Title: Profiling the post-match recovery response in male rugby: A systematic review

Running Head: Recovery profiles in rugby

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ABSTRACT

To minimize underperformance, injury and illness, and to enhance readiness for training and match-play, post-match responses are commonly monitored within professional rugby. As no clear consensus exists regarding the magnitude and duration of post-match recovery, this review summarized literature (17 studies yielded from literature searching/screening) reporting neuromuscular (countermovement jump; CMJ: peak power output; PP, flight-time; FT), biochemical (creatine kinase; CK), endocrine (cortisol; C, testosterone; T concentrations) and subjective (wellness questionnaire, muscle soreness) indices following rugby match-play. For neuromuscular responses (11 studies), reductions in PP <31.5% occurred <30 min post-match, returning to baseline within 48-72 h. Post-match reductions in FT of <4% recovered after 48 h. For biochemical and endocrine responses (14 studies), increases in CK, ranging from 120-451%, peaked between 12-24 h, returning to baseline within 72 h of match-play. Initial increases of <298% in C, and reductions in T concentrations (<44%), returned to pre-match values within 48-72 h. Mood disturbances (six studies) required 48-72 h to normalize after peak decrements of <65% at 24 h. This review highlights that 72 h were needed to restore perturbations in neuromuscular, biochemical and endocrine, and subjective/perceptual responses following competitive rugby match-play. Notably, only four studies reported responses in more ecologically valid scenarios (i.e., those in which regular training and recovery strategies were employed) whilst also reporting detailed match demands. A lack of research focusing on youth players was also evident, as only three studies profiled post-match responses in younger athletes. Deeper insight regarding post-match responses in ecologically valid scenarios is therefore required.

KEY WORDS: Fatigue, monitoring, wellness, team sport, muscle damage

INTRODUCTION

Rugby is an intermittent team sport, typically played between two teams that field between seven and 15 players, depending on the code and format of the game. During match-play, players perform high-intensity activities such as high-speed running (>5.5 $m \cdot s^{-1}$) and sprinting (>7.0 $m \cdot s^{-1}$) that are separated by lower-intensity activities like standing, walking or jogging. In addition, players frequently engage with collisions and bouts of wrestling/grappling (19-21, 68, 82). Whilst many similarities exist between different rugby codes (i.e., rugby league: RL, rugby union: RU, rugby seven's: R7), it should be acknowledged that each code also has unique physical demands; particularly with respect to the tackles and collisions. RU players are exposed to multiple forms of collision, such as rucking and mauling (26) and are typically involved in 15-45 collisions per match (14, 66). RL players are subjected to 30-65 collisions (30), dependant on position (21), whereas, because of the shorter playing duration and the smaller number of players on the field, R7 players are typically involved in 5-25 collisions per game (31, 69). Observations following competitive matches show that these impacts, in combination with activities that involve a high frequency and intensity of eccentric muscle actions (e.g., high speed running with changes of direction, braking activities etc.), result in acute (i.e., immediately post-match) (12, 37, 62, 71) and residual (i.e., up to 120 h) perturbations in both performance and physiological responses following match-play (16, 48-51). Such findings are typically indicative of fatigue; a term that is widely used in several different contexts which acknowledges two main attributes: (1) a decline in an objective measure of performance or the inability to produce power, and (2) sensations of perceived tiredness (41).

Considerable methodological variation exists amongst studies profiling post-exercise responses in rugby players. With respect to the mode of exercise stimulus, responses to training (10, 15, 32, 61), simulated match-play (24, 54, 58, 78), tournaments or intensified periods of competition (7, 34, 36, 74), a full season (1, 9, 23), or a (single) competitive match (49-51, 56, 62) have all been examined. Likewise, incongruence exists between studies in the reporting of match demands (i.e., playing time, distance covered, high-speed running, number of carries, number and intensity of collisions and total match loads) with publications either providing a comprehensive analysis (38, 49, 50, 56, 62, 79), whereas others include only limited information (12, 45, 48, 67, 71), if any at all (16, 37, 51, 84). Given the ergogenic effects of compression garments (25, 80), cold-water immersion (CWI) (4, 22, 72), contrast water therapy (27, 28, 83) or supplementation (53, 59), the use of specific recovery strategies employed in the time between exercise completion and the post-exercise measurements also warrants consideration (38, 49, 51). While some studies report adherence to usual recovery practices (48, 50, 67), others omit information relating to any practices employed during the post-exercise period (12, 62, 71, 84). Also, the training that is concurrently performed after match-play is inconsistently reported with some studies employing high experimental control and omitting training for the full duration of the study (62, 71, 84), whereas others report adherence to a normal training regime (48-50). Accordingly, questions remain as to the ecological validity (i.e., the extent to which the findings are able to be generalized to real-life settings) (44) of the protocols adopted within these investigations.

Post-match responses to competitive rugby match-play have typically been assessed via measurement of neuromuscular (13, 49, 63), biochemical and endocrine (12, 16, 38, 45, 50, 71) or perceptual (18, 23) responses; with the majority of studies reporting more than one marker of recovery (37, 48, 51, 56, 62, 67, 79, 84). A recently published review (73) largely focused on the efficiency of different recovery strategies, whereas the present review aims to provide more of a contextual overview and describe post-match recovery timelines whilst highlighting the methodology and measures used between studies. Currently, no clear consensus exists regarding post-match recovery profiles and the timelines of such responses, whilst also considering the type of measurements performed as well as recognition of the different training regimes, recovery protocols, and other sources of methodological variation. The inclusion or exclusion of these contextual variables is likely to affect the magnitude and duration of the post-match response, which would have implications on the practical application of such data. In order to provide a correct interpretation of the post-exercise response, such contextual variables are to be accounted for. Therefore, this systematic review aimed to (a) determine the post-match monitoring tools, to (b) quantify the magnitude and time-course of post-match responses and to (c) account for contextual variables that may affect this response in male rugby players, with a view to informing current practice and highlighting opportunities for future research.

METHODS

At two time-points (i.e., March 2018 and January 2020), searches were performed in online databases (PubMed, Google Scholar) and included publications from February 1996 (to incorporate the start of the English Super League). The additional and most recent literature search (i.e., January 2020) was performed to ensure that any studies published since the original search were included. The search strategy conducted in the different databases, along with Medical Subject Heading (MeSH) descriptors, related terms and keywords followed the general principles of: name of the sport (i.e., rugby) entered in combination with key terms associated with 'fatigue' and 'recovery;' an indicative example of the search strategy for PubMed being: ("football"[MeSH Terms] OR "football"[All Fields] OR "rugby"[All Fields]) AND ("fatigue"[MeSH Terms] OR "fatigue" [All Fields]) AND recovery[All Fields]. Thereafter, Boolean searching of the terms 'post-match', 'post-game', 'muscle damage' and 'markers' in combination with different terms for, and related to, performance tests ('neuromuscular', 'muscle function', 'countermovement jump', 'CMJ', 'squat jump', 'jumps', 'drop jump', 'plyometric' 'press-up', 'force', 'power', 'velocity', 'sprint', 'bike', 'kinetic', 'kinematic', 'SSC', 'stretch-shortening cycle', 'test' and 'measurement), physiological responses ('biochemical', 'endocrine', 'creatine kinase', 'CK', 'cortisol', 'testosterone', 'inflammation', 'hormones', 'hormonal', 'markers', 'ratio', 'soreness', 'immune' and 'homeostasis'), psychological responses ('subjective', 'wellness', 'well-being', 'questionnaire', 'perceptual', 'perception', 'mood', 'mental', 'POMS', 'REST-Q', 'psychometric', 'indicators', 'score', 'scale', 'question', 'rating', and 'quality'), and recovery strategies ('interventions', 'strategies', 'compression', 'immersion', 'pool', 'swim', 'sauna', 'steam', 'thermoregulation', 'stimulation', 'techniques', 'REST', 'phototherapy', 'float therapy', 'laser therapy', 'massage', 'stretching', 'cryotherapy', 'sleep', 'nutritional', 'nutrition', 'protein', 'carbohydrates', 'stress', 'effects', 'improvement', 'response', 'active' and 'passive') followed. This search strategy was peer-reviewed by co-authors (SH & MR) as part of the systematic review process.

After eliminating duplicates, the titles and abstracts were analyzed and if there was not enough information, the full text was evaluated. Most articles found were written in English, but there were no language restrictions. Reviews, congress publications, theses, books, book chapters, abstracts, and studies with poor protocol description or insufficient data were not included. After screening of the title and abstract (and the full text if necessary) studies were also excluded based on the following exclusion criteria: (a) if the post-exercise response was measured following any exercise stimulus other than match-play (i.e., simulation or training), (b) if measures were averages taken over a whole season, (c) if measures were not taken at more than one time-point following match-play, (d) if measures were taken following an intensified competition schedule or multiple short games within the space of a couple days (i.e., tournaments), (e) if measures applied to in-game fatigue as opposed to post-match fatigue, (f) if the effects of recovery strategies on post-match responses were primarily investigated, or (g) if the players sampled were women. Articles were selected by two independent reviewers (HA and SH) according to inclusion and exclusion criteria. In the case of a disagreement, a third author (MR) was consulted. In addition, references cited in the retrieved articles and articles known to the authorship team were also considered for inclusion.

Given the characteristics of most observational profiling research (i.e., single-arm within-participant comparisons back to baseline measures), many study quality tools that have been used in previous systematic reviews (i.e., Physiotherapy Evidence Database; PEDro scale (81); (29, 64)) were not eligible due to the omission of key risk of bias indicators (e.g., participant and adjudicator blinding, allocation concealment etc.) attributable to the lack of randomized multiple-arm control group or placebo-controlled comparisons. Nevertheless, following a calibration exercise, two authors (HA and SH) independently assessed each study using a checklist of criteria relating to threats to the internal and external validity of observational studies (75). Items 11,13 and 21 were deemed not applicable as they were subcomponents of other questions unrelated to the majority of study designs represented and thus were removed, meaning that the modified scale was scored out of a possible 30 points. Overall adherence to such criteria was presented rather than implementing an arbitrary threshold for eligibility.

Data extraction forms were developed for each study and were piloted (HA and SH) before use. From each eligible study, and where applicable, the following information was independently extracted by two reviewers (HA and SH): name(s) of the author(s), subject characteristics, code and level of rugby, match-play details (i.e., stimulus), recovery strategies, outcome measures and main findings. No inter-reviewer differences in data extraction occurred. Eligible studies were grouped by outcome variable as follows: neuromuscular, biochemical/endocrine and subjective/perceptual responses. The absence of randomized control trials and the diverse range of study conditions and outcomes precluded meta-analytical statistics. However, for the most commonly reported indices, we applied a simple percentage change-from-baseline metric to investigate the mean influence of match-play on the outcomes of interest. Such data were presented graphically with further details represented in table form.

