in mean power and percentage change in 40 m sprint velocity and lower-body strength were small ($r = 0.16$ and 0.21 respectively).

Discussion

This study examined the magnitude of change in measures of lower-body neuromuscular fatigue and physical performance over the course of a preseason in young professional rugby union players. Very likely to almost certain reductions in CMJ mean power (-10 ± 4.3 to $-14.7 \pm 6.9\%$) were present during the latter half of the preseason, indicating the presence of lower-body neuromuscular fatigue. Regardless of this, possible improvements in strength and very likely improvements in 40 m sprint velocity were apparent. Furthermore the relationships between the number of times a player demonstrated neuromuscular fatigue and changes in both 40 m sprint velocity and lower-body strength was trivial or small (<0.22). These findings suggest that increases in 40 m sprint velocity and lower-body strength can still be achieved when changes in CMJ metrics are indicative of fatigue.

This is the first study to provide training load data during a preseason period for young professional rugby union players. The training load observed in the current pre-season (1810 ± 339 AU) was moderately lower (Cohen's $d = -1.01$) than those reported in other UK professional rugby union clubs for senior players (2175 ± 380 AU) (Cross et al., 2015). This is likely the result of the difference in training content between a Senior Academy and first team squad. Although players in this study engaged in some first team field sessions, the overall training exposure was

1
2
3
4
5
6 determined as appropriate for young professional rugby union players by the coaching
7 team.
8

9 This study demonstrated that both CMJ mean power and flight-time decreased
10 following the highest period of training volume (weeks 3-5), suggesting a
11 neuromuscular fatigue response. Following the rest week, flight-time began to return
12 to baseline, although still possibly decreased. However, mean power remained almost
13 certainly decreased. Similarly as training load in the latter stages of the preseason
14 began to reduce, flight-time began to return to baseline, while mean power still
15 remained almost certainly reduced. According to the fitness fatigue model, it is only
16 when the fatigue-inducing training stimulus has been removed or reduced, that
17 improvements in fitness can be observed (Banister, 1991). It is possible that the rest
18 week during week 7 was not long enough to remove the training-induced fatigue and
19 restore CMJ mean power, thus explaining the suppression of this CMJ metric during
20 the latter weeks of the preseason period.
21
22
23
24
25
26

27 Neuromuscular fatigue may be caused by a combination of central nervous
28 system and peripheral (muscle-tendon unit and nervous system) factors (Boyas &
29 Guével, 2011), both of which contribute to reductions in CMJ performance (Taylor et
30 al., 2015). Given that changes in CMJ mean force were likely to almost certainly
31 trivial at the majority of time-points, it appears that training-induced fatigue in these
32 players influenced the velocity of the movement rather than absolute force
33 production. These findings are in agreement with changes in CMJ force and power
34 reported in professional rugby league players following match-play (McLellan &
35 Lovell, 2012; McLellan, Lovell, & Gass, 2011).
36
37
38
39

40 In a similar study design, Gathercole et al (2015) monitored CMJ performance
41 over a 6-week training period in elite female rugby sevens players. The authors
42 observed substantial changes (likely to almost certain) in flight-time during the latter
43 4-weeks similar to the present study. Conversely however, the authors observed no
44 substantial changes in mean power despite greater overall training loads. The authors
45 suggested that mean power might not be as useful as other CMJ metrics (e.g. flight-
46 time) for assessing lower-body neuromuscular fatigue. However in their study,
47 weekly CMJ testing was undertaken following speed sessions, which may have led to
48 transient post-activation potentiation, masking the effects of neuromuscular fatigue on
49 this CMJ metric. Nevertheless, in the present study, the CMJ was assessed in the
50 morning prior to any training being undertaken, with mean power demonstrating the
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 greatest changes of all the CMJ metrics analysed during the preseason period. The
7 difference between the respective studies highlights the importance of standardising
8 methodologies (e.g. time of day) in order to better understand the effects of training
9 on markers of fatigue.
10

