Physiological responses to an intensified period of rugby league competition

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This is a pre-copyedited, author-produced version of an article accepted for publication in *Journal of Strength and Conditioning Research*.

The published version of record Johnston, R. D., Gibson, N. V., Twist, C., Gabbett, T.. J., MacNay, S. A. and MacFarlane, N. G. (2013). Physiological responses to an intensified period of rugby league competition. *Journal of Strength and Conditioning Research*, 27(3), pp. 643-654 is available online at: https://doi.org/10.1519/JSC.0b013e31825bb469

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ABSTRACT

This study investigated the physiological responses to an intensified period of rugby league competition and the subsequent impact on match performance. Participants were seven rugby league players competing in a student international tournament. The tournament involved three 80 minute games over a five-day period, with 48 hours between each match. Baseline measures of upper and lower body neuromuscular function via a plyometric press-up (PP) and countermovement jump (CMJ), respectively (peak power and peak force were measured), blood creatine kinase (CK), and perceptions of wellbeing were assessed with a questionnaire. These measures were repeated every morning of the competition; neuromuscular fatigue and CK were additionally assessed within 2 hours after the cessation of each game. During each match, player movements were recorded via global positioning system units. There were meaningful reductions in upper (ES = -0.55) and lower body (ES = -0.73) neuromuscular function, and perceptual wellbeing (ES = -1.56) as well as increases in blood CK (ES = 2.32) following game 1. These changes increased in magnitude as the competition progressed. There were large reductions in the relative distance covered in high speed running (ES = -1.49) and maximal accelerations (ES = -0.85) during game 3. Additionally, moderate reductions in the percentage of successful tackles completed were obseverd during game 3 (ES = -0.59). Collectively, these results demonstrate that during an intensified period of rugby league competition characterized by only 48 hours between matches, fatigue will accumulate. This cumulative fatigue may compromise high-intensity match activities such as high speed running, accelerations, and tackling. Furthermore, CMJs and PPs appear sensitive measures for monitoring neuromuscular function in rugby league players.

KEY WORDS: Neuromuscular fatigue; muscle damage; recovery; contact sport; match performance

INTRODUCTION

Rugby league is a contact team sport that is intermittent in nature, with periods of high-intensity activity (e.g. high-speed running, sprinting and physical collisions) and low-intensity recovery (e.g. standing, walking and jogging) performed over two 40 minute halves. Depending on playing position, players cover distances in the range of 3,000-8,000 m during a match (27,33,43). Over the course of a rugby league season, players are required to compete on a weekly basis over a 7-8 month period, with generally 5-10 days between matches. After games, players need to recover quickly in order to recommence training and prepare for the next scheduled game. For this reason, monitoring fatigue and subsequent recovery from competition is thought to be important so that appropriate training activities and recovery strategies can be implemented.

Given the demands imposed during matches, players typically experience immediate and prolonged symptoms of fatigue, defined as sensations of tiredness and associated decrements in muscular performance and function (1). Recent studies have investigated the fatigue induced by a single rugby league match and the time course of subsequent recovery (29,30,31,32). These studies have reported increases in neuromuscular fatigue (assessed via countermovement jumps; CMJ) for up to 48 hours (29,31), perceptual fatigue (assessed by a questionnaire) for up to 4 days (29) and elevated plasma creatine kinase (CK) for up to 5 days (30,32) following a match. Although the existing literature suggests there is significant fatigue induced by a game of rugby league, there is currently no evidence examining fatigue over a series of rugby league matches. During the competitive season there are intensified periods of competition where players are required to compete in multiple matches within a week, accentuating the need for recovery. During these periods of intensified competition when players are not afforded the 5 days required to fully recover from a game, fatigue is likely to accumulate. Despite this, there is currently no research pertaining to the demands imposed on rugby league players during intensified periods of competition and the effect on fatigue, recovery and match performance. Such information is vital to gain an understanding into the nature and time course of cumulative fatigue during a period of intensified rugby league competition. This will allow coaching staff to manage player fatigue more effectively.