RESULTS

The combined searches yielded 3539 possible results. After removal of duplicates, and screening based on the title and abstract, 61 studies remained and were screened as per the exclusion criteria based on their full text. A total of 44 studies were excluded based on the seven exclusion criteria (i.e., a-g); thus, 17 studies were included in the final review. Figure 1 shows the flow chart of the systematic review process. Regarding the threats to the internal and external validity of each study, 15 out of 17 studies satisfied at least 50% of the criteria on the modified scale, with the remaining two studies scoring 47%. The mean score of all studies satisfying each of the 30 criteria was 58±7%.

***** INSERT FIGURE 1 NEAR HERE *****

Of the 17 studies included in this review, 11 studies profiled neuromuscular responses, 14 studies reported biochemical or endocrine responses and six studies reported subjective or perceptual responses to match-play. Eight studies reported a combined recovery profile, including more than one marker of post-match status, and thus were included in more than one theme.

Neuromuscular responses

In a total sample of 177 players (mass 93.5±7.3 kg; height: 1.84±0.02 m), the 11 studies that profiled a neuromuscular response following match-play implemented various measurement techniques, including isometric tests on the knee extensors (13), an adductor squeeze test (63), and a plyometric push-up (37, 56, 62), whilst the most common measure was the countermovement jump (CMJ) (13, 37, 48, 49, 51, 56, 62, 67, 79, 84) (Table 1). Although different CMJ variables (e.g., peak rate of force development; PRFD, peak force; PF, mean power) were reported (49, 51, 62), peak power output (PP) (37, 48, 49, 51, 67, 84) and flight-time (FT) (48, 56, 79) were the most frequently analyzed. Reductions in PP (<31.5%) occurred <30 min post-match, returning to baseline values within 48-72 h (Figure 2) whereas post-match reductions in FT (<4%) recovered after 48 h (Figure 3). The average age of the players in the studies profiling a neuromuscular response was ~22 years, whilst three studies (two of which used the same sample) focused on younger (i.e., <20 years old) athletes (37, 62, 63). Three studies (49, 56, 79) provided detailed information regarding the match demands of the exercise stimulus and four studies (49, 51, 56, 79) reported the use of recovery strategies post-match.

***** INSERT TABLE 1 NEAR HERE *****

***** INSERT FIGURE 2 NEAR HERE *****

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Biochemical and/or endocrine responses

In total, 14 studies (Table 2) assessed biochemical and/or endocrine responses following match-play in a total sample of 243 players (mass 94.9±6.5 kg; height: 1.84±0.03 m). Nine studies reported changes in Creatine Kinase (CK) concentrations, whereas eight studies reported relative changes in salivary or blood cortisol (C) concentrations, and six studies assessed the salivary or blood testosterone (T) response. Disturbances in CK peaked (120-451%) between 12-24 h, returning to baseline within 72 h of match-play (Figure 4). Initial increases in C (34-298%), and reduced T (<44%) concentrations, returned to pre-match values within 48-72 h (Figures 5 and 6, respectively). The average age of the players in the studies profiling endocrine and/or biochemical responses following match-play was ~24 years, with two studies profiling responses in younger (i.e., under-20s) (37) or academy RU (i.e., 16-19 years) players (62). In total, five studies provided detailed information in relation to match demands (38, 50, 56, 62, 79) while four studies reported the use of recovery strategies (38, 51, 56, 79), suggesting that the majority of these studies omit the influence of confounding variables that could influence the interpretation of the data.

***** INSERT TABLE 2 NEAR HERE *****

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Subjective/perceptual responses

Six studies (Table 3) profiled self-reported wellness responses in a total sample of 92 players (mass 97.8±6.4 kg; height: 1.84±0.01 m). After peaking at 24 h (<65%), mood disturbances required 48-72 h to normalize (Figure 7). The average age of the players in the studies profiling subjective responses was ~23 years, while a single study profiled responses in younger athletes (under-20s) (62). Detailed information in relation to match demands was reported in three studies (56, 62, 79), while specific details on recovery strategies have been reported in two studies (56, 79).

***** INSERT TABLE 3 NEAR HERE *****

***** INSERT FIGURE 7 NEAR HERE *****

DISCUSSION

As no clear consensus exists regarding the magnitude and duration of post-match recovery responses following rugby match-play, especially when accounting for sources of methodological variation (i.e., the type of measurements performed, recognition of training and recovery protocols implemented concurrently during the post-match period), this systematic review aimed to (a) determine the post-match monitoring tools, to (b) quantify the magnitude and time-course of post-match responses and to (c) account for contextual variables that may affect this response in male rugby players. It is highlighted that 72 h were needed to restore perturbations in neuromuscular, biochemical and/or endocrine, and subjective/perceptual responses following competitive rugby match-play. However, inconsistencies in training regimes and/or use of post-match recovery strategies meant that only four studies reported responses in ecologically valid scenarios (i.e., those in which normal training and recovery strategies were employed) while also reporting detailed match demands.

Neuromuscular response

Peak power output

Out of the five studies profiling the PP response to match-play (Figure 2), three reported an acute response post-match (i.e., within 60 min), observing decrements ranging between 6.5% and 31.5% (37, 49, 51). Whilst two of these studies (49, 51) also observed decrements of up to 37% at 24 h post-match, Johnston et al. (37) reported no significant differences at this time-point. This discrepancy in the magnitude of the responses between studies may be due to the exercise stimulus performed. While the smaller (i.e., ~6.5%) decrements represented responses to a lesser standard of the game (i.e., a feeder competition to the National Rugby League; NRL), other studies measured greater (i.e., ~37%) perturbations in PP in response to in-season NRL games (49, 51). While the two playing standards have similar game-specific skills, variation exists in the physical demands of the matches, with NRL players typically playing the game at a higher intensity (68).

In contrast to those studies reporting an acute post-match response (37, 49, 51), others (67, 84) took their first measurements at 12 h post-match. At this time-point, reductions of PP of 8% (67) and 15% (84) were reported to peak. Smaller reductions of up to 6% have been reported after 36 h, with almost full restoration of PP at 60 h post-match. Given that larger decrements have been reported at 24 h compared with 12 h following rugby match-play (49, 51), omitting measurements at 24 h (67, 84) could lead to an underestimation of the fatigue response. As neuromuscular responses are likely to peak within 24 h of match-play, additional training that has the potential to prolong or exacerbate fatigue in the same muscle groups (i.e., high-intensity field-based training or lower-body resistance training) should, where possible, be avoided at this time if recovery is deemed to be the priority.

Increases in PP of up to 49% have been reported between 24 h and 48 h post-match (49, 51), although not all studies support such a magnitude of change (36, 67, 84). Such discrepancies may reflect the different recovery strategies used throughout the duration of these studies (i.e., CWI, stationary cycling, massage and physiotherapy). Although conflicting findings exist (73), CWI has been proposed to enhance the speed of restoration of neuromuscular function (22, 83), and together with several other recovery modalities (i.e., stationary cycling, massage and physiotherapy), this could at least partly explain the large increases in PP measures following the initial 24 h post-match period. While a comprehensive overview of recovery strategies is beyond the scope of this review, the effective use of such strategies is likely to facilitate a quicker recovery of neuromuscular function, especially when multiple interventions are used concurrently.

Large inverse correlations have been reported between the number of very heavy and severe impacts and PP values measured at 24 h post-match (49). At this time-point, PF has already recovered to pre-match levels, while PP shows a continued reduction, possibly indicating that the velocity component of CMJ testing was more sensitive to fatigue than the force component. As this has been supported further (6, 65), it could be suggested that variables including a velocity component (i.e., PP or PRFD) are more fatigue-sensitive and are thus more useful than PF when monitoring post-match neuromuscular fatigue. While some variables may be more sensitive than others, it appears that neuromuscular fatigue mechanisms could require up to 72 h to normalize following rugby match-play (67, 84). Although, the precise origin of neuromuscular fatigue remains unclear, it has been reported that both central (i.e., decreased neural drive to the muscle originating from the brain and/or spinal cord) and peripheral factors (i.e., changes in contractile capabilities at, or distal to, the neuromuscular junction) contribute (5, 17, 43, 55). While recovery of PP is commonly achieved at 72 h post-match, day-to-day depressions have been observed after this time-point (49, 51). That being said, such findings have occurred when additional training sessions focusing on speed/agility, strength, or skills have been performed throughout the recovery period (49, 51). In order to provide information that is most applicable to practical environments, post-match responses should be profiled in ecologically valid scenarios (i.e., alongside ‘normal’ training regimes).

Flight-time

Three studies (48, 56, 79) reported the post-match FT response during CMJ testing (Figure 3). Two of these studies provided detailed information in relation to match demands as well as the post-match recovery strategies employed (56, 79). All studies have described a similar pattern of response in which FT is acutely reduced (i.e., within 60 min), before further decrements occur at 24 h post-match. Changes at 48 h and beyond have mostly been reported as trivial or insignificant, indicating a return to near pre-match values (56, 79).

It has been reported that the number of contacts experienced during match-play is inversely related to FT values assessed post-match (79). However, owing to the non-significance of findings, Oxendale et al. (56) did not report FT correlations with match demands. As other CMJ variables (i.e., PP) have demonstrated strong correlations with the demands of the preceding match, and given the relationship to the fatigue response (49, 61), it would appear worthwhile for applied practitioners to consider the loading imposed by collisions and activities requiring eccentric muscle actions (i.e., high-intensity running, accelerations and decelerations) when designing post-match training and recovery protocols.

An additional CMJ variable, the flight time:contraction time (FT:CT) ratio (the relationship between the time spent in the countermovement phase and the resulting flight time) has been proposed in the literature that has examined responses to Australian Football (8). FT:CT showed significant reductions initially post-match and after 24 h. Unlike FT however, small decreases after 72 h were still detected (8). Previous research has shown changes in hip and knee angle (2) as well as a decrease in muscle-tendon stiffness (76) during hopping tasks when players are in a fatigued state. These adapted mechanics could be responsible for any changes in FT:CT and may therefore be extremely useful to consider when measuring neuromuscular fatigue.

