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**Section:** Review

**Article Title:** Monitoring Fatigue and Recovery in Rugby League Players

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**Journal:** *International Journal of Sports Physiology and Performance*

**Acceptance Date:** December 12, 2012

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Title: Monitoring fatigue and recovery in rugby league players

Submission type: Review

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Running head: Fatigue and recovery in rugby league

Abstract Word Count: 250
Text only Word Count: 3783
Number of Figures: 0
Number of tables: 1
Abstract

Rugby league is a contact team sport performed at an average intensity similar to that of other team sports (~70-80% VO\textsubscript{2max}), made up of unsystematic movements of varying type, duration and frequency. The high number of collisions, repeated eccentric muscle contractions associated with accelerating and decelerating, and prolonged aerobic nature of rugby league matches result in the development of fatigue in the days after exercise. Monitoring the presence and magnitude of this fatigue in order to maximise performance and training adaptation is an important consideration for the applied sports scientist. Several methods have been proposed to measure the magnitude of fatigue in athletes. Perceptual measures (e.g. questionnaires) are easy to employ and are sensitive to changes in performance. However, the subjective nature of such measures should be considered. Blood biochemical markers of fatigue may provide a more objective measure of homeostatic disturbances associated with fatigue, however the cost, level of expertise required and high degree of variability of many of these measures often preclude them from being used in the applied setting. Accordingly, simple measure of muscle function (e.g. jump height) and simulated performance offer the most practical and appropriate method of determining the extent of fatigue experienced by rugby league players. A meaningful change in each measure of fatigue for the monitoring of players can be easily determined providing the reliability of the measure is known. Multiplying the coefficient of variation (CV) by 0.3, 0.9 and 1.6 can be used to determine a small, moderate and large change, respectively.
Introduction

Rugby league is a high-intensity, collision sport that is not as well represented in the literature as other intermittent team sports, e.g. soccer. Given the demands placed on elite rugby league players from both competition and training, the purpose of this review is to provide a critical appraisal of the monitoring tools that might be adopted by practitioners when trying to manage exercise-induced fatigue in these athletes.

Demands of rugby league and potential contributors to post-match fatigue

Rugby league is a contact team sport that is intermittent in nature, with periods of high-intensity activity (running, tackling) and low-intensity recovery (walking, jogging, and standing) taking place over two 40 minute halves (excluding injury time) with a 10 minute half-time interval. Playing time for outside backs (~80 min) is greater than pivots (~70 min) and forwards (~50 min) in senior players. Depending on playing position, elite players cover distances between 3,000 and 8,800 m during matches, comprising time spent in low-intensity running (~0.1–6.9 km·h⁻¹), moderate-intensity running (~7.0–13.9 km·h⁻¹), high-intensity running (~14.0–21.0 km·h⁻¹), and very high-intensity running/sprinting (>21 km·h⁻¹). Despite playing for shorter periods of time and covering less distance during a match, locomotive rates for forwards (~95 m·min⁻¹) are similar to those of backs (~90 m·min⁻¹) and adjustables (~94 m·min⁻¹). Forwards are involved in a collision (tackle or being tackled) approximately every minute, whereas this occurs less frequently for backs (0.3 per minute) and adjustables (0.6 per minute) during a match. Consequently, forwards perform repeated high-intensity efforts once every 5 minutes compared to once every 8 and 9 minutes for adjustables and backs, respectively. Mean heart rates ~82-84% of maximum heart rate have been reported for elite players during competitive matches. This study also reported summated heart rate values of ~200, ~270 and
~300 AU, and session RPE values of ~240, ~435 and ~380 AU for forwards, adjustables and outside backs, respectively. Collectively, these data suggest that rugby league matches impose high internal metabolic loads on players coupled with the need to contend with a high number of collisions.