Several studies have shown that assessing lower body neuromuscular performance (11,29,31,42) may be a useful measure for monitoring recovery and fatigue in rugby league players. Despite this, these markers give no indication of fatigue in the upper body. This paucity of information appears surprising given the large involvement of the upper body musculature in the frequent collisions that occur during competition (2,42). As such, it would appear important to assess upper body neuromuscular function when monitoring fatigue and recovery from competition.

While studies from other team sports have found residual fatigue to compromise performance (10,36), the occurrence of cumulative fatigue during a period of intensified competition and its effects on subsequent match performance in rugby league are yet to be elucidated. With this in mind, the aim of this study was to (1) determine the physiological and perceptual responses to an intensified period of rugby league competition, and (2) determine whether match performance in rugby league players is compromised in the presence of cumulative fatigue. We hypothesized that fatigue and muscle damage would accumulate over the competition period, and match performance would deteriorate as the competition progressed.

METHODS

Experimental Approach to the Problem

In order to test our hypotheses, rugby league players were monitored over an intensified three game competition spanning five days. The dependent variables assessed were neuromuscular fatigue, blood CK response, perceptual wellbeing, and match performance. In order to determine the neuromuscular responses to competition, peak force and peak power from the upper body and lower body neuromuscular fatigue were assessed by players performing plyometric press-ups (PP) and CMJs on a force platform. These two tests are simple to administer and are similar to movements experienced during competition. Moreover, these movements are unlikely to compromise recovery from competition. The whole blood CK response was examined to indirectly assess the skeletal muscle damage induced by competition. CK is widely used as an indirect marker of skeletal muscle damage; assessing the CK response allows comparisons to be made with the existing literature. Perceptual fatigue was quantified by means of questionnaires to determine player wellbeing. Previous research (29) has shown this measure to be useful in measuring subjective feelings of fatigue following competitive rugby league matches. Match performance was measured during each game via video analysis, and global positioning system (GPS) monitoring. GPS analysis allowed player movements to be objectively and reliably tracked over the course of the competition. Video analysis allowed vital game statistics to be assessed over the course of the competition. Physical performance measures derived from the GPS units included distance covered, distance covered at high and low intensities, and accelerations (both absolute and relative). Offensive and defensive statistics were coded from the videos of each game. Offensive statistics included the number of carries, decoy and support runs, as well as meters per carry. Defensive statistics included completed, missed, ineffective, and successful tackles, as well as tackles per minute of match play. These measures from both video analysis and GPS allowed match performance to be assessed over the three games and therefore determine whether performance changed over the course of the competition.

Subjects

Seven (backs, n = 3; forwards, n = 4) amateur male rugby league players (mean ± SE, age 21.7 ± 0.35 years; body mass 87.5 ± 3.47 kg; and height 180.5 ± 1.51 cm) competing in an international student rugby league competition over a five-day period volunteered to take part in the study. The competition took place in April; all players had been training and competing in weekly fixtures with their respective teams for seven months preceding the tournament. All players were free from injury at the time of testing, and only players who competed in each game of the competition were included in the study. Before the study, players attended a presentation and received an information sheet outlining the experimental procedures, and the associated risks and benefits of participation. Written informed consent was obtained from each player, and all players were free to withdraw from the study at any time without penalty. The University of Chester's ethical review board and Scotland Rugby League approved all experimental procedures.

Procedures

Each player competed in three games over a five-day period; there was exactly 48 hours between each game. Over the three games, the team won one and lost two fixtures, scoring 80 points and conceding 104. The games were played at the same time of day (19:00 hrs) on the same outdoor floodlit pitch (temperature: 10.3 ± 1.5°C; humidity: 80.3 ± 7.6%). Baseline measures for neuromuscular fatigue, muscle damage, and perceptual fatigue were taken 36 hours prior to game 1 between 08:00-10:00 hrs after each player receiving 8-10 hours sleep. Subsequent measures were performed every morning at the same time under the same conditions for the next six days. In addition, neuromuscular fatigue, and CK were assessed within 2 hours after each of the three games (22:00-23:00 hrs). Match performance was assessed via video and GPS analysis of each game. Players were asked to maintain their normal diet in the lead up to the competition, and throughout the competition. A schematic representation of the experimental protocol and competition schedule are shown in Table 1.