Biochemical and/or endocrine responses

Creatine kinase concentrations

As an intracellular protein commonly associated with muscle damage, CK is found in both the cytosol and mitochondria of tissue where energy demands are high (e.g., skeletal muscle) and is important in the regeneration of cellular adenosine triphosphate (ATP) (3). As the primary source of CK is cardiac muscle, the validity of reflecting changes in CK values as a consequence of the level and intensity of physical activity remains equivocal. High levels of day-to-day variation also exist in junior RU (60) and RL players (77). Nonetheless, intense exercise leads to cellular disturbances (i.e., cell damage and cell disruption) which causes CK to leak from cells into the blood serum, where CK concentrations have been measured (3).

Throughout most studies (Figure 4), after an acute post-match increase, the largest increase in CK levels was found after 24 h (37, 50, 51, 62, 71, 79). However, as some studies omitted measurements at this time-point, peak values have also been reported between 12-16 h. Therefore, whilst substantial variability exits between the magnitude of the responses in different studies (i.e., increments ranging from 120% to 451%), the highest CK concentrations were observed during the 12-24 h period following match-play (12, 38, 56).

For those studies that reported responses beyond 48 h, all but one (71) still observed significant increases in CK concentrations compared to baseline measures. Notably, as some studies profiled CK responses over five days (50, 51), significant elevations relative to baseline remained after 120 h (51). While it might appear useful to assess post-match CK responses over a prolonged period (i.e., >4 days), it should be considered that large inter-individual variability exists in such measures. Indeed, because non-modifiable (e.g., age, gender, ethnicity) and modifiable (e.g., hydration status, energy status, training status) factors have been shown to influence serum CK levels (3), it could therefore be questioned whether prolonged CK responses are an indication of continued exercise-induced muscle damage or natural perturbations. Indeed, changes in CK concentrations post-exercise may reflect merely the fact that muscle damage has occurred as opposed to the magnitude of the damage response. Nevertheless, although prolonged CK responses (i.e., >4 days) might occur, this is unlikely to significantly affect the prescription of post-match training regimes in an applied setting, as preparations for the following game will likely be taking priority (assuming one week between consecutive matches).

Some studies (50, 51) profiled recovery responses in ecologically valid scenarios in which training regimes (i.e., weight training, speed/agility and skills sessions) and recovery protocols (i.e., CWI, active recovery, massage and physiotherapy) were carried out and enforced as per the team's normal practices. It could be argued that these confounding variables would be expected to impact upon the recovery process. Notably, the inclusion of training (i.e., an additional stimulus in the form of speed/agility, strength or skills session) within the recovery period could prolong the return to baseline measures (10, 15), whereas the inclusion of effective strategies is likely to facilitate recovery (73). Although evidence highlights that a minimum of 72 h is needed to recover CK responses to pre-match levels in ecologically valid scenarios, it should be emphasized that not all training has to be omitted within this 72 h window. Training type and intensity (e.g., active recovery to possibly facilitate the ability to train) could be adapted to avoid prolonging the initial fatigue response (70, 73).

Match demands such as collisions and high-speed running are positively correlated with changes in CK concentrations, indicating that players who were more frequently involved in high-intensity running or collision bouts typically experienced greater increases in CK concentrations (38, 56, 79). It is therefore recommended that future research reports these specific demands, as they are likely to affect the interpretation of CK responses and consequently the timescale of recovery. Exposure to high-speed running and collisions is known to differ according to playing position, with forwards typically performing a greater amount of collisions and backs typically covering more distance at higher intensities (35). As specific match demands (i.e., high-speed running and collision bouts) differ between codes and positions (38, 56, 79), this would consequently affect position-specific recovery timelines and should be considered in applied practice.

Cortisol concentrations

As it is considered an important catabolic hormone, the release of C is stimulated by adrenocorticotrophic hormone as a response to stress. Elevations in C result in increases in protein degradation in muscle and connective tissue (8). Within physiological limits, the magnitude of C secretion is generally proportional to the stress incurred (i.e., severe stress would result in a larger increase in C concentration than mild stress) (8). Consequently, post-match C concentrations have been used to give a representation of the level of stress that players have endured throughout the match and therefore have been used as a recovery marker. The majority of studies observed salivary C responses (Figure 5), whereas one study reported concentrations of serum C (12). It is known that specific endocrine responses demonstrate circadian rhythmicity; a factor which alongside the potential for large individual variability, should be considered when using endocrine responses as an indication of recovery (46).

Out of the seven studies observing changes in C responses following match-play, five reported acute measurements (i.e., within 60 min following match-play) (12, 16, 45, 50, 51), whereas two studies performed their first post-match measure at a later (i.e., 12 h) time-point (67, 84). Of these five studies carrying out acute measurements, four studies reported an immediate rise in C concentrations, which would be the likely result of the intensity and duration of exercise (42), and any anxiety responses (57) that are associated with rugby match-play. In large contrast to the increased C concentrations in the majority of studies (12, 45, 67, 84), a single study reported an almost immediate (i.e., within 2 h) decrease in C concentrations, which persisted throughout the duration of the study (i.e., 144 h) (16). However, information regarding playing time for the 20 participants, including five substitutes, was lacking. It is therefore possible that a reduced playing time for substitutes, and thus differences in the overall match-demands experienced, may have influenced the mean C responses for the whole group. To avoid underestimation of the C response, future research incorporating post-match measurements of C concentrations should consider performing initial post-match measurements within 60 min, as multiple studies have indicated that this is a crucial period in which peak C concentrations are reported.

Despite an immediate post-match elevation in C concentrations being observed, substantial variability still exists. Indeed, Lindsay et al. (45) reported a four-fold increase in C concentrations at 30 min post-match, which is more than twice that observed in other studies (12, 50, 51). An argument is made in this study that this was the result of a difference in game intensity (45). However, this remains unclear as very little information was reported in relation to specific match demands. The only information provided related to total distance covered (6029 ± 690 m) and the number of impacts (46 ± 25), which do not differ drastically from values reported in other studies (50) and are therefore unlikely to explain differences in the C concentrations observed. This finding emphasizes the point that contextualization of match demands is required to improve the interpretation of recovery data collected throughout such studies.

Testosterone concentrations

Testosterone (T) is an important psychosocial hormone which may help to regulate emotions and behaviors (e.g., motivation, mood and aggression) (11). Although evidence suggests that the role of T in anabolic processes may be questioned (85), it has been used as a marker of recovery. Changes in T concentrations have been reported to be proportional to the duration and intensity of exercise (i.e., longer and more intense exercise elicits a larger effect in T). Out of the five studies reporting relative T responses (Figure 6), three studies reported an acute (i.e., within 60 min following match-play) response, of which two studies observed decreased concentrations ranging from ~14 to ~44% (12, 16). When the first post-match measurements were taken at a later time-point (i.e., 12 h), decrements of ~30% were reported (67, 84). It could be argued that studies omitting measurements directly post-match underestimated the magnitude of the fatigue response, as a number of studies have identified this as the period in which peak reductions occur. Largely in contrast to the body of literature (12, 67, 84), McLellan et al. (50) reported an immediate rise in T concentrations post-game. However, this appears to be the result of a sudden decrease in T concentrations 30 min pre-match when compared with measures taken 24 h beforehand.

After an initial post-match decrease, T concentrations typically rise and approached baseline values after 38 (12) or 60 (67, 84) h, possibly indicating that two or three days are required for T concentrations to recover post-match. In contrast, a single study (16) reported recovery of T values as early as 12 h post-match. However, because this study applied no exclusion criteria based on playing time, it may be that average responses were affected by potentially minor physiological changes within substitute players who were exposed to fewer minutes of match-play.

Subjective/perceptual responses

Disturbances in wellness could be caused by a variety of match-related variables (i.e., result of the game, individual match demands, individual performance and feedback on individual performance) and external (i.e., sleep disturbance, family commitments, relationships, work and education) factors (39). Peak disturbances in wellness (ranging from 24 to 65%) occurred 24 h post-match, before the response stabilized or began a gradual return towards baseline (Figure 7). Although complete recovery was not reported in any of the studies, no significant changes in wellness disturbance compared to baseline measures were reported between 48 and 72 h, indicating that responses have returned to near pre-match values.

A common method by which players provide feedback on wellness is via the use of questionnaires. Although many different questionnaires exist, two short 6-item questionnaires, whereby players indicated their responses on a 5-point Likert-scale have often been used in practice, being, a psychological questionnaire assessing different facets of wellness (48, 62), and the brief assessment of mood (BAM) (67, 84); a brief version of the Profile of Mood States (POMS) (52) that assesses different mood adjectives. Large variability exists between these two questionnaires; the rated items in each questionnaire assess different facets of the recovery process while ratings also represent reversed responses (i.e., in some studies (48, 62) a low score represents a negative response and a high score represent a positive response, whereas in other studies (67, 84), the opposite was true). This emphasizes that although post-match wellness responses appear similar, large methodological differences make direct comparisons between studies challenging.

Another common method to provide feedback on wellness is via ratings of perceived muscle soreness (18); for which there is no standardized rating system, with some studies using a 1-5 Likert scale (48, 79), whereas others have used a 0-6 Likert scale (56). However, a more expansive scale (i.e., 1-10 or 1-100) might be preferable to express a more accurate representation of the response and thus sensitivity of the scales (47). While most studies use a general muscle soreness score, a more expansive approach was adopted in Australian Football (40), which required a score of soreness of different body parts on a 1-10 Likert scale (both left and right side of calf, hamstring, quadriceps, adductor, hip flexor and glutes) and an average of those ratings was taken for a full body muscle soreness score. This approach may be useful as it gives more specific feedback to the coaches about soreness in different body parts so training could be adapted accordingly. However, it may be useful that this also accounts for upper-body sites. The use of a rating of muscle soreness as opposed to a questionnaire (in which ratings of muscle soreness may also be included (48, 62)) could both prolong and reduce a return to baseline measures as the sensitivity of the mode of measurement may influence the interpretation of the time-course of recovery observed.

The importance of reporting match demands in detail is further highlighted by observations that repeated-high-intensity-efforts (RHIE) and number of collisions (heavy collisions particularly) during match-play displayed strong correlations with increased muscle soreness (56). It is argued that a combination of blunt-force trauma caused by physical collisions and high-intensity eccentric movements have a greater effects on muscle damage and muscle soreness than each factor in isolation (33). Subsequent positional comparisons may be a useful addition to future research, as the increased number of collisions and RHIE performed by forwards may lead to greater muscle soreness in comparison to backs, which could affect the consequent recovery period (56).

