The Effects of Game and Training Loads on Perceptual Responses of Muscle Soreness in Australian Football

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Australian Football is an intense team sport played over ~120 min on a weekly basis. To determine the effects of game and training load on muscle soreness and the time frame of soreness dissipation, 64 elite Australian Football players (age 23.8 ± 1.8 y, height 183.9 ± 3.8 cm, weight 83.2 ± 5.0 kg; mean ± SD) recorded perceptions of muscle soreness, game intensity, and training intensity on scales of 1–10 on most mornings for up to 3 competition seasons. Playing and training times were also recorded in minutes. Data were analyzed with a mixed linear model, and magnitudes of effects on soreness were evaluated by standardization. All effects had acceptably low uncertainty. Game and training-session loads were 790 ± 182 and 229 ± 98 intensity-minutes (mean ± SD), respectively. General muscle soreness was 4.6 ± 1.1 units on d 1 postgame and fell to 1.9 ± 1.0 by d 6. There was a small increase in general muscle soreness (0.22 ± 0.07–0.50 ± 0.13 units) in the 3 d after high-load games relative to low-load games. Other soreness responses showed similar timelines and magnitudes of change. Training sessions made only small contributions to soreness over the 3 d after each session. Practitioners should be aware of these responses when planning weekly training and recovery programs, as it appears that game-related soreness dissipates after 3 d regardless of game load and increased training loads in the following week produce only small increases in soreness.

Keywords: DOMS, monitoring, player management

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the structural change is an increase of circulating enzymes and protein concentrations. A perceptual response to muscle damage is delayed-onset muscle soreness, which peaks within 72 hours. The exact cause of the soreness response is not known but may involve an inflammatory reaction to the damage. Circulating creatine kinase has been used as an indirect marker of muscle damage during elite junior Australian Football play, differentiating fast running and moderate to high acceleration/deceleration profiles. It appears that there is a window of ~3 days in which the responses of players to game demands requires careful consideration and monitoring to ensure that training loads are suitable to minimize injury risk and maintain performance and ensure that optimal recovery strategies are in place to enhance regeneration.

Athlete monitoring has become an area of high interest and development recently, as practitioners increase their efforts to understand psychophysiological responses to sporting demands. If the demands of a sport are known, and the athlete responses to those demands are quantified and understood, there is an expectation that appropriate action can be taken in the areas of musculoskeletal recovery, metabolic regeneration, and psychological rejuvenation to maintain training capacity and hence competition performance. Emerging GPS technology has the ability to quantify loads through algorithms combining accelerometer vectors and appears to be a progressive practice to assess physical training load. The monitoring of competition and training load has generally been completed in team sports through the use of the session-RPE method. Use of this uncomplicated classification tool is well supported in the literature, yet, given the simplistic nature of this method, there has been little investigation into the correlations between the outcomes of this method and player responses to game demands.

When daily responses from team-sport athletes regarding their competition-related soreness, fatigue, and wellness are required, the investigation tool needs to be easily administered and time efficient for both the athlete and the practitioner collating data. Questions need to be unambiguous in relation to soreness of specific muscle groups and have responses that indicate the type and effectiveness of recovery for various psychophysiological parameters. The most comprehensive assessment tool for determining athlete recovery is the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport). The extensive nature of the test is not applicable for daily assessments, but when it is used over a 4- to 6-week period it can describe the responses of team-sport athletes to training, the training relationships to injury, and the impact of recovery on illness rates. Recently, a Perceived Recovery Status scale to subjectively assess an individual’s level of recovery in relation to exercise performance was proposed. This scale is similar to the Borg CR-10 scale, which allows direct correlations to training when a similar scale is used to determine training intensity. This philosophy follows from the Total Quality Recovery (TQR) scale developed previously by Kenttä and Hassmén, but, unfortunately, the TQR program received little acceptance due to its complexity and untested validity.

Given that many team sports collect extensive data related to training and competition loads and monitor players on a daily basis to determine the responses to these loads, the aim of this retrospective analysis was to determine the effect of weekly game load and the combined effect of game and training loads when assessed by the session-RPE method on subjective measures of muscle soreness in the week following competition, as well as to quantify the rate of soreness changes over the subsequent training week.

Methods

Participants

Participants for this analysis were 64 (mean ± SD; 23.8 ± 1.8 y, 183.9 ± 3.8 cm, 83.2 ± 5.0 kg) elite Australian Football players competing in the Australian Football League. All players were aware that scientific investigation and analysis may occur under their contractual agreements, and the study conformed to the Declaration of Helsinki. Only data from players who were training for and competing in the 2008–2010 seasons were used in the analysis.

Data Collection

All data were collected on custom-designed electronic questionnaires using the KineticAthlete program (Kinetic Pty Ltd, Canberra, Australia). Questionnaire responses to muscle soreness were reported on a scale adapted from the Borg CR-10 ranging from 1 (no soreness) to 10 (extremely sore). All players were required to complete the forms each morning before any musculoskeletal treatment or training. Quantification of game load was performed using the session-RPE method, previously reviewed as a valid measure of exercise intensity. In brief, this process involves players providing a rating of the game and training intensity on a previously validated CR-10 scale, and this unit is multiplied by each player’s individual game or training time to obtain an overall value. The only verbal prompt given was “How hard was that game/session?” Each player provided his game rating ~24 hours postgame or posttraining rating ~15 to 30 minutes posttraining. The postgame rating was collected at ~24 hours to ensure that players could provide an accurate reflection of intensity, rather than being influenced by postgame requirements. During games, only data for players who played for more than 30 minutes were used, ensuring that low values due to early substitution were excluded.

Statistical Analysis

All estimations were made using the Statistical Analysis System (Version 8.2, SAS Institute, Cary, NC, USA). Each measure of soreness was analyzed separately as the
dependent variable in a mixed linear model. The data were processed to give each player a single observation for each occasion on which soreness was measured. Each observation had values for variables representing the season of play (3 levels), identity of the player (64 levels), the number of days since the last game (6 levels, represented by integer values of 1–6), the game load (previously described), the date of the game (80 levels), the presence or absence of training up to 6 days prior (6 dummy variables coded 1 or 0), and the training load on each of those days (6 variables calculated as for the game load). The fixed effects in the model were all these variables (except for player identity), with game date nested within season and with an interaction between days since the last game and game load (to estimate the linear effect of game load on days subsequent to the game).

To model the repeated measurements on players within and between seasons, the random effects were subject identity, interactions of subject identity with season and game date, and the residual. The mean soreness on each of the 6 days after a game was estimated as the least-squares means for the variable representing days since the last game. The effect of training on each of the 6 days before the measurement of soreness was estimated as the coefficients of the