TABLE 1 NEAR HERE

Upper and lower body neuromuscular fatigue

A plyometric press-up (PP) and countermovement jump (CMJ) were used to detect upper and lower body neuromuscular fatigue, respectively. Both exercises were performed on a force platform (Force Platform, Ergotest Innovation, Porsgrunn, Norway) sampling at 100 Hz connected to a laptop (Dell Inspiron 9100, Dell, UK); data were analyzed using software provided by the manufacturer (MuscleLab 4020e, Ergotest Innovation, Porsgrunn, Norway) for peak power and peak force. Prior to assessment, players were habituated with procedures, and performed a standardized warm-up consisting of dynamic stretches and plyometrics for both the upper and lower body lasting approximately two minutes. Players were randomly divided into two groups; half of the players performed the PP followed by the CMJ, with the other half of the players performing the exercises in reverse order, this order was maintained for all testing sessions. For the PP, players were told to start in a press-up position with their hands on the force platform in a self-selected position, and arms extended. On the experimenter's signal, players were required to lower their body by flexing their elbows to a self-selected depth before extending the elbows as fast as possible so that their hands left the platform. For the CMJ players were instructed to keep their hands on hips for the entire jump, and to jump as high as possible. As reported previously (10,29), players received no instruction as to the depth of the countermovement performed prior to the concentric phase of the jump. Players performed two practice attempts of both PP and CMJ before performing a single effort of each that was recorded. The ICC for the PP was 0.86 and 0.86 for peak power and peak force respectively, and for the CMJ was 0.98 and 0.97 for peak power and peak force respectively.

Muscle damage

Whole-blood CK activity was assessed from a fingertip capillary sample with the player in a seated position. After pre-warming of the hand to approximately 42˚C, a 30 µl sample of blood was taken and subsequently analyzed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, quality control (calibration) measurements were undertaken, according to the manufacturer recommendations. The "normal" reference range for CK activity, as provided by the manufacturer using this method, is 24–195 $IU \cdot l^{-1}$.

Performance

During competition, player movements were monitored via GPS units sampling at 10 Hz (Team 6.5, Catapult Sports, VIC, Australia) fitted within a custom made vest. The units also included tri-axial accelerometers, gyroscopes, and magnetometers sampling at 100 Hz to provide information on collisions. Each player was fitted with the GPS vest prior to the pre-game warm-up. After the warm-up, and approximately 15 minutes prior to kick-off, the GPS unit was switched on, and inserted into a padded compartment at the rear of the vest so that it sat between the shoulder blades in the upper thoracic-spine region. The GPS unit was switched off immediately after each game. Data were subsequently downloaded to a laptop (Dell Inspiron 1545, Dell, UK) and analyzed using software provided by the manufacturer (Logan Plus, Version 4.7, Catapult Sports, VIC, Australia). Non-playing minutes were omitted from the analysis. Data were categorized into movement speed bands representing low (0-17 $km \cdot h^{-1}$) and high speeds (>17.1 $km \cdot h^{-1}$); and collision intensity bands corresponding to mild, moderate, and heavy (17). Maximal accelerations were defined as changes in velocity greater than 2.78 $m \cdot s^{-2}$. Previous research has found these units to be reliable when quantifying movements that are commonplace during rugby league competition (5,8,19).

In addition to GPS analysis, each game was filmed using a Sony DCR-HC51 video camera (Sony, UK). The camera was positioned on a tripod at the top of the main stand of the stadium on the halfway line so that the entire playing field could be filmed. The zoom function was set so that there was a field of view of approximately 10 m around the ball at all times. The games were analyzed using a simple hand notation analysis procedure. The performance variables analyzed are described in Table 2 and procedures outlined previously (20,37). The test re-test reliability of the analysis was assessed by re-analyzing the first game 4 weeks apart. The average ICC for the variables assessed was 0.92, ranging from 0.79-0.99.