Conclusions and directions for future research

The aim of this review was to summarize the magnitude and time-course of the post-match responses following competitive encounters in rugby. Although, contextual factors meant that considerable variability was observed, recovery timelines have been reported. Neuromuscular responses have been assessed through monitoring CMJ performance (PP and FT), with acute reductions in PP of up to 31.5% being followed by decrements of up to 37% at 24 h post-match. Measurements of PP appear to be a more sensitive marker of fatigue than FT as prolonged decreases are observed beyond 48 h, while any decreases in FT beyond 48 h are mostly found to be trivial or insignificant. With this in mind, practitioners should seek to assess those variables that represent the most sensitive markers of neuromuscular fatigue within their testing battery. That being said, it would be worthwhile for future research to explore additional CMJ variables as well as the utility of other measures of fatigue in response to rugby match-play in order to assess their sensitivity and thus the efficacy of their adoption within both research and practice.

Studies profiling changes in CK concentrations reported peak increases of 120-451% between 12 and 24 h post-match. In contrast, in most studies profiling a C and T response, peak values were reported acutely post-match. However, while biochemical and/or endocrine responses are often reported within rugby literature, it is important to consider that large inter-individual variability exists, and thus findings must be interpreted with caution. Subjective responses to match-play have proven difficult to compare due to the large variability in methodologies (e.g., differences in Likert scales, different 'topics' or 'emotions' that require to be rated and reversed responses). Notwithstanding, all studies that have reported a subjective response have observed peak disturbances in wellness of 24-65% occurring at 24 h post-match, after which near baselines measures are achieved between 48 and 72 h.

Out of the studies reported, only four (38, 49, 56, 79) provided detailed information relating to match demands (i.e., total distance, high-speed running, number of collisions etc.), training regimes (i.e., type and timing of training sessions) and recovery strategies (i.e., type and timing of specific strategies). Reporting such information is important as these variables may profoundly influence the recovery responses observed. For example, performing intense training within the recovery period could prolong the return to baseline measures, whereas the inclusion of effective recovery strategies is likely to have the opposite effect.

The average age of the participants in studies profiling a fatigue response following match-play was 23 years, with only three studies (of which two worked with the same sample) using junior athletes (under-20 or academy teams), suggesting there is a lack of research that profiles recovery within junior athletes. As it is reported that correlations exist between match demands and the magnitude of post-match responses (38, 56, 79), it could be argued that recovery timelines in junior athletes might be different as a result of differing match demands. Additionally, junior athletes often do not play rugby full-time and as a result face competing lifestyle demands (i.e., education, work), which could influence their recovery profiles. Future research should be focused around junior athletes in order to have a better understanding of their recovery timelines and consequently provide applied practitioners with recommendations regarding the recovery process specific to this age group.

This review has explored the literature that currently exists around the post-match response in relation to different rugby codes (i.e., RL, RU). However, while novel, our review is not without its limitations; chiefly, the lack of randomized control trials and the diversity of study outcomes precluded meta-analytical statistical approaches. We therefore presented findings as a simple percentage change-from-baseline metric, but admittedly this approach may limit the interpretability of the results due to omission of confidence intervals reflecting the uncertainty inherent in the estimates. Furthermore, a limited number of studies have profiled responses following match-play in ecologically valid conditions, and scant data exists concerning the adequacy of current tools when assessing study quality in observational repeated measures study designs that omit randomization and/or blinding and concealment allocation processes. Accordingly, rather than classify studies as eligible or not according to a specific arbitrary threshold, we reported the proportion of studies meeting the criteria of the modified scale used. As defined by Tooth et al. (75), information relating to sample-size justification, the impact of biases, and the missingness of data items at each measurement point were commonly omitted across the 17 studies reported. It is therefore possible that our findings are influenced somewhat by these observations. Nevertheless, we sought to systematically source and review relevant literature, while graphically outlining the relative changes of the different recovery profiles, and thus provide a unique insight into how recovery manifests following rugby match-play. Consequently, this has highlighted that there is a need for further investigations to be carried out in realistic practical scenarios and environments in order to guide fatigue profiling and the recovery process in practice. Furthermore, different avenues for future research have been suggested in order to provide new insights and developments in the recovery process of rugby players.

PRACTICAL APPLICATIONS

With a view to minimizing underperformance and/or injury and to enhance readiness for subsequent training and match-play, it is recommended that where possible, practitioners actively monitor post-match responses. Collectively, findings suggest that 72 h are needed to restore neuromuscular, biochemical and/or endocrine, and subjective responses to pre-match levels. However, evidence shows that the type of profiling has a large effect on the different timelines of fatigue responses (i.e., depressions or elevations peak and return back to baseline at different time-points based on the type of profiling used). This should be taken into consideration by practitioners when selecting their monitoring tools to assess post-match responses. Although it would be desirable to take a holistic approach and perform different types of profiling, time and budget considerations may restrict this in practice. For these reasons, reliable indices of subjective wellness may represent an important monitoring tool for applied practitioners, particularly for those working in environments where funding for post-match recovery monitoring is low. Alongside monitoring the post-match response, it may be worthwhile for applied practitioners to collect data in relation to match demands, and specifically details in relation to collisions and eccentric muscle actions (i.e., high-intensity running, accelerations and decelerations), as they have shown to be correlated to several markers of fatigue following match-play. Notably, because these variables are known to differ according to playing position, there is the potential for position-specific recovery recommendations and training (i.e., type and intensity) requirements to be implemented in the time post-match.

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LEGENDS

Figure 1: Literature search strategy

Figure 2: Recovery time-course percentage changes in countermovement jump (CMJ) peak power output (PP) following rugby union (RU) and league (RL) match-play

Figure 3: Recovery time-course percentage changes in countermovement jump (CMJ) flight-time (FT) following rugby union (RU) and league (RL) match-play

Figure 4: Recovery time-course percentage changes in creatine kinase concentrations following rugby union (RU) and league (RL) match-play

Figure 5: Recovery time-course percentage changes in cortisol concentrations following rugby union (RU) and league (RL) match-play

Figure 6: Recovery time-course percentage changes in testosterone concentrations following rugby union (RU) and league (RL) match-play

Figure 7: Recovery time-course percentage changes in subjective responses following rugby union (RU) and league (RL) match-play. * represents wellness questionnaire, [a] represents energy index measure, [b] represents muscle soreness rating, [c] represents perceived fatigue rating, [d] represents attitude to training rating

Table 1: Studies investigating the recovery profile of neuromuscular responses following rugby match-play

Table 2: Studies investigating the recovery profile of biochemical and endocrine responses following rugby match-play

Table 3: Studies investigating the recovery profile of subjective responses following rugby match-play

Table 1: Studies investigating the recovery profile of neuromuscular responses following rugby match-play.

Study	Players	Code + Level	Stimulus	Recovery Strategies	Measures taken	Results
Johnston et al. (37)	Professional U20 players (n: 21; age: 19±2 years; stature: 1.81±0.06 m; mass: 89.9±10.0 kg)	RL; feeder team competition to the NRL	Not reported	Not reported	CMJ (PP) (%Δ from baseline)	+30 min: -6.5±7.0% ↓ from baseline, +24 h: -3.1±8.2% ↔, +48 h: -1.5±5.9% ↔
McLean et al. (48)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	CMJ (FT) (Δ from baseline)	+24 h: ↓ from baseline (*d*: 1.67), +96 h: ↔ (*d*: 0.96)
McLellan & Lovell (49)	Professional players (n:22; age: 24±7 years; stature: 1.88±0.02 m; mass: 94.6±26.8 kg)	RL; NRL team	Distance: 7886±1695 m (B), 7462±1566 m (F); #tackles: 11±9 (B), 26±15 (F); #carries: 12±5 (B), 14±5 (F)	Post-match: cycle (10min), CWI, light meal → MD+1 (AM): stationary cycling (10min), CWI, physiotherapy + massage available → MD+1 (PM): cycle (10min), CWI, physiotherapy + massage available, active rest	CMJ (PP)	+30 min: 3109±892 W ↓ from baseline (4539±976 W), +24h: 2865±824 W ↓, +48 h: 4286±1142 W ↔, +72 h: 4843±1087 W ↔, +96 h: 4621±1379 W ↔, +120 h: 4447±1274 W ↔
McLellan et al. (51)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Not reported	Post-match: cycle (10min), CWI → MD+1 (AM): cycle (10min), CWI, physiotherapy + massage available → MD+1 (PM): active rest	CMJ (PP)	+30 min: 3123±850 W ↓ from baseline (4429±991 W), +24 h: 3479±717 W ↓, +48 h: 4540±898 W ↔, +72 h: 4632±959 W ↔, +96 h: 5050±979 W ↔, +120 h: 4485±875 W ↔
Oxendale et al. (56)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	CMJ (FT)	+12h: 0.612 s ↓ from baseline (0.637 s), +36 h: 0.6115 s ↓, +60 h: 0.623 s ↔
Shearer et al. (67)	Professional players (n:12; age: 25±4 years)	RU; professional team in South Wales, UK	Playing duration: 82±11 min.	Participants instructed to follow normal individual recovery strategies. No details reported.	CMJ (PP)	+12 h: 5628±660 W ↓ from baseline (6119±526 W), +36 h: 5777±684 W ↓, +60 h: 5976±497 W ↓

Twist et al. (79)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	CMJ (FT)	F: +24 h: 0.59±0.06 ↓ from baseline (0.61±0.04 s), +48 h: 0.6±0.05 s ↓ B: +24 h: 0.64±0.04 ↓ from baseline (0.66±0.04 s), +48 h: 0.64±0.03 ↓
West et al. (84)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	CMJ (PP)	+12 h≈ 5190 W ↓ from baseline (≈6100 W), +36 h≈ 5750 W ↓, +60 h: (≈5910 W) ↓

Δ: Change, ↓: Significant decrease from baseline, ↔: No significant change from baseline, #: Number of, B: Backs, CMJ: Countermovement jump, *d* :Cohen's d, F: Forwards, FT: Flight-Time, MD: Match day, MD +1: First day post-match, NRL, National Rugby League, PP: Peak power output, RelPP, Relative Peak Power, RHIE: repeated high-intensity effort, RL: Rugby League, RU: Rugby Union, SL: Super League.

Table 2: Studies investigating the recovery profile of biochemical and endocrine responses following rugby match-play.