11
12 Despite the negative changes in CMJ metrics in this study, lower-body
13 strength showed improvements ($5.8\pm 2.7\%$) across the preseason that are similar to
14 those previously reported in professional rugby union players across 2 preseason
15 periods (6.5-11.5%) (Appleby, Newton, & Cormie, 2012). However it is possible that
16 greater increases in these physical qualities may have been developed had
17 neuromuscular fatigue not been present, although given the observational nature of
18 this study, this requires further investigation. Argus et al (2010) observed an
19 $11.3\pm 4.7\%$ increase in box squat over a 4-week intensive block of preseason in
20 professional rugby union players. This is in contrast to the $5.8\pm 2.7\%$ in front squat
21 made in the current study. Nevertheless, Argus and colleagues acknowledge that the
22 large increase in strength was likely the result of players being in a 'deconditioned'
23 state following a 6-week off-season period prior to the commencement of preseason.
24 Conversely, the players in the present study only had a 2-3 week off-season and either
25 equally or bettered their previous testing scores during week 1 of preseason. This
26 suggests that the improvements made in the present study were the result of true
27 changes and not of 'reconditioning', as in the case of Argus and colleagues (2010).
28
29

30
31 Like lower-body strength, 40 m sprint velocity demonstrated improvements
32 ($5.5\pm 3.6\%$) across the preseason period. These results are slightly greater than
33 seasonal changes of 40 m sprint velocity ($\sim 2-3\%$) reported in international under-20
34 and senior players (Barr, Sheppard, Gabbett, & Newton, 2014). However, the players
35 in the study by Barr and colleagues were of a higher playing standard than in the
36 present study and therefore may have been closer to realising their absolute speed
37 potential. Additionally, the greater increases observed in the present study might be
38 partly the result of running re-education and improvements in technique (Appleby et
39 al., 2012), as sprint training was not undertaken during the latter stages of the
40 previous competitive season. Furthermore, it is also possible that the improvements in
41 lower-body strength transferred through to improvement in 40 m sprint velocity
42 (Seitz, Reyes, Tran, Saez de Villarreal, & Haff, 2014).
43
44

45
46 Previous studies have shown that CMJ metrics are correlated with sprint
47 performance (Loturco et al., 2015), thus it would be expected that sprint velocity
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 would decline in the presence of reduced CMJ performance. In agreement with the
7 findings of the present study however, Coutts et al (2007) observed no change in 10m
8 and 40 m sprint performance during a deliberate period of over-reaching in semi-
9 professional rugby league players. This was in spite of substantial decreases in other
10 performance measures including lower-body strength, isokinetic power and vertical
11 jump. Furthermore, recovery of sprint performance has been shown to be far quicker
12 than CMJ following field-based training (Gathercole, Sporer, Stellingwerff, &
13 Sleivert, 2015). It is therefore possible that 40 m sprint velocity is less sensitive to
14 neuromuscular fatigue than CMJ mean power.
15

16
17
18
19 Alternatively, it is also possible that the development of neuromuscular
20 fatigue, as measured by CMJ, does not compromise the ability to produce an all-out
21 effort in a 40 m sprint test. In the present study, sprint testing was undertaken in a
22 group setting, where competition between players may have influenced maximal
23 exertion (Corbett, Barwood, Ouzounoglou, Thelwell, & Dicks, 2012). Therefore in
24 such motivational situations, players may be able to produce maximal efforts and
25 temporarily negate the acute effects of neuromuscular fatigue on an isolated 40 m
26 sprint performance.
27

28
29
30
31 Although it appeared that neuromuscular fatigue did not influence 40 m sprint
32 velocity or strength development, neuromuscular fatigue may have had a negative
33 effect on other training activities in this group of players. Findings from Australian
34 Rules football suggest that the presence of neuromuscular fatigue unfavourably
35 altered accelerometer-loading patterns of players during match-play (Cormack,
36 Mooney, Morgan, & McGuigan, 2013), and negatively influenced the relationship
37 between the relative accumulated accelerometer load and coaches' perception of
38 player performance (Mooney, Cormack, O'Brien B, Morgan, & McGuigan, 2013).
39 Therefore the fatigue experienced by the players in the present study may have
40 affected rugby specific performance during the preseason period. Unfortunately, an
41 objective measure of such activity was not collected. Future research is needed to
42 examine the influence of neuromuscular fatigue on rugby union specific activities.
43