TABLE 2 NEAR HERE

Perceptual wellbeing

Subjective perceptions of wellbeing were measured using a previously used psychological questionnaire (29). The questionnaire rated feelings of fatigue, sleep quality, general muscle soreness, stress levels and mood, on a 1-5 Likert scale with 0.5-point increments. Each score was summated to provide an overall wellbeing score with a higher score suggesting greater wellbeing. The questionnaire was completed each morning upon waking between 08.00-10.00 am (Table 1). Similar scales have been shown to have good reliability and validity (14).

Session rating of perceived exertion

Session rating of perceived exertion (RPE) was obtained within 30 minutes after each game using a modified RPE scale (15). Match load was calculated by multiplying the RPE score with playing minutes. This method for quantifying load has been previously shown to have high test re-test reliability in rugby league players (17,26).

Statistical analysis

Differences in muscle damage, neuromuscular fatigue, match performance and perceived wellness were compared using traditional significance testing as well as using more practical statistical tests based on the real world relevance of the findings (4,9,24). Analyses were performed using SPSS 17.0 (SPSS Inc, Chicago, IL, USA). Changes in CK, neuromuscular fatigue, perceived wellness and match performance were assessed using repeated measures analysis of variance (ANOVA). If significant main effects were found, Bonferroni *post hoc* analyses were performed to locate the differences. Cohen's effect size (ES) statistic with 95% confidence intervals (CI) was utilized to determine the practical significance of observations

(9). Effect sizes of <0.09, 0.10-0.49, 0.50-0.79, and >0.80 were considered trivial, small, moderate and large respectively (9). Intraclass correlation coefficients (ICC) were used to determine the test re-test reliability of the dependent variables. All data are reported as means ± standard error (SE); the significance level was set at $p \leq 0.05$.

RESULTS

Lower body neuromuscular fatigue

Moderate reductions in peak power during the CMJ were observed at 12 ($p > 0.05$; ES = -0.70 [-1.25 – -0.20]) and 36 hours after game 1 (i.e. 12 hours before game 2; $p < 0.001$; ES = -0.73 [-1.28 – -0.20]). No reductions in peak force during the CMJ were observed at any time point after game 1 ($p > 0.05$). Neuromuscular fatigue during the CMJ had not recovered by game 2 as peak power remained lower than baseline at 2 hours ($p < 0.01$; ES = -0.6 [-1.16 – -0.10]), 12 hours ($p < 0.05$; ES = -1.07 [-1.64 – -0.50]), and 36 hours ($p < 0.05$; ES = -1.09 [-1.67 – -0.50]) after game 2. Once again, there were only trivial and small reductions in peak force at 2 hours ($p > 0.05$; ES = -0.01 [-0.54 – 0.50]), 12 hours ($p > 0.05$; ES = -0.20 [-0.74 – 0.30]), and 36 hours ($p > 0.05$; ES = -0.18 [-0.71 – 0.40]) after game 2 (Fig. 1 and 2).

FIGURES 1 & 2 NEAR HERE

Upper body neuromuscular fatigue

There were small to moderate reductions in upper body peak power at 2 ($p > 0.05$; ES = -.017 [-0.70 – 0.40]), 12 ($p > 0.05$; ES = -0.54 [-1.09 – 0.00]) and 36 hours ($p > 0.05$; ES = -0.55 [-1.09 – 0.00]) after game 1. There were no changes in peak force at 2 ($p > 0.05$; ES = 0.66 [0.11 – 1.20]), 12 ($p > 0.05$; ES = 0.02 [-0.51 – 0.60]) and 36 hours ($p > 0.05$; ES = -0.06 [-

0.61 – 0.50]) after game 1 (Fig. 3 and 4). Following game 2, peak power was significantly lower than baseline 12 hours (p < 0.05, ES = -1.11 [-1.69 – -0.50]) after the match. There were non-significant, but moderate to large reductions in peak power 2 hours (p > 0.05, ES = -0.74 [-1.29 – -0.20]), and 36 hours (p > 0.05; ES = -0.95 [-1.51 – -0.40]) after game 2. Peak force for the PP was lower than baseline at 2 (p < 0.01; ES = -0.89 [-1.49 – -0.30]), 12 (p < 0.05; ES = -0.63 [-1.18 – -0.10]) and 36 hours (p < 0.05; ES = -0.72 [-1.28 – -0.20]) after game 2. Furthermore, peak force at 36 hours after game 2 was significantly lower than peak force 12 hours after game 1 (p < 0.05; ES = -0.78 [-1.39 – -0.40]).