The two major professional competitions exist in the southern (National Rugby League; NRL) and northern (Super League; SL) hemispheres. The NRL (16 teams) and SL (14 teams) involve 24 and 27 games (or rounds) per season, respectively. The eight highest ranked teams then compete in the play-off finals, providing potential for players to experience an additional four matches. The SL also has a domestic knockout cup competition that runs concurrently with league fixtures, which adds a maximum of five matches to the competitive season depending on the team’s success. Representative players might also be expected to play additional games during the season. In the competitive phase of the season (February to October) there are typically 5-9 days between matches, although players can occasionally play in games separated by only two days. In addition, games are supplemented with periodized, multi-component training programmes throughout the year. These comprise approximately five field-based sessions and four gymnasium-based strength sessions per week in the pre-season period (November to February), reducing to 2–4 field-based sessions and 1–2 gymnasium-based strength and power sessions per week in the competitive phase of the season. Training loads are known to be manipulated depending on the number of days between games, with lower training loads observed when players have five days between games compared to one week.

The demands imposed during a rugby league match lead to fatigue, comprising sensations of tiredness and associated decrements in muscular performance and function. Recovery is also complicated by the number of days and training load imposed on players
between games in-season. The mechanisms of this post-match fatigue, however, are somewhat complex.

Muscle damage, and associated inflammation, contributes to fatigue after matches and is caused by several potential mechanisms. Rugby league players perform high numbers of accelerations and decelerations during a game, resulting in many eccentric muscle actions that cause structural damage to skeletal muscle tissue preceding an associated localized inflammation. The positive correlations between the number of collisions and blood markers of tissue damage (e.g. creatine kinase) suggest that muscle damage is also caused by blunt trauma. Furthermore, metabolic stress from prolonged, high-intensity exercise is also likely to contribute to tissue damage in these players.

Muscle damage is characterized by myofibrillar disruption, followed by the inflammatory response and alterations in excitation-contraction coupling. Alongside indirect measures including increases in muscle soreness, blood myofibre proteins (e.g. creatine kinase and myoglobin) and muscle swelling, the occurrence of low frequency neuromuscular fatigue is believed to be most significant for the athlete. An increase in plasma creatine kinase is evident up to 96 h after an elite-standard rugby league match. Increases in creatine kinase are also correlated to the number of collisions the player experiences, suggesting these data reflect blunt trauma as well as mechanical damage. Recent studies in elite rugby league players show that countermovement jump performance is also impaired up to day one after a competitive match, but has recovered by day two. Conversely, reductions in isokinetic knee extensor and flexor torque have been reported up to 48 hours after a simulated rugby league match, although the participants in this study were sub-elite. Deteriorations in upper body force and power have also been reported for rugby league players after matches. Finally, increases in muscle soreness
occur in the days after a match, with values peaking at 24 h,\textsuperscript{5,6} but remaining elevated from baseline values for up to four days. Changes in these indirect markers are similar to those observed in other team sports,\textsuperscript{17,18} and provide strong evidence that such sports are characterized by tissue damage and low frequency fatigue in the days after a game.

Muscle glycogen is a key energy substrate for energy production during intermittent sports.\textsuperscript{19} In soccer, depletion of muscle glycogen is known to be responsible for impaired performance during high intensity exercise as the match progresses.\textsuperscript{19} Thereafter, recovery of muscle glycogen takes between 2-3 days,\textsuperscript{20} which might be further exacerbated in type II fibres by muscle damage caused by eccentric exercise.\textsuperscript{21} While no studies have considered glycogen depletion after a rugby league match, the evidence from other team sports with similar metabolic demands and game durations\textsuperscript{19,20} indicates that reductions in muscle glycogen is a potential mechanism of post-match fatigue.

Changes in psychological well-being have been reported after matches\textsuperscript{5,6} and during intensified periods of competition\textsuperscript{16} for rugby league players. Given that the training and competition demands imposed on elite players might last for 11 months of the calendar year, changes in psychological well-being have the potential to cause mental fatigue that is manifested as a deterioration in performance.