44
45
46
47
48
49 A limitation of the present study is the lack of measurement of upper-body
50 neuromuscular fatigue. It has previously been demonstrated that rugby league players
51 experience considerable upper-body neuromuscular fatigue following collision-based
52 training (R. D. Johnston, Gabbett, Seibold, & Jenkins, 2014) and match-play (R. D.
53 Johnston, Gabbett, Jenkins, & Hulin, 2015). Therefore future research is needed to
54
55
56
57
58
59
60

1
2
3
4
5
6 investigate this phenomenon during the preseason period. A further limitation of the
7 present study is the use of GPS to measure maximum velocity during 40m sprinting.
8 It has been demonstrated that GPS is associated with greater testing error at higher
9 speeds (R. J. Johnston, Watsford, Kelly, Pine, & Spurrs, 2014), which must be taken
10 into consideration when making conclusions about changes in these measurements
11 over time. Finally, as objective measures of training load were not collected during
12 the study (for example volume load, GPS metrics) it was not possible to examine the
13 relationship between such measures and strength and speed development.
14 Consequently, future research is needed to examine the relationship between changes
15 in physical performance and objective measures of training load in this cohort during
16 a preseason period.
17
18
19
20
21
22

23 **Conclusion**

24
25
26 In conclusion, possible and very likely increases in lower-body maximal
27 strength and 40 m sprint velocity respectively occurred despite the presence of
28 neuromuscular fatigue during an 11-week preseason period in young professional
29 rugby union players. Future research is needed to investigate whether reductions in
30 CMJ performance negatively impact rugby specific activities in order to determine the
31 usefulness of this test as a measure of fatigue in rugby union players.
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

References

- Appleby, B., Newton, R. U., & Cormie, P. (2012). Changes in strength over a 2-year period in professional rugby union players. *J Strength Cond Res*, 26(9), 2538-2546.
- Argus, C. K., Gill, N., Keogh, J., Hopkins, W. G., & Beaven, C. M. (2010). Effects of a short-term pre-season training programme on the body composition and anaerobic performance of professional rugby union players. *J Sports Sci*, 28(6), 679-686.
- Banister, E. W. (1991). Modeling Elite Athletic Performance. In J. D. MacDougall, H. A. Wenger, & H. J. Green (Eds.), *Physiological Testing of the High Performance Athlete*. (pp. 403-424). Champaign: Human Kinetics.
- Barr, M. J., Sheppard, J. M., Gabbett, T. J., & Newton, R. U. (2014). Long-term training-induced changes in sprinting speed and sprint momentum in elite rugby union players. *J Strength Cond Res*, 28(10), 2724-2731
- Boyas, S., & Guével, A. (2011). Neuromuscular fatigue in healthy muscle: Underlying factors and adaptation mechanisms. *Annals Phys Rehabil Med*, 54(2), 88-108.
- Bradley, W. J., Cavanagh, B. P., Douglas, W., Donovan, T. F., Morton, J. P., & Close, G. L. (2015). Quantification of training load, energy intake, and physiological adaptations during a rugby preseason: a case study from an elite European rugby union squad. *J Strength Cond Res*, 29(2), 534-544.
- Chiu, L. Z. F., & Barnes, J. L. (2003). The Fitness-Fatigue Model Revisited: Implications for Planning Short- and Long-Term Training. *Strength Cond J*, 25(6), 42-51.
- Claudino, J. G., Mezencio, B., Soncin, R., Ferreira, J. C., Couto, B. P., & Szmuchowski, L. A. (2012). Pre vertical jump performance to regulate the training volume. *Int J Sports Med*, 33(2), 101-107.
- Corbett, J., Barwood, M. J., Ouzounoglou, A., Thelwell, R., & Dicks, M. (2012). Influence of competition on performance and pacing during cycling exercise. *Med Sci Sports Exerc*, 44(3), 509-515.
- Cormack, S. J., Mooney, M. G., Morgan, W., & McGuigan, M. R. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *Int J Sports Physiol Perform*, 8(4), 373-378.