FIGURES 3 & 4 NEAR HERE

Muscle damage

The whole blood CK response to competition is highlighted in Fig. 5. There was a significant increase in CK at 12 (p < 0.01; ES = 2.32 [1.63 – 3.00]) and 36 hours after game 1 (p < 0.05; ES = 2.01 [1.36 – 2.70]), and 12 (p < 0.05; ES = 2.14 [1.47 – 2.68]) and 36 hours after game 2 (p < 0.05; ES = 1.36 [0.77 – 2.00]). In addition, CK activity 12 hours after game 2 was significantly greater than CK 12 hours before game 2 (p < 0.05; ES = 0.64 [0.13 – 1.20]). While not significant, there were large differences in CK observed at 2 hours after game 1 (p > 0.05; ES = 1.4) and 2 hours after game 2 (p > 0.05; ES = 1.87 [1.23 – 2.50]).

FIGURE 5 NEAR HERE

Perceived wellbeing

Total wellbeing scores for each day of the competition are shown in Fig. 6. After game 1, there was a significant decrease in total wellbeing (p < 0.05; ES = -1.56 [-2.64 – -0.50]) at 12 hours compared with baseline. Although total wellbeing was not significantly greater than baseline at 12 hours before game 2, the difference was of large practical significance (p >

0.05; ES = -0.62[-1.64 – 0.40]). After game 2, total wellbeing was significantly lower than baseline at 12 ($p < 0.05$; ES = -1.65[-2.74 – -0.60]) and 36 hours ($p < 0.05$; ES = -1.14[-2.19 – -0.10]) post match. Perceptions of fatigue were significantly increased after game 1, and this increase persisted for the remainder of the competition period (12 hours after game 1, $p < 0.01$; ES = -1.71[-2.34 – -1.10]; 12 hours before game 2, $p < 0.05$; ES = -0.76 [-1.31 – -0.60]; 12 hours after game 2, $p < 0.01$; ES = -1.30 [-1.88 – -0.70]; 36 hours after game 2, $p < 0.01$; ES = -0.91 [-1.47 – -0.40]). There were significant and large increases in general muscle soreness 12 hours after game 1 ($p < 0.01$; ES = -2.00 [-2.61 – -1.40]), and 12 hours after game 2($p < 0.01$; ES = -1.53 [-2.09 – -1.00]). Non-significant but moderate and large increases in general muscle soreness were observed 12 hours before game 2 ($p > 0.05$; ES = -0.90 [-1.42 – -0.40]), and 36 hours after game 2 ($p > 0.05$; ES = -0.68 [-1.19 – -0.20]).

FIGURE 6 NEAR HERE

Match performance

The match performance variables for each of the three games are summarized in Table 3.

Physical Performance: There was a large increase in the percentage of distance covered at low running speeds between games 1 and 3 ($p > 0.05$; ES = 1.29 [0.70 – 1.90]), and games 2 and 3 ($p < 0.05$; ES = 1.82 [1.18 – 2.50]). Concomitantly, there was a large decrease in the absolute and relative distance covered at high running speeds between games 1 and 3 (absolute: $p > 0.05$; ES = -1.25 [-1.84 – -0.70]; relative: $p > 0.05$; ES = -1.29 [-2.45 – -1.20]) and games 2 and 3 (absolute: $p < 0.05$; ES = -1.25 [-1.84 – -0.70]; relative: $p < 0.05$; ES = -1.82 [-1.88 – -0.70]). Moreover, there were large reductions ($p > 0.05$; ES = -0.88 [-1.44 – -0.30]) in the number of maximal accelerations per minute between games 1 and 3. There were no other significant changes in general performance variables over the competition period (Table 3).