Study	Players	Code + Level	Stimulus	Recovery Strategies	Measures taken	Results
Cunniffe et al. (12)	Professional players (n: 10; age: 26±1 years; stature: 1.87±0.03 m; mass: 103.1±3.9 kg)	RU; international team (Wales)	Playing duration: 69±9 min	Not reported	C,T,CK	C: +30 min: 534±47 nmol·L^{-1} ↔ from baseline (313±6.3 nmol·L^{-1}), +14 h: 400±21 nmol·L^{-1} ↔, +38 h: 261±21 nmol·L^{-1} ↔ T: +30 min: 13.8±1.3 nmol·L^{-1} ↓ from baseline (24.6±0.6 nmol·L^{-1}), +14 h: 20.2±1.3 nmol·L^{-1} ↔, +38 h: 24.3±2.1 ↔ CK: +30 min: 519±60 IU·L^{-1} ↔ from baseline (333±49 IU·L^{-1}), +14 h: 1182±231 IU·L^{-1} ↑, +38 h: 750±99 IU·L^{-1} ↑
Elloummi et al. (16)	Semi-professional players (n: 20; age: 25±4 years; stature: 1.80±0.05 m; mass: 88.0±2.9)	RU; Tunisian national team	Not reported	Not reported	C,T	C: +30 min ≈20.2 nmol·L^{-1} ↔ from baseline (≈17.8 nmol·L^{-1}), +2 h≈ 12.1 nmol·L^{-1} ↓, +4 h≈ 6.9 nmol·L^{-1} ↓, +12 h≈ 10.1 nmol·L^{-1} ↓, +24 h≈ 5.3 nmol·L^{-1} ↓, +36 h≈ 9.1 nmol·L^{-1} ↓, +48 h≈ 4.7 nmol·L^{-1} ↓, +60 h≈ 10.0 nmol·L^{-1} ↓, +72 h≈ 4.5 nmol·L^{-1} ↓, +84 h≈ 9.4 nmol·L^{-1} ↓, +96 h≈ 5.6 nmol·L^{-1} ↓, +108 h≈ 13.7 nmol·L^{-1} ↓, +120 h≈ 6.1 nmol·L^{-1} ↓, +132 h≈ 15.3 nmol·L^{-1} ↓, +144 h≈ 6.4 nmol·L^{-1} ↓ T: +30 min≈ 20.2 nmol·L^{-1} ↔ from baseline (≈365 pmol·L^{-1}), +2 h≈ 305 pmol·L^{-1} ↓, +4 h≈ 315 pmol·L^{-1} ↓, +12 h≈ 430 pmol·L^{-1} ↔, +24 h≈ 400 pmol·L^{-1} ↔, +36 h≈ 410 pmol·L^{-1} ↔, +48 h≈ 415 pmol·L^{-1} ↔, +60 h≈ 465 pmol·L^{-1} ↔, +72 h≈ 355 pmol·L^{-1} ↔, +84 h≈ 402 pmol·L^{-1} ↔, +96 h≈ 402 pmol·L^{-1} ↔, +108 h≈ 365 pmol·L^{-1} ↔, +120 h≈ 390 pmol·L^{-1} ↔, +132 h≈ 415 pmol·L^{-1} ↔, +144 h≈ 410 pmol·L^{-1} ↔
Johnston et al. (37)	Professional U20 players (n: 21; age: 19±2 years; stature: 1.81±0.06 m; mass: 89.9±10.0 kg)	RL; feeder team competition to the NRL	Not reported	Not reported	CK (%Δ from baseline)	+30 min: ↑ from baseline (relative changes not reported), +24 h: 120±92% ↑, +48 h: 55±58% ↑
Jones et al. (38)	Professional players (n: 28; age: 24±3 years; (B); body mass: 111.6±5.7 kg (F), 94.2±7.9 kg (B))	RU; Team in the European Cup	Game time: 80±13 min (F), 87±11 min (B), total distance: 4906±902 m (60.4±7.8 m/min) (F), 5959±1013 m (67.8±8.2 m/min) (B); high-speed running (>5 m·s^{-1}): 231±167 m (F), 509±150 m (B); sprinting (>5.6 m·s^{-1}): 121±112 m (F), 333±122 m (B); #total impacts: 25±9 (F), 15±7 (B)	Post-game: CWT. MD+1: Active recovery.	CK	B: +16 h: 1511±871 U·L^{-1} ↑ from baseline (274±155 U·L^{-1}), +40 h: 814±412 U·L^{-1} ↑ F: +16 h: 1073±483 U·L^{-1} ↑ from baseline (368±127 U·L^{-1}), +40 h: 657±412 U·L^{-1} ↑

Linsday et al. (45)	Professional players (n: 11; stature: 1.87 m (1.81-1.89 m); mass: 96 kg (88.5-101.5 kg)	RU; Division one team in New-Zealand	Distance: 6029±690 m; #impacts: 46±25	Not reported	C	C: +30 min: 60.5±24.6.6 µmol·L^{-1} ↑ from baseline (15.2±7.2 µmol·L^{-1}), +17 h≈ 33.4 µmol·L^{-1} ↔, +25 h≈ 15.1 µmol·L^{-1} ↔, +38 h≈ 33.7 µmol·L^{-1} ↔, +62 h≈ 34.1 µmol·L^{-1} ↔
McLean et al. (48)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	C & T (Δ from baseline)	C: +24 h: ↔ from baseline, +96 h: ↑ (*d*: 0.60) T: +24 h: ↔ from baseline, +48 h: ↔, +96 h: ↔
McLellan et al. (50)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Distance: 5747±1095 m (B), 4774±1186 m (F); distance at high-intensity running (5-5.5 m·s^{-1}): 135±49 m (B), 82±21 m (F); sprinting (>5.5 m·s^{-1}): 290±69 m (B), 149±32 m (F)	MD+1: Two recovery sessions. No details reported.	CK, C, T (%Δ compared to previous time-point)	CK: +30 min: 56% ↑ from baseline, +24 h: 91% ↑, +48 h: -32% ↔, +72 h: -3% ↔, +96 h: -18% ↔, +120 h: 12% ↔ C: +30 min: 68% ↑ from baseline, +24 h: -32% ↑, +48 h: -37% ↔, up to +120 h ↔ (relative changes not reported) T: +30 min: 14% ↔ from baseline, +24 h: 33% ↑, +48 h≈ 1.6% ↑, +72 h≈ 8.5% ↑, +96 h: -29.3% ↔, +120 h: -7.56% ↔
McLellan et al. (51)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Not reported	Post-match: cycle (10min), CWI → MD+1 (AM): cycle (10min), CWI, physiotherapy + massage available → MD+1 (PM): active rest	CK, C	CK: +30 min: 454±167 U·L^{-1} ↑ from baseline (302±128 U·L^{-1}), +24 h: 941±392 U·L^{-1} ↑, +48 h: 592±201 U·L^{-1} ↑, +72 h: 553±191 U·L^{-1} ↑, +96 h: 442±154 U·L^{-1} ↑, +120 h: 365±139 U·L^{-1} ↑ C: +30 min: 21.9±4.4 nm·L^{-1} ↑ from baseline (13.1±2.6 nm·L^{-1}), +24 h: 15.3±3.5 nm·L^{-1} ↔, +48 h: 9.5±1.4 nm·L^{-1} ↔, +72 h: 9.5±1.6 nm·L^{-1} ↔, +96 h: 7±1.1 nm·L^{-1} ↓, +120 h: 9.2±1.5 nm·L^{-1} ↔
Oxendale et al. (56)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	CK (MDif from baseline)	+12 h: 808.0±169.3 U·L^{-1} ↑ from baseline, +36 h: 525.0±136.4* U·L^{-1} ↑, +60 h≈ 95 U·L^{-1} ↑
Roe et al. (62)	Professional U19 players (n: 14; age 17±1 years; stature: 1.83±0.08 m; mass: 86.2±11.6 kg)	RU; English academy team	Match duration: 73 min; AML: 334±121 AU; distance covered: 4691±878 m (74±6m.min^{-1}) of which 2215±461 m jogging, 663±238 m striding and 41±40 m sprinting; APLTM: 451±102; PLTMs: 187±47	Not recovery session	CK (%Δ from baseline)	+30 min: 138.5±33.1% ↑ from baseline, +24 h: 326.0±77.6% ↑, +48 h: 176.4±62.4% ↑, +72 h: 56.7±34.5% ↑
Shearer et al. (67)	Professional players (n: 12; age: 25±4 years)	RU; professional	Playing duration: 82±11 min.	Participants instructed to follow normal	C, T	C: +12 h: 0.55±0.11 µg/dL ↑ from baseline (0.40±0.10 µg/dL), +36 h: 0.610±0.20 µg/dL ↑, +60 h: 0.52±0.23 µg/dL ↔

		team in South Wales, UK		individual recovery strategies. No details reported.		T: +12 h: 147.6±60.1 pg/mL ↓ from baseline (204.9±80.8 pg/mL), +36 h: 163.6±68.5 pg/mL ↓, +60 h: 186±79.7 pg/mL ↔
Takarada (71)	Amateur players (n: 15; age: 23-30 years; stature: 1.8±0.01 m; mass: 87.4±2.2 kg)	RU; Japanese amateur team	#Tackles: 14.0±7.4; Mean duration of work: 21.5±2.2 s; Mean duration of rest: 24.3±3.1 s	Not reported	CK	+0 min≈ 520 U/L ↔ from baseline (≈ 250 U/L), +45 min≈ 570 U/L ↔, +90 min≈ 600 U/L ↔, +24 h≈ 1050 U/L ↑, +48 h≈ 750 U/L ↔, +72 h≈ 300 U/L ↔
Twist et al. (79)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	CK	B: +24 h: 420.8 IU·L^{-1} ↑ from baseline (141 IU·L^{-1}), +48 h: 257 IU·L^{-1} ↑ F: +24 h: 431 IU·L^{-1} ↑ from baseline (171.7 IU·L^{-1}), +48 h: 266 IU·L^{-1} ↑
West et al. (84)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	C, T	C: +12 h≈ 0.58 ug·dL^{-1} ↑ from baseline (≈0.39 ug·dL^{-1}), +36 h≈ 0.58 ug·dL^{-1} ↑, +60 h≈ 0.51 ug·dL^{-1} ↔ T: +12 h≈ 151 pg·ml^{-1} ↓ from baseline (≈ 215 pg·ml^{-1}), +36 h≈ 167 pg·ml^{-1} ↓, +60 h≈ 178 pg·ml^{-1} ↔

#: Number of, Δ: Change, ↓: Significant decrease from baseline, ↑: Significant increase from baseline, ↔: No significant change from baseline, AML: Average match load (RPE x time), APL^{TM}: Average PlayerLoad^{TM}, AU: Arbitrary units, B: Backs, C: Cortisol, CK: Creatine Kinase, *d* :Cohen's d, F: Forwards, MD: Match-day, MD +1: first day post-match, MDif: Mean difference, NRL, National Rugby League, PLTMs: PlayerLoad^{TM} slow, RL: Rugby League, RPE: Rate of perceived exertion, RU: Rugby Union, SL, Super League, T: Testosterone.