- 1
2
3
4
5
6 Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability
7 of measures obtained during single and repeated countermovement jumps. *Int J*
8 *Sports Physiol Perform*, 3(2), 131-144.
9
10 Cormack, S. J., Newton, R. U., McGuigan, M. R., & Cormie, P. (2008).
11 Neuromuscular and endocrine responses of elite players during an Australian
12 rules football season. *Int J Sports Physiol Perform*, 3(4), 439-453.
13
14 Coutts, A., Reaburn, P., Piva, T. J., & Murphy, A. (2007). Changes in selected
15 biochemical, muscular strength, power, and endurance measures during
16 deliberate overreaching and tapering in rugby league players. *Int J Sports Med*,
17 28(2), 116-124.
18
19 Cross, M. J., Williams, S., Trewartha, G., Kemp, S. P., & Stokes, K. A. (2015). The
20 Influence of In-Season Training Loads on Injury Risk in Professional Rugby
21 Union. *Int J Sports Physiol Perform*.
22
23 Darrall-Jones, J. D., Jones, B., & Till, K. (2015). Anthropometric and Physical
24 Profiles of English Academy Rugby Union Players. *J Strength Cond Res*, 29(8),
25 2086-2096.
26
27 Duthie, G. M. (2006). A framework for the physical development of elite rugby union
28 players. *Int J Sports Physiol Perform*, 1(1), 2-13.
29
30 Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . .
31 Dodge, C. (2001). A new approach to monitoring exercise training. *J Strength*
32 *Cond Res*, 15(1), 109-115.
33
34 Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement Jump
35 Performance with Increased Training Loads in Elite Female Rugby Athletes. *Int*
36 *J Sports Med*, 36(9), 722-728.
37
38 Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015).
39 Comparison of the Capacity of Different Jump and Sprint Field Tests to Detect
40 Neuromuscular Fatigue. *J Strength Cond Res*, 29(9), 2522-2531.
41
42 Grassi, B., Rossiter, H. B., & Zoladz, J. A. (2015). Skeletal muscle fatigue and
43 decreased efficiency: two sides of the same coin? *Exerc Sport Sci Rev*, 43(2),
44 75-83.
45
46 Halson, S. (2014). Monitoring Training Load to Understand Fatigue in Athletes.
47 *Sports Medicine*, 44(2), 139-147.
48
49 Hopkins, W. G. (2004). How to Interpret Changes in an Athletic Performance Test.
50 *Sportscience* (8), 1-7.
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive
7 statistics for studies in sports medicine and exercise science. *Med Sci Sports*
8 *Exerc*, 41(1), 3-13.

9
10 Hori, N., Newton, R.U., Kawamori, N., McGuigan, M.R., Kraemer & Nosaka, K.
11 (2009). Reliability of performance measurements derived from ground reaction
12 force data during countermovement jump and the influence of sampling
13 frequency. *J Strength Cond Res*, 23 (3), 874-882.

14
15 Johnston, R. D., Gabbett, T. J., Jenkins, D. G., & Hulin, B. T. (2015). Influence of
16 physical qualities on post-match fatigue in rugby league players. *J Sci Med*
17 *Sport*, 18(2), 209-213.

Formatted: Font: Not Italic

18
19 Johnston, R. D., Gabbett, T. J., Seibold, A. J., & Jenkins, D. G. (2014). Influence of
20 physical contact on neuromuscular fatigue and markers of muscle damage
21 following small-sided games. *J Sci Med Sport*, 17(5), 535-540.

Formatted: Font: Not Italic

22
23 Johnston, R. J., Watsford, M. L., Kelly, S. J., Pine, M. J., & Spurrs, R. W. (2014).
24 Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing
25 athlete movement demands. *J Strength Cond Res*, 28(6), 1649-1655.

Formatted: Font: Not Italic

26
27 Linthorne, N. P. (2001). Analysis of standing vertical jumps using a force platform.
28 *American Journal of Physics*, 69(11), 1198-1204.

Formatted: Font: Not Italic

29
30 Loturco, I., D'Angelo, R. A., Fernandes, V., Gil, S., Kobal, R., Cal Abad, C. C., . . .
31 Nakamura, F. Y. (2015). Relationship between sprint ability and
32 loaded/unloaded jump tests in elite sprinters. *J Strength Cond Res*, 29(3), 758-
33 764.

Formatted: English (U.S.)

34
35 McLellan, C. P., & Lovell, D. I. (2012). Neuromuscular responses to impact and
36 collision during elite rugby league match play. *J Strength Cond Res*, 26(5),
37 1431-1440.