Defensive performance: The percentage of successful tackles was reduced ($p > 0.05$; ES = -0.59 [-1.14 – 0.00]) and ineffective tackles increased ($p > 0.05$; ES = 0.67 [0.12 – 1.21]) between games 1 and 3. The difference in tackles per minute between game 1 and 2 ($p > 0.05$; ES = -0.41 [-0.13 – 1.00]) and game 1 and 3 ($p > 0.05$; ES = -0.24 [-0.73 – 0.30]) was small to moderate in magnitude. No other changes in defensive performances were observed across matches.

Offensive performance: The average meters per carry were significantly reduced in games 2 ($p < 0.05$; ES = -0.62 [-1.17 – -0.10]) and 3 ($p < 0.05$; ES = -0.67 [-1.22 – -0.10]) when compared with game 1. There was a large increase ($p > 0.05$; ES = 1.60 [0.98 – 2.20]) in the number of decoy runs from game 1 to game 3. No other changes in offensive performances were observed across matches.

TABLE 3 NEAR HERE

Rating of perceived exertion

Table 3 shows the RPE and game load data for each match during the competition. There was no change in RPE between games 1 and 2 ($p > 0.05$; ES = 0.05 [-0.48 – 0.06]), but there were small increases in RPE between games 2 and 3 ($p > 0.05$; ES = 0.36 [-0.18 – 0.90]) and games 1 and 3 ($p > 0.05$; ES = 0.46 [-0.08 – 1.00]). There were similar, non-significant increases in game load between games 1 and 2 (*p* > 0.05; ES = 0.14 [-0.40 – 0.70]), 2 and 3 (*p* > 0.05; ES = 0.05 [-0.49 – 0.60]) and games 1 and 3 (*p* > 0.05; ES = 0.17 [-0.36 – 0.70]).

DISCUSSION

Although previous studies have determined fatigue and recovery after single games of rugby league (29,30,31,32,42), the present investigation is the first to study fatigue and performance during an intensified period of competition. This study confirmed our hypotheses and found neuromuscular fatigue, perceptual fatigue, and markers of muscle damage to accumulate over a three game intensified rugby league competition. Furthermore, the cumulative fatigue appeared to compromise high-intensity running, maximal accelerations, and defensive performance in the final game of the competition. These results suggest that when players do not receive adequate time to recover between matches then fatigue will accumulate, and compromise vital aspects of match performance.

Moderate reductions in CMJ power below baseline values were seen 12 hours after game 1; this reduction became larger in magnitude as the tournament progressed. There were no meaningful reductions in CMJ peak force at any time point throughout the competition period. Such findings are consistent with previous research (31) and the notion of preferential disruption to type II muscle fibers during muscle damaging exercise (6,16), resulting in changes in the force-velocity relationship towards slower muscle. Indeed, evidence of tissue disruption is supported by the very large increases in whole blood CK observed throughout the competition. This finding may also reflect that maximal strength, as opposed to peak power, is affected less by delayed onset muscle soreness and the inflammatory response (7).

Alternatively, the maintenance of peak force may be due to a greater involvement of the lower body in high velocity movements as opposed to high force movements during competition (21,22,43). These findings suggest that rugby league competition compromises the velocity of lower body movements rather than the ability to generate force. Consequently, CMJ variables incorporating a velocity component are more sensitive at detecting fatigue in rugby league players and offer greater utility as a monitoring tool.