Table 3: Studies investigating the recovery profile of perceptual responses following rugby match-play

Study	Players	Code + Level	Stimulus	Recovery Strategies	Measures taken	Results
McLean et al. (48)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	Five-item wellness Q on a 5p LS (1: negative outcome,5: positive outcome) + fatigue levels + muscle soreness (Δ from baseline)	Q: +24: ↓ from baseline (*d*: -1.64), +48 h: ↓ (*d*: -1.53), +96 h: ↔ Fatigue: +24 h: ↑ from baseline (*d*: -1.65), +48 h: ↑ (*d*: -1.42), +96 h: ↔ Muscle soreness: +24 h: ↑ from baseline (*d*: -1.57), +48 h: ↑ (*d*: -1.44), +96 h: ↔
Oxendale et al. (56)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	Rating of perceived muscle soreness on a 7p LS (0: extreme soreness – 6: no soreness) (MDif to baseline)	+12 h: -1.1±0.5 ↓ from baseline, +36 h: -0.8±0.5 ↓, +60 h: ↔ (not reported)
Roe et al. (62)	Professional U19 players (n: 14; age 17±1 years; stature: 1.83±0.08 m; mass: 86.2±11.6 kg)	RU; English academy team	Match duration: 73 min; AML: 334±121 AU; distance covered: 4691±878 m (74±6m.min^{-1}) of which 2215±461 m jogging, 663±238 m striding and 41±40 m sprinting; APLTM: 451±102; PLTMs: 187±47	No recovery session	Six-item wellness Q on a 5p LS (1: negative outcome, 5: positive outcome) (%Δ from baseline)	+24 h: -24.0±4.3% ↓ from baseline, +48 h: -8.3±5.9% ↓, +72 h: -3.6±3.7% ↔
Shearer et al. (67)	Professional players (n: 12; age: 25±4 years)	RU; professional team in South Wales, UK	Playing duration: 82±11 min.	Participants instructed to follow normal individual recovery strategies. No details reported.	Six-item wellness Q on a 5p LK (BAM) (1: not at all – 5: extremely)	Mood Disturbance: +12 h: 7.67±4.49 ↑ from baseline (4.92±2.27), +36 h: 6.33±2.96 ↑, +60 h: 5.17±3.56 ↔ Energy Index: +12 h: 0.86±0.6 ↓ from baseline (1.52±1.19), +36 h: 0.92±0.6 ↓, +60 h: 1.26±0.7 ↔
Twist et al. (79)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	Rating on muscle soreness, fatigue, and attitude to training on a 5p LS (1: positive outcome -5: negative outcome)	Muscle soreness: (B): +24 h: 3.5±0.7 ↑ from baseline (2.3±0.7), +48 h: 3.2±0.6 ↑ (F): +24 h: 3.2±0.8 ↑ from baseline (2.0±0.4), +48 h: 3.3±0.9 ↑ Fatigue: (B): (2.4±0.5) +24 h: 3.3±0.7 ↑ from baseline, +48 h: 3.0±0.8 ↑; (F): +24 h: 3.0±0.8 ↑ from baseline (2.2±0.4), +48 h: 3.0±0.9 ↑ Attitude to training: (B): +24 h: 2.4±0.7 ↑ from baseline (1.9±0.8), +48 h: 2.5±1.4 ↔ (F): +24 h: 2.3±1.1 ↑ from baseline (1.4±0.7), +48 h: 2.2±1.2 ↔

West et al. (84)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	Six-item wellness Q on a 5p LS (BAM) (0: not at all – 4: extremely outcome)	Mood disturbance score: +12 h≈ 7.49 (56%) ↑ from baseline (≈4.80), +36 h≈ 6.38 (33%) ↔, +60 h≈ 5.18 (8%) ↔

#: Number of, Δ: Change, ↓: Significant decrease from baseline, ↑: Significant increase from baseline, ↔: No significant change from baseline, 5p LS: 5-point Likert Scale, 7p LS: 7-point Likert Scale AML: Average match load (RPE x time), APLTM: Average PlayerLoad™, AU: Arbitrary units, B: Backs, BAM: Brief Assessment of Mood, *d* :Cohen's d, F: Forwards, MD: Match day, MD +1: First day post-match, MDif: Mean Difference, NRL, National Rugby League, PLTMs: PlayerLoad™ slow, RL: Rugby League, RPE: Rate of perceived exertion, RU: Rugby Union, SL, Super League, Q: Questionnaire.

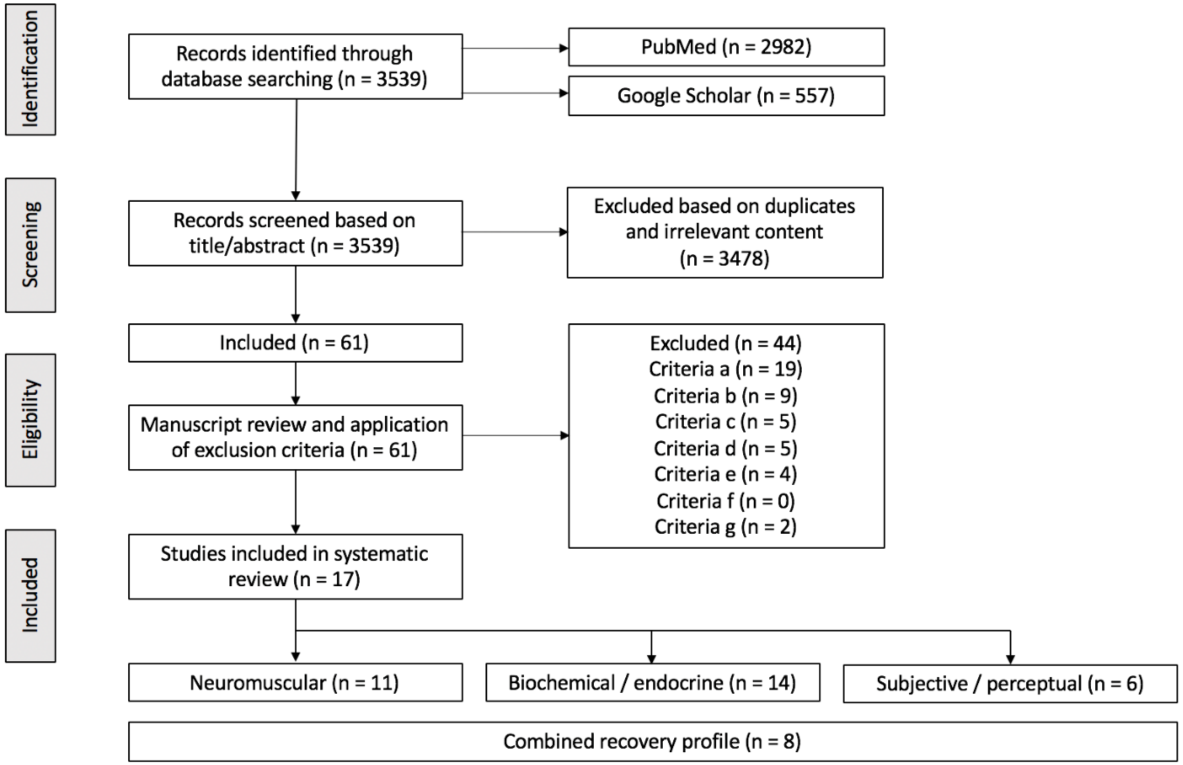

Figure 1: Literature search strategy

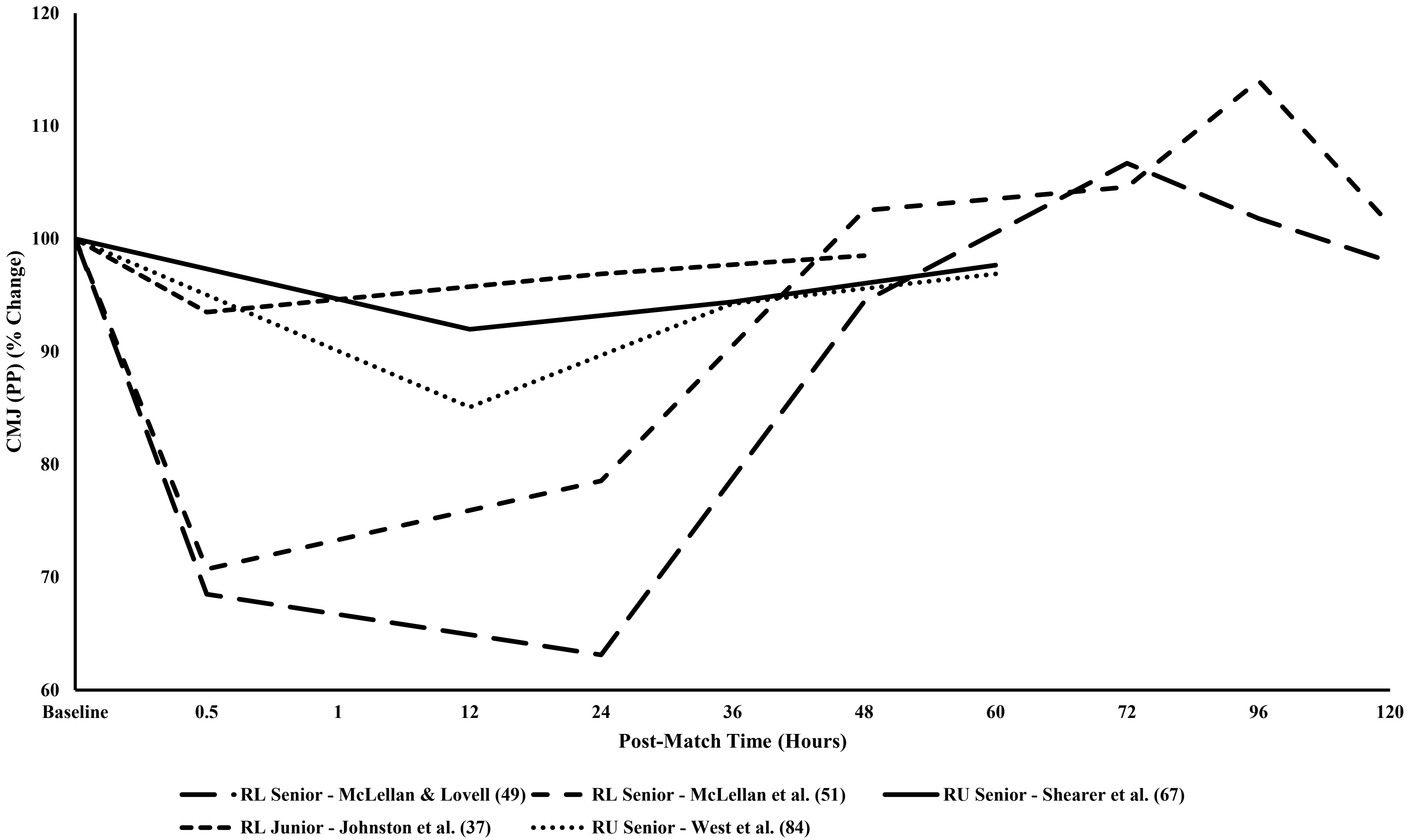

Figure 2: Recovery time-course percentage changes in countermovement jump (CMJ) peak power output (PP) following rugby union (RU) and league (RL) match-play