38
39 McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). Markers of postmatch fatigue in
40 professional Rugby League players. *J Strength Cond Res*, 25(4), 1030-1039.

41
42 Mooney, M. G., Cormack, S., O'Brien B, J., Morgan, W. M., & McGuigan, M.
43 (2013). Impact of neuromuscular fatigue on match exercise intensity and
44 performance in elite Australian football. *J Strength Cond Res*, 27(1), 166-173.

45
46 Roe, G., Darrall-Jones, J., Till, K., Phibbs, P., Read, D., Weakley, J., & Jones, B.
47 (2015). Between-Day Reliability and Sensitivity of Common Fatigue Measures
48 in Rugby Players. *Int J Sports Physiol Perform*.

- 1
2
3
4
5
6 Seitz, L. B., Reyes, A., Tran, T. T., Saez de Villarreal, E., & Haff, G. G. (2014).
7 Increases in lower-body strength transfer positively to sprint performance: a
8 systematic review with meta-analysis. *Sports Med*, 44(12), 1693-1702.
9
10 Shearer, D. A., Kilduff, L. P., Finn, C., Jones, R. M., Bracken, R. M., Mellalieu, S.
11 D., . . . Cook, C. J. (2015). Measuring Recovery in Elite Rugby Players: The
12 Brief Assessment of Mood, Endocrine Changes, and Power. *Res Q Exerc Sport*,
13 1-8.
14
15 Taylor, K. L., Cronin, J. B., Chapman, D. W., Hopkins, W. G., & Newton, M. (2015).
16 Relationship between changes in jump performance and laboratory measures of
17 low frequency fatigue. *Gazzetta Medica Italiana Archivio per le Scienze*
18 *Mediche*, 174(6), 241-250.
19
20 Twist, C., & Highton, J. (2013). Monitoring fatigue and recovery in rugby league
21 players. *Int J Sports Physiol Perform*, 8(5), 467-474.
22
23 Twist, C., Waldron, M., Highton, J., Burt, D., & Daniels, M. (2012). Neuromuscular,
24 biochemical and perceptual post-match fatigue in professional rugby league
25 forwards and backs. *J Sports Sci*, 30(4), 359-367.
26
27 Varley, M. C., Fairweather, I. H., & Aughey, R. J. (2012). Validity and reliability of
28 GPS for measuring instantaneous velocity during acceleration, deceleration, and
29 constant motion. *J Sports Sci*, 30(2), 121-127.
30
31 West, D. J., Finn, C. V., Cunningham, D. J., Shearer, D. A., Jones, M. R., Harrington,
32 B. J., . . . Kilduff, L. P. (2014). Neuromuscular function, hormonal, and mood
33 responses to a professional rugby union match. *J Strength Cond Res*, 28(1),
34 194-200.
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Table 1: Weekly training schedule during the 11-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)			