The match demands imposed on rugby league players leads to immediate and prolonged fatigue, characterized by changes in neuromuscular function, inflammation, impaired metabolism and an altered sense of effort. The practitioner must be aware of these mechanisms in order to manage fatigue after matches and training.
Monitoring fatigue in rugby league players

Understanding the fatigue response of rugby league players after games and throughout the season is necessary to avoid injury, performance decrements and overtraining. This requires a suitable battery of tests that enables the sport scientist to make informed decisions on each player’s health status. While a plethora of tests exist to assess fatigue, those selected must be valid, reliable and practically convenient in the applied setting.

Questionnaires and subjective assessments of fatigue

Subjective assessments of fatigue are known to be sensitive to changes in training stress and have been used to assess fatigue and recovery in rugby league players. Alterations in perceived fatigue and muscle soreness are also known to outlast reductions in neuromuscular performance and biochemical markers in elite rugby league players. This change in psychological state, or mental fatigue, is also known to alter an individual’s sense of effort, forcing athletes to down-regulate their exercise capacity. Measurement of these subjective markers is therefore deemed necessary to better understand recovery in rugby league players. A range of tools for the measurement of perceptual fatigue exist, including Profile of Mood States questionnaire (POMS), Daily Analysis of Life Demands for Athletes questionnaire (DALDA), the Recovery-Stress Questionnaire for athletes (RESTQ-Sport) and the Total Quality Recovery scale (TQR). These enable coaches to easily monitor the complex psychophysiological stresses that are associated with fatigue and poor recovery, such as muscle soreness, sleep quality, mood disturbances and alternated attitudes to training. Indeed, the time course of changes in an athlete’s psychological state during periods of intense training and underperformance are contemporaneous with changes in physiological and performance changes. However, a concern raised by coaches is the individuality and subjectivity of
these measures, and the scope for athletes to manipulate responses in order to facilitate a favourable outcome. Moreover, where questionnaires are completed daily, coupled with the length of some questionnaires, concerns over player compliance should be considered. Solutions include using shorter and simpler questionnaires, like that proposed by. However, despite being more time efficient, coaches should be cognisant of the reduced sensitivity of shorter questionnaires to quantify fatigue. Players could also complete questionnaires on a weekly basis to avoid the tedium of daily measures, without reducing the sensitivity to change. Coaches should, however, ensure that if weekly measures are adopted that they are completed on the same day and at the same time to avoid daily and diurnal variations.

**Blood and salivary borne markers of fatigue and recovery**

It is possible that various biochemical, hormonal and immunological markers measured from blood or saliva might assist in assessing the acute response and time course of recovery after matches. For example, an increase in creatine kinase is indicative of tissue damage and has been recommended as a useful measure to monitor acute recovery from rugby league match play. However, that creatine kinase has been strongly correlated with the number of collisions a player makes suggests its inability to detect between mechanically induced muscle damage and that caused by blunt trauma. Perhaps more importantly, elevated plasma creatine kinase and other similar proteins (e.g. myoglobin, C-reactive protein) are also known to possess a poor temporal relationship with muscle function recovery after exercise-induced muscle damage. CK also has extremely large individual variability, and data from our laboratory has shown this measure to have poor day-to-day variation (CV = 27%; Twist, unpublished observations).

Reduced plasma glutamine and elevated plasma glutamate concentrations that result in a reduced glutamine to glutamate ratio have been observed during intensified periods of training in
rugby league players.\textsuperscript{35} Indeed, reductions in the glutamine to glutamate ratio below 3.58 might provide a sensitive index of increased training stress.\textsuperscript{36} Decreases in glutamine could be related to a greater uptake of amino acids for increased gluconeogenesis caused by glycogen depletion.\textsuperscript{22} However, little evidence relates reduced glutamine with impaired immune function. Consequently, more research is needed to confirm the utility of the glutamine and glutamate ratio as a marker of fatigue.

Salivary testosterone and cortisol concentrations (including the testosterone: cortisol ratio) have been studied for up to 120 hours after elite rugby league matches.\textsuperscript{7,9} A lowered testosterone: cortisol ratio suggests that players experience a catabolic hormonal profile for up to 24 h after a game.\textsuperscript{7} A high post-match testosterone: cortisol ratio is probably required to restore homeostasis induced by the psychological and physical stress associated with a rugby match.\textsuperscript{37} Therefore, such data might be used to better understand the balance between anabolic and catabolic activity as consequence of training or matches.