This is the first study to assess upper body neuromuscular fatigue after rugby league matches. Peak power and peak force were unchanged after game 1, with moderate reductions immediately after game 2 and the magnitude of fatigue increasing as players approached game 3. These results indicate that there is a significant amount of upper body fatigue induced by an intensified period of rugby league competition, and that the time course and mechanisms of upper body fatigue during a rugby league tournament differs to that of the lower body. The distinct movements performed during a match by the upper and lower body could contribute to the disparity in fatigue. For example, the lower body typically performs lower force, higher velocity movements during competition (e.g. running and jumping), whereas the upper body is involved in higher force, lower velocity movements (e.g. tackles and wrestles). Moreover, the greater number of physical contacts involving the upper body compared with the lower body (2,42) suggests that upper body fatigue in the days after a match could be influenced by soreness or muscle damage caused by blunt force trauma. Indeed, previous research suggests that the muscle damage response to rugby competition is linked to physical collisions (13,38,39,42). Taken together, these results indicate that monitoring upper body fatigue after and during intensified periods of competition is important in rugby league players.

There were large increases in CK at 2, 12 and 36 hours after each game, which is similar to findings reported elsewhere in professional rugby league players (30,32,42). The CK response in the present study peaked at 12 hours after competition. This is in contrast to previous studies that reported CK activity peaked 24 hours after match play (30,32,42). The reason for this disparity could be due to methodological differences. We only assessed CK 12 and 36 hours after competition and therefore may have missed the true peak. Another possible explanation could be due to the lower level of competition in the current study which induced less muscle damage to those reported previously from elite competition (30,32,42). Despite this, the current findings suggest that a sub-elite game of rugby league induces significant muscle tissue damage and that CK increases cumulatively when there is only 48 hours between three competitive matches. Furthermore, the CK response shows a temporal relationship with the reductions in neuromuscular function during the competition period. Therefore, it seems plausible that muscle damage observed in the present study contributed to the deterioration in neuromuscular function (3,25,31,34). Despite this, the mechanisms responsible for the increases in CK cannot be ascertained in the present investigation. Traditionally, it is believed that eccentric muscle actions (e.g. decelerations) are largely responsible for exercise induced muscle damage (35). However, recent research also suggests that increases in circulating CK is proportional to the number of physical collisions experienced during rugby matches (13,38,39,42). Finally, the metabolic stress imposed by prolonged, high intensity exercise periods (40) over several days of competition might have also contributed to the increases in circulating CK. It is likely that a combination of these three mechanisms explain the increases in blood CK over the five-day competition.

Players' perceptions of wellbeing were progressively reduced during the three-game competition and are in agreement with studies reporting disturbed psychological states after periods of intensified training (11,23). These data corroborate the neuromuscular and muscle damage responses to an intensified period of competition, suggesting that when players are not fully recovered between matches, fatigue will accumulate. An increase in perceived muscle soreness and fatigue could increase perceived effort and reduce the ability to perform exercise. Indeed, in the present study, despite reductions in distances covered and locomotive rates, session RPE for each game showed small increases as the competition progressed. Such findings are consistent with an altered sense of effort and impaired central drive, stimulated by the increases in muscle soreness and perceived fatigue (11,23,28,41). Therefore, reductions in neuromuscular and match performances in the latter stages of the tournament might have been mediated by decreased central drive. Consequently, coaches should acknowledge the increase and time course of muscle soreness and perceptual fatigue after a match, and the potential impact on a player's exercise tolerance. Given the sensitivity and simplicity, these findings support the use of perceptual questionnaires on a daily basis as a monitoring tool to inform coaches and guide training practices, particularly during periods of intensified competition.

The match demands analysis (Table 3) revealed a large increase in the relative distance covered in low speed activity during game 3 and a concomitant decrease in high speed running. In addition, there were practically meaningful differences in the number of maximal accelerations, number of ineffective tackles, and the percentage of successful tackles in game 3 compared with the previous matches. The time course of many of these changes is in line with the neuromuscular, muscle damage and perceptual wellbeing results exhibited after game

2. Players were able to maintain performance between games 1 and 2, but after game 2, as fatigue accumulated, performance deteriorated. Research in rugby league players has shown that CMJ height and squat jump relative power are correlated with sprint performance over 5, 10, and 30 m (12). As such, it may be that as CMJ peak power deteriorated so too did the ability to perform high-intensity movements during game 3. With this in mind, in order to maintain peak performance, it appears important for coaches to ensure that lower body power production is not compromised prior to competition.