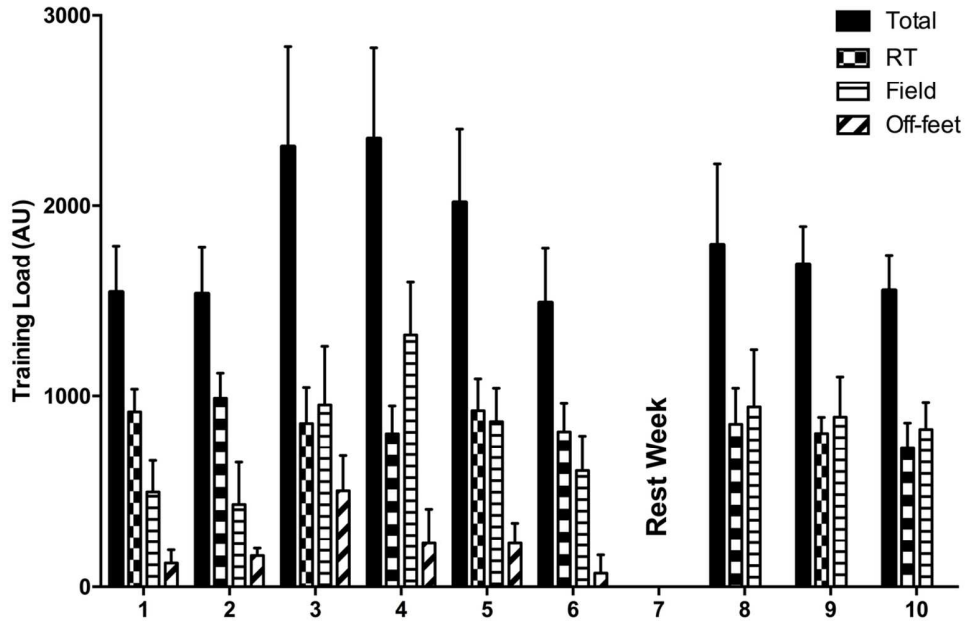


Figure 1: Mean (\pm SD bars) total weekly training loads and weekly distributions of training loads across each training category. RT = resistance training, Field = field training, Off-feet= off-feet conditioning, Total = total weekly training load.
113x74mm (300 x 300 DPI)

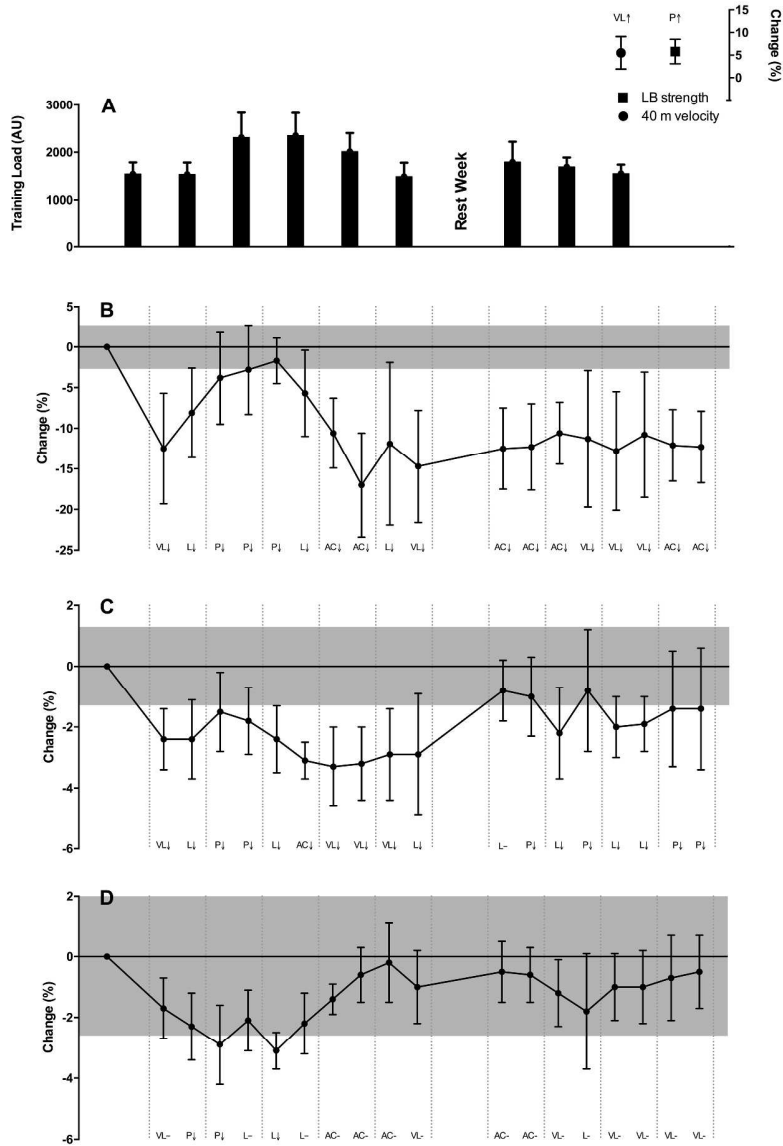


Figure 2: Mean weekly training load (\pm SD bars) (A), changes in 40 m sprint velocity and lower-body (LB) strength (A), and changes in CMJ mean power (B), flight-time (C) and mean force (D). Change data are percentage change with 90% confidence interval bars and the shaded area representing the smallest worthwhile change as a percentage. P = possibly, L = likely, VL = very likely, A = almost certainly, \uparrow = increase, \downarrow = decrease, - = trivial.
268x391mm (300 x 300 DPI)