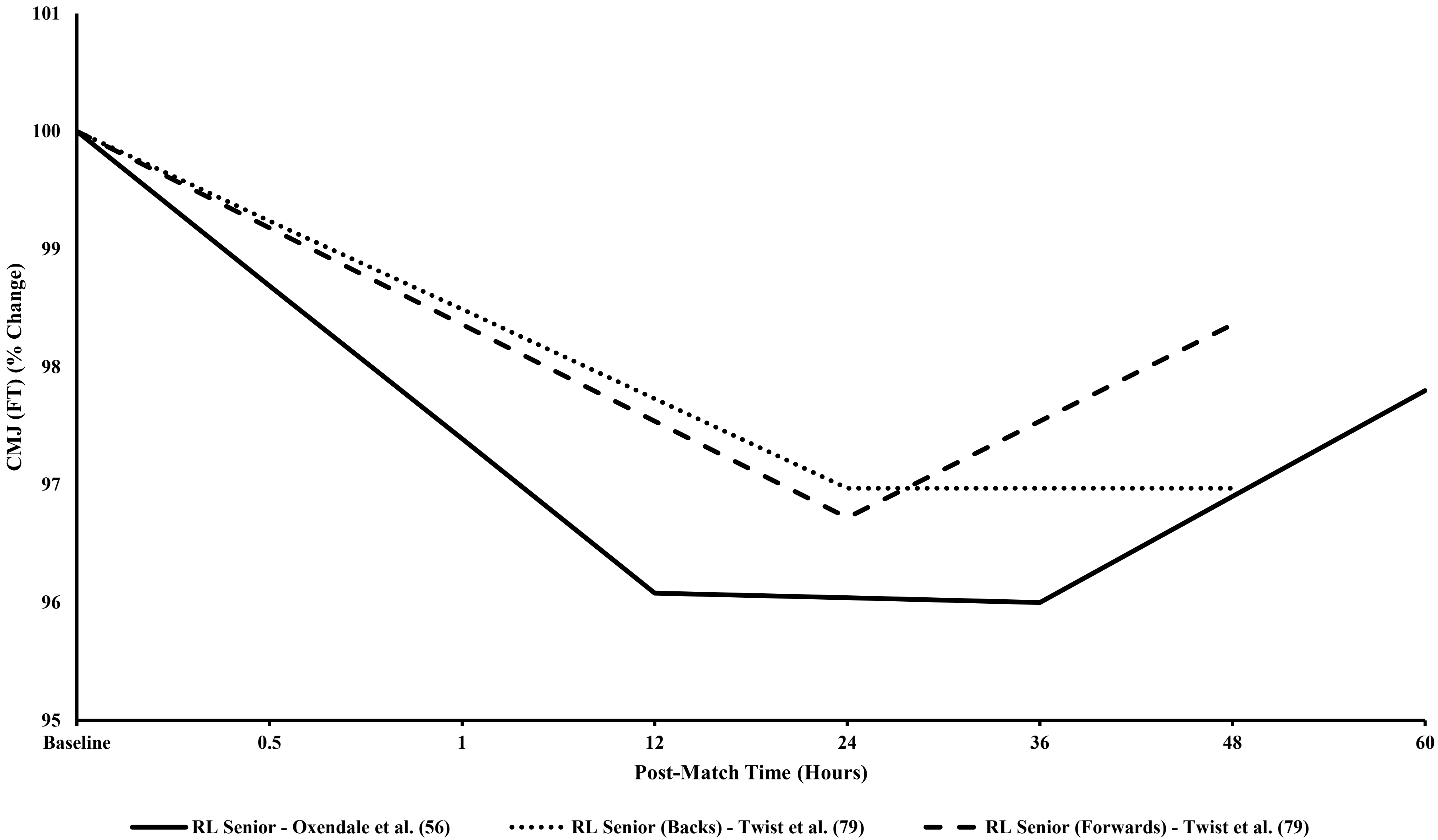

Figure 3: Recovery time-course percentage changes in countermovement jump (CMJ) flight-time (FT) following rugby union (RU) and league (RL) match-play

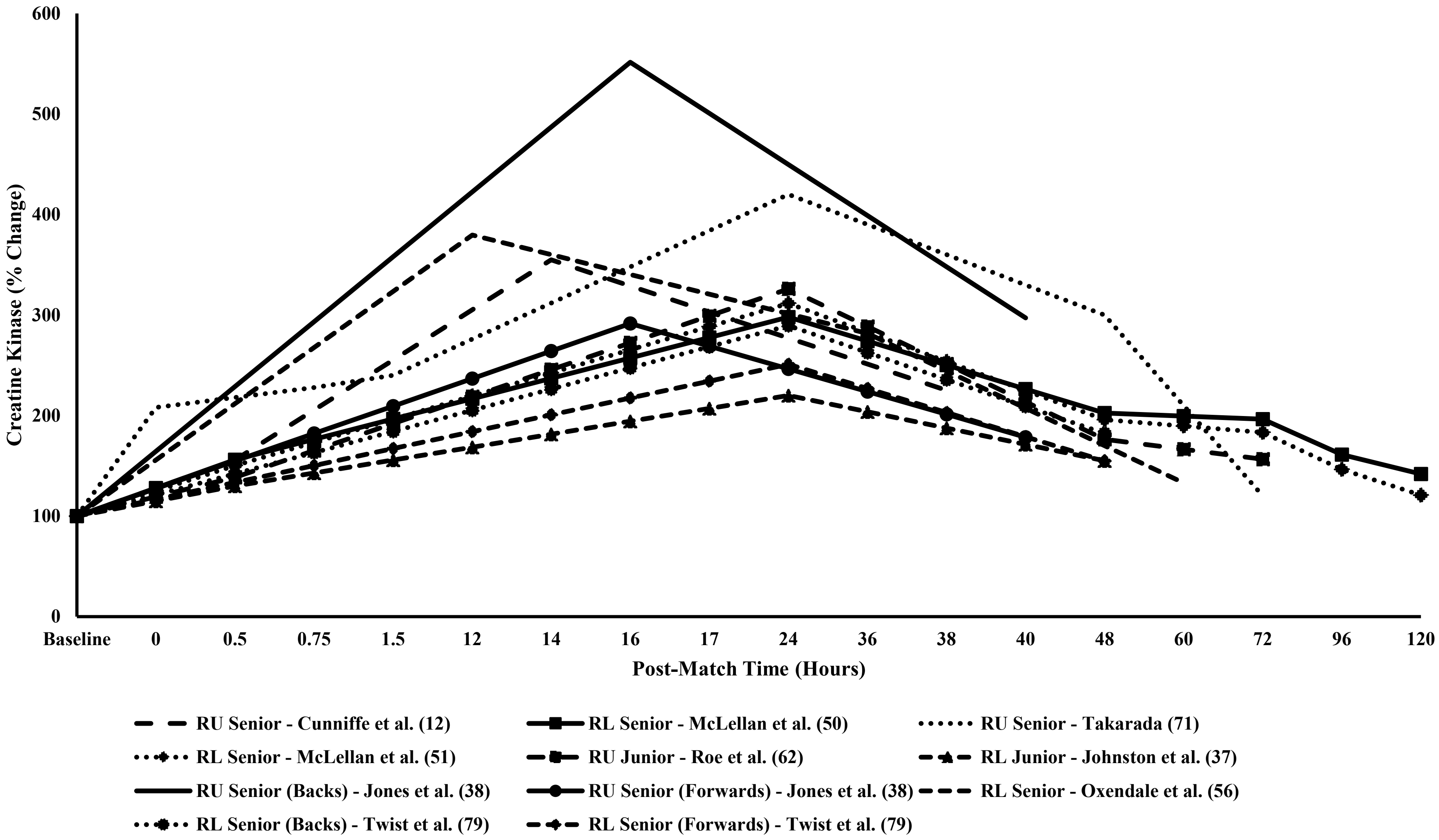

Figure 4: Recovery time-course percentage changes in creatine kinase concentrations following rugby union (RU) and league (RL) match-play