The decrements in defensive performance seen in game 3 may also be linked to the changes in neuromuscular function after game 2. Indeed, research has shown that high-intensity activity similar to that experienced in competition compromises tackling performance (18). In addition, lower body power is an important prerequisite for tackling ability (20). As such, it is possible that the decrements in upper and lower body neuromuscular function and overall increases in fatigue contributed to the decrements in defensive performance seen in game 3. A reduction in lower body power could result in players being unable to position themselves quickly enough in defense, or utilize sufficient leg drive to execute successful tackles. The changes in upper body peak force may also contribute to the attenuation in tackling performance seen in game 3. Previous research has not investigated upper body neuromuscular function and tackling ability, however, given the large involvement of the upper body during tackles (2,42) it is likely to be important. Tackling often involves slower movements where players are required to generate high forces in order to 'win' the tackle contest. As such, a decrease in force generating abilities of the upper body could be a contributing factor in the attenuation of defensive performance seen in game 3. With this in mind, it appears important that neuromuscular function is not compromised prior to competition. The findings from the present study suggest that neuromuscular fatigue may compromise running performance and tackling ability. Therefore, the assessment of neuromuscular fatigue may be useful in helping to determine readiness to compete in matches.

PRACTICAL APPLICATIONS

There are a number of practical applications from this study that are of relevance to coaches and support staff. Over an intensified period of rugby league competition when there is insufficient time to recover between games, fatigue accumulates. High levels of residual fatigue prior to competition may compromise high-intensity activities during match play such as high speed running, maximal accelerations, and tackling. As such, careful monitoring strategies should be implemented in order to determine a players' readiness for training and competition.

Variables obtained from a CMJ that include a velocity component appear more sensitive in detecting fatigue during a rugby league competition and therefore offer great utility as a monitoring tool. There is a significant involvement of the upper body during rugby league competition. The plyometric press-up appears a suitable measure for determining upper body neuromuscular fatigue following competition. The force component of this movement appears to be compromised by rugby league competition to a greater extent than velocity. As such, assessing upper body force from a plyometric press-up may prove to be a sensitive measure for assessing upper body neuromuscular fatigue.

Questionnaires that assess perceptions of fatigue and wellbeing are useful measures for monitoring fatigue and recovery during competition. These questionnaires are non-invasive, simple, and cost-effective measures that can be utilized at all levels of competition, and can provide useful information on individual players' exercise tolerance.

ACKNOWLEDGMENTS

The authors would like to thank Scotland Rugby League and the coaching staff of the team for allowing us to collect the data. Special thanks go to the players who gave up their time to participate in the study. None of the authors have any conflicts of interest with regards to the content of this study. The results of the present study do not constitute endorsement of any product by the authors or the NSCA.

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FIGURE CAPTIONS

Fig. 1 Peak power output for the countermovement jump at each time period during the week-long intensified competition. * Denotes a significant difference ($p < 0.05$) to baseline. Data are presented as means ± standard error (SE).

Fig. 2 Peak Force for the countermovement jump at each time period during the week-long intensified competition. Data are presented as means ± standard error (SE).

Fig. 3 Peak power for the plyometric press-up at each time period during the week-long intensified competition. * Denotes a significant difference ($p < 0.05$) to baseline. Data are presented as means ± standard error (SE).

Fig. 4 Peak force for the plyometric press-up at each time period during the week-long intensified competition. * Denotes a significant difference ($p < 0.05$) to baseline; † denotes a significant difference ($p < 0.05$) to12 hours post game 1. Data are presented as means ± standard error (SE).

Fig. 5 Whole blood creatine kinase activity at each time period during the week-long intensified competition. * Denotes a significant difference ($p < 0.05$) to baseline; † denotes a significant difference ($p < 0.05$) to12 hours pre game 2, and 36 hours post game 2. Data are presented as means ± standard error (SE).

Fig. 6 Perceived wellbeing scores for each time period during the week-long intensified competition. * Denotes a significant difference ($p < 0.05$) to baseline. Data are presented as means ± standard error (SE).