The use of regular blood and saliva monitoring provides detailed information on the health status of the rugby league player and are useful in a research setting to provide mechanistic insights into fatigue. However, these measures are expensive, time consuming and practically challenging in the applied environment. Moreover, that there are poor temporal relationships with neuromuscular performance, the multi-faceted components of fatigue cannot be judged on a single biochemical, hormonal or immunological measure. Therefore, practitioners should think carefully about the utility of biochemical, hormonal and immunological measures to monitor fatigue and recovery in rugby league players.
Measures of neuromuscular function are often used to assess recovery after team sport activity because of their greater utility to monitor low frequency fatigue compared to other indirect markers. Measures of neuromuscular function include various jump tests (e.g. countermovement jump, squat jump), sprint performance, isokinetic and isoinertial dynamometry.

Jump procedures are useful because they reflect stretch-shortening capability of the lower limb musculature and the ability to evaluate muscle fatigue. Moreover, jump procedures are easy to administer and cause minimal additional fatigue. While some authors have questioned the sensitivity of jump procedures to assess neuromuscular fatigue in team sport athletes, impaired muscle function has been detected using this method in rugby league players after matches. Video analysis is considered the criterion method to evaluate jump performance; however, this procedure is time consuming and impractical in an applied setting. A portable force platform provides comprehensive data on muscle force, power, rate of force development, jump height and flight time characteristics during jumping. Another useful variable that appears to be sensitive to fatigue changes after matches is the flight time: contraction time ratio, which represents the time from the initiation of the counter-movement until the player leaves the force plate. Collecting data on several parameters is particularly useful given that peak force recovers more quickly than peak power and rate of force development in rugby league players after a match. Protocols have included single countermovement jumps, while others have suggested multiple jumps (i.e. 5 repeated countermovement jumps) because several variables within this protocol might react differently than a single jump and could be useful in understanding the mechanisms of fatigue. The reliability of the countermovement jump using a
force platform is acceptable, with the previously described jump parameters all possessing intra- and inter-day coefficients of variation (CV) of between 1-6%. Jump performance can also be assessed using a contact mat or similar system, but provides only measures of flight time, predicted jump height based on vertical displacement, and contact time (i.e. drop jump). This method underestimates jump height when compared to the criterion measure, but has good inter-day reliability with CVs between 1.9-6.6%.

Measurements of upper body muscle function are useful for rugby league players because of fatigue caused by pushing, pulling and grappling actions during physical collisions. Johnston et al. measured peak power and peak force during a plyometric push-up performed on a portable force platform. The test possessed good relative reliability (ICC = 0.86) and was able to detect reductions in upper body function of rugby league players because of fatigue caused by intensified competition.

The introduction of rotary encoders into the training environment that can measure bar velocity during typical resistance exercises also provide a useful tool for monitoring upper and lower body neuromuscular function. As players are likely to resume resistance training in the days after a match, practitioners could consider monitoring the power output during core exercises (e.g. bench press, squat and prone pull) to ascertain recovery status and make informed judgments on the necessary training load. These apparatus have good reliability for the assessment of power output in single (ICC = 0.97; 95% limits of agreement = 0.1 ± 13.6 W) and multi-joint (ICC = 0.97; 95% limits of agreement = -17 ± 96 W) exercises. Given the
practicality and acceptable measurement error of these rotary encoders, changes in resistance training performance in the days after a match is an area that warrants further investigation.

Neuromuscular function in team sport athletes can also be assessed using isometric and isokinetic dynamometry. While these methods are able to provide data on isolated muscle groups, their ecological validity is poor because they do not replicate sport-specific movements. Consequently, isokinetic and isometric dynamometry are not recommended in applied settings for the assessment of neuromuscular fatigue.

Measures of sprint performance are typically impaired after prolonged intermittent activity and might provide insight into movement-specific fatigue. Typical sprint distances during rugby league matches are ~10 m, so this seems a logical distance to assess. Over-ground sprinting ability is often assessed using infra-red timing gates, which have been shown to provide reliable data over short (10 m to 30 m) distances (CV = 1.0-1.5%). Alternatively, sprint performance can be monitored using global position system (GPS) devices. Despite GPS devices providing systematic underestimations of movement velocity when compared against concurrent devices, they do provide reliable measures of sprint velocity over short distances (CV = 0.8-2.1%). The importance of such systematic underestimations is further reduced given the now widespread use of GPS technology to measure movement velocity during matches. Thus, comparisons of movement velocity need only be made using one method of assessment (i.e. GPS), negating the consequences of between method variations. Consequently, GPS enables practitioners to measure sprint performance during training and matches, rather than in a closed environment, providing a better understanding of the impact of fatigue on training quality.

Assessing of upper and lower body neuromuscular function provides the practitioner with useful data on a players fatigue status. While simple measures of jump performance are cheap
and easy to administer with large groups, measurements of force and muscle power provide a more comprehensive understanding of neuromuscular performance. The use of portable force platforms and rotary encoders offer the most effective tools of muscle function that can easily be incorporated into training practice. In addition, movement-specific measures of neuromuscular performance are best derived from training using GPS technology.

**Performance tests**

Measures of sub-maximal and maximal performance have been used to assess fatigue in team sport athletes. During a period of intensified competition, Rowsell and colleagues used a 5-minute submaximal (~12 km·h⁻¹) 20 m shuttle running protocol with concomitant measures of mean heart rate and RPE. Under conditions of fatigue, RPE is increased for a given exercise intensity, and can therefore determine an athlete’s recovery status. Such protocols are easy to administer as part of a warm-up; however, the validity of subjective measures of RPE is problematic, particularly when assessed in large groups. Maximal shuttle running to exhaustion has been used to assess the fatigue status of rugby league players during a 6-week intensified training period. In overreached players maximal running speed was reduced by ~5 and ~10% at weeks 5 and 6, respectively. However, practitioners should carefully consider the utility of maximal performance tests given their potential to cause additional fatigue.

A criticism of many performance tests used in the literature is that they are not sport-specific. Indeed, several studies evaluating training-induced fatigue in athletes use incremental or time to exhaustion tests that fail to replicate the movement or physiological demands of the sport. However, the recent development of a reliable rugby league match simulation protocol provides a model that replicates the movement demands of a match. Where perceptual and neuromuscular data alert the practitioner to signs of fatigue, having
players perform short cycles (~5-10 min) of the simulation protocol would enable an understanding of the player’s match performance capacity. This should be coupled with movement (GPS), physiological (heart rate) and perceptual measures (RPE) to quantify the fatigue status. Additionally, the simulation could be used to establish that an athlete has recovered from a period of intensified training or their suitability to resume playing after injury and rehabilitation.

**Interpretation of fatigue data**

Whilst several tools exist for the measurement of fatigue in the days after training and rugby league matches, the magnitude of change in any measurement that warrants intervention for an individual is not clear. This is exacerbated by the varied reliability associated with each measure of fatigue discussed above. Accordingly, we would discourage the use of arbitrary cut-off points (e.g. change of 5%) across different measurements to identify a fatigued condition, as this may fall within the boundaries of typical variation for some measurements (e.g. jump measurements ~ 1-6%; Cormack et al.⁴²), but not others (e.g CK ~ 27%; Twist, unpublished observations). Likewise, the simple observation of a change in any measure, whilst appealing, should be interpreted with caution if its reliability is poor. Therefore, we believe that the first stage of detecting a meaningful change in fatigue status should be to establish the inter-day reliability of the measure (CV) for each individual by simply taking repeated measures in similar conditions (i.e. non-fatigued, same time of day, controlled diet etc.), and calculating the (SD/mean) x 100. Based on modified standardized effects, this can be multiplied by factors of 0.3, 0.9 and 1.6 to determine what would be a small, moderate and large change in the measure of fatigue, respectively.⁵⁰ In this way, the reliability of the measure is accounted for when detecting a meaningful change, and the magnitude of that change can be determined.
Unfortunately, given the categorical nature of questionnaire data, such an approach to measuring a meaningful change in perceptual fatigue is not appropriate (for example, a calculated small change of 0.3 is not attainable when scores are only free to change by increments of 1). However, we believe that the combination of measured changes in neuromuscular function or performance (outlined above) can be used in combination with perceptual data to determine the fatigue status of a rugby league player. We have previously observed changes of approximately 1-2 (on a scale of 1-5) in muscle soreness, fatigue and attitude to training in the 48 h after a rugby league match. As such, a change of this magnitude, in addition to a meaningful change in neuromuscular performance, would be indicative of fatigue consistent with rugby league matches. Large changes in performance with increases in perceptual fatigue (greater than those previously reported), may warrant special attention and the initiation of rest or a given recovery strategy until measures return to values close to baseline.

Conclusion

The rugby league player is exposed to high-volume and high-stress participation that has the potential to cause poor recovery. Poorly managed, there are detrimental outcomes for the player, such as decrements in performance, increased injury risk and poor health. Therefore, the role of the sport scientist is to select appropriate monitoring tools to ensure an optimal health status for the athlete and to ensure that such deleterious outcomes are minimized.

A range of measurements tools and their utility have been discussed and are summarized in Table 1. Given the multifaceted nature of fatigue, practitioners should strategically employ a range of appropriate measurement tools to manage the fatigue status of each player. However, these tests should be unobtrusive, cost effective and easily embedded into the training schedule. Practitioners should also endeavor to educate athletes and coaches to the purpose of this process
to ensure that data are not misinterpreted and are used to manage the health status of the athlete effectively.
References


Table 1: An overview of tools for measuring fatigue and recovery status in rugby league players

<table>
<thead>
<tr>
<th>Tool</th>
<th>Measures</th>
<th>Change after match</th>
<th>Reliability</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Minimum recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaires</td>
<td>Muscle soreness</td>
<td>↑ peak 1-2d</td>
<td>Unknown</td>
<td>Easy to administer and sensitive to changes in performance</td>
<td>Subjectivity means players can easily manipulate responses</td>
<td>Record weekly, within 2-3d post match (depending on training schedule)</td>
</tr>
<tr>
<td></td>
<td>Fatigue</td>
<td>↑ peak 1-2d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mood</td>
<td>?</td>
<td></td>
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<tr>
<td></td>
<td>Sleep quality</td>
<td>?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood-borne markers</td>
<td>Creatine kinase</td>
<td>↑ peak 1d</td>
<td>Varied</td>
<td>Useful to understand the mechanisms of fatigue and health status</td>
<td>Costly and invasive. Poor temporal relationship with performance and perceptual changes.</td>
<td>Only use when other markers suggest investigation of health status</td>
</tr>
<tr>
<td></td>
<td>Testosterone:Cortisol</td>
<td>↓ peak 1d</td>
<td></td>
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<tr>
<td></td>
<td>Glutamate:Glutamine</td>
<td>↓</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>CMJ flight time</td>
<td>↓ peak 1d</td>
<td>Good</td>
<td>Indirect marker of fatigue and can be easily embedded in the training programme</td>
<td>Difficult to identify match-specific fatigue.</td>
<td>Record weekly, 2-3d post match (depending on training schedule)</td>
</tr>
<tr>
<td>performance</td>
<td>Force</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Power</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance tests</td>
<td>Running velocity</td>
<td>↓</td>
<td>Good</td>
<td>Can identify match-specific fatigue and performance capability.</td>
<td>Time consuming and causes additional fatigue</td>
<td>Use when other markers suggest fatigue or when returning from injury.</td>
</tr>
<tr>
<td></td>
<td>RPE</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Heart rate</td>
<td>⇔</td>
<td></td>
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</tr>
</tbody>
</table>

↑ = increased; ↓ = decreased; ⇔ = unchanged; d= day(s); CMJ = countermovement jump