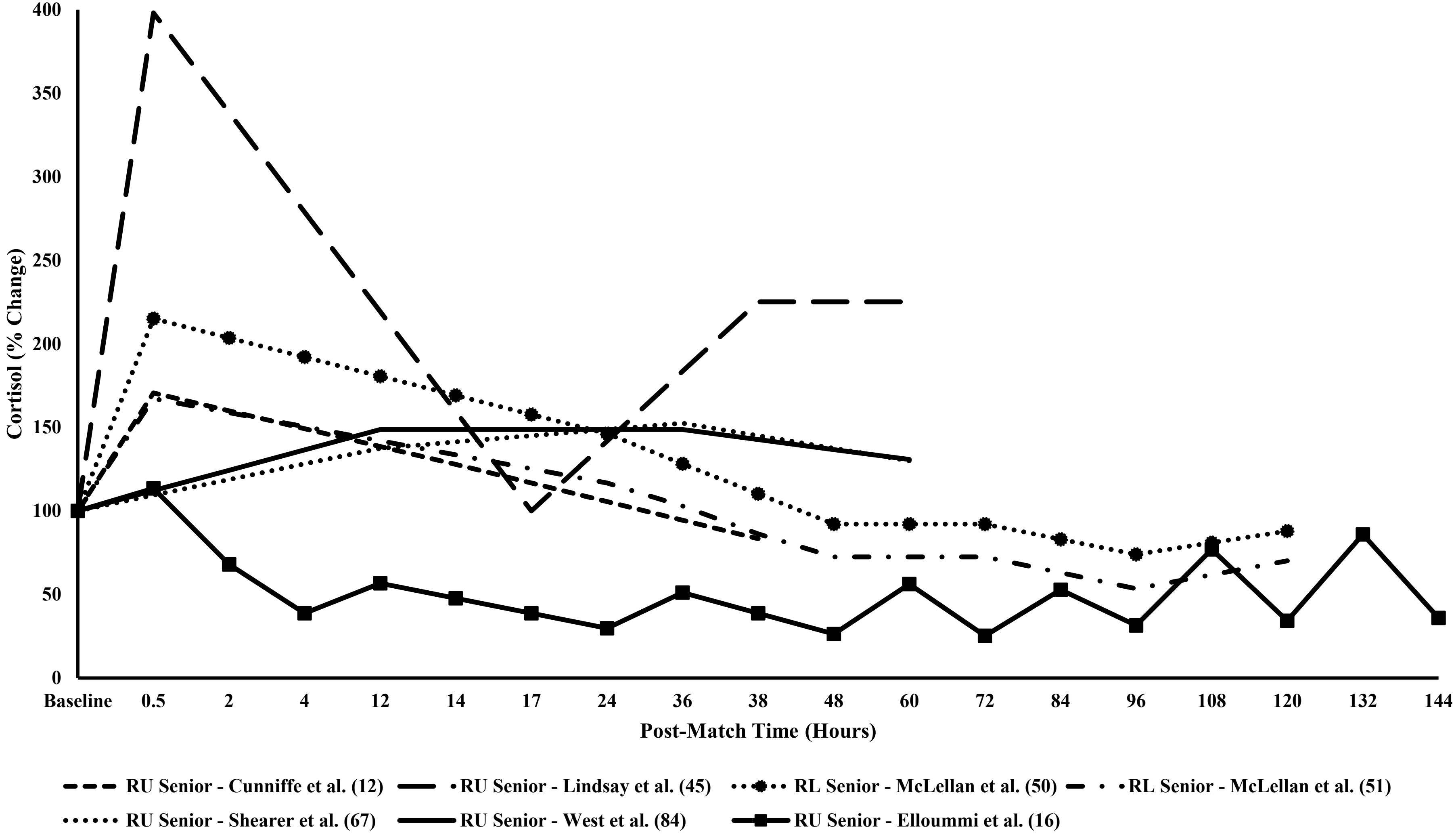

Figure 5: Recovery time-course percentage changes in cortisol concentrations following rugby union (RU) and league (RL) match-play

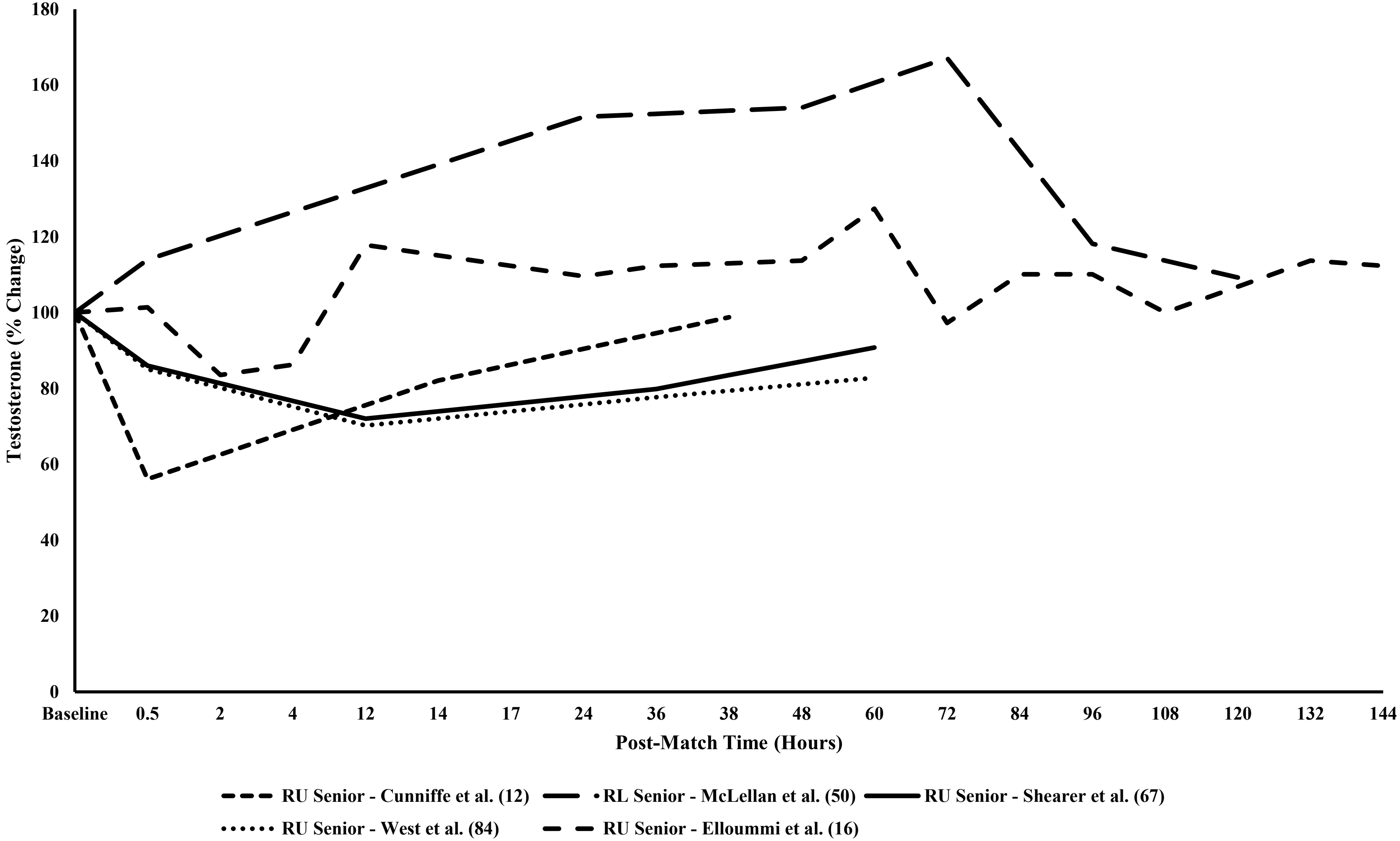

Figure 6: Recovery time-course percentage changes in testosterone concentrations following rugby union (RU) and league (RL) match-play

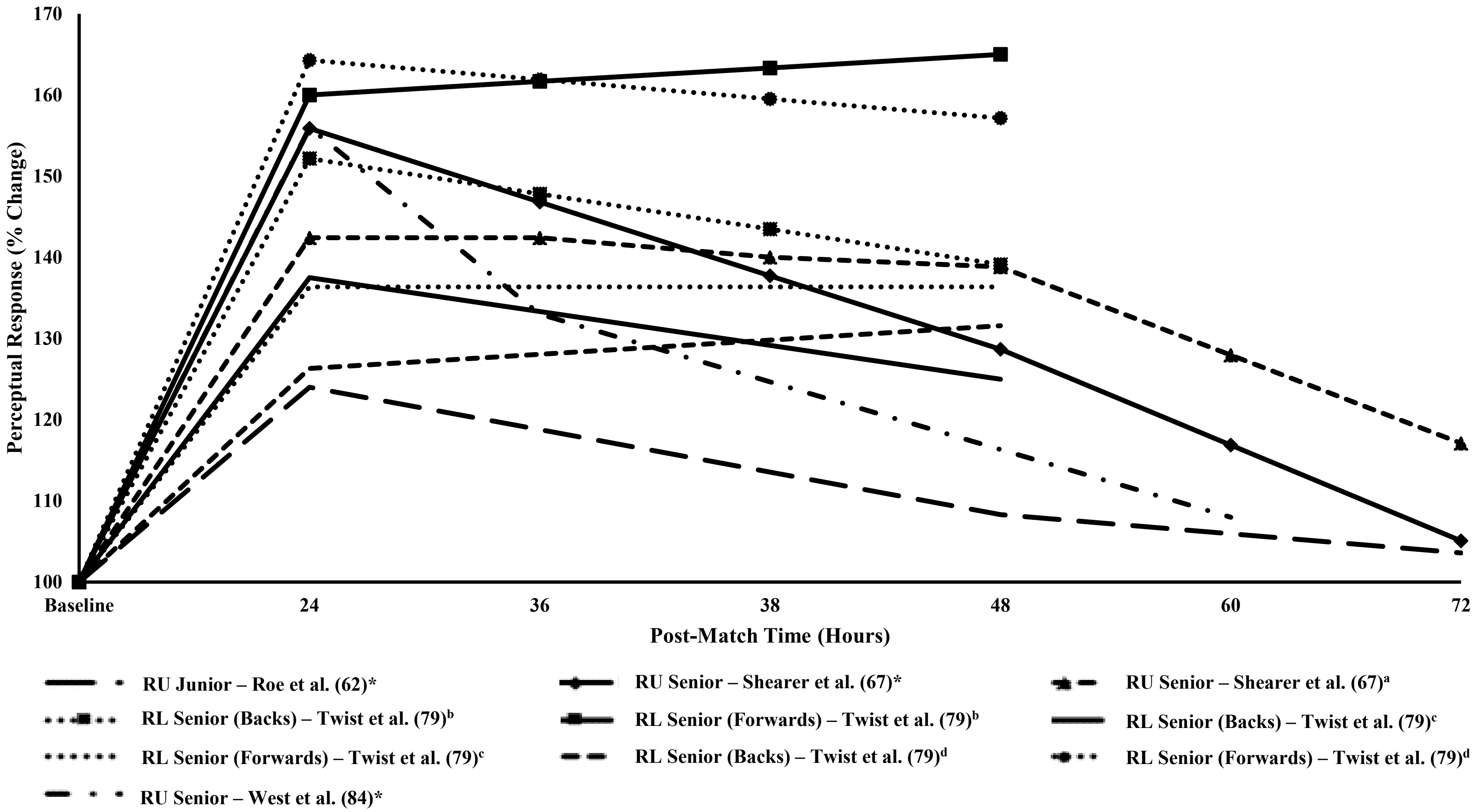

Figure 7: Recovery time-course percentage changes in subjective responses following rugby union (RU) and league (RL) match-play. * represents wellness questionnaire, [a] represents energy index measure, [b] represents muscle soreness rating, [c] represents perceived fatigue rating, [d] represents attitude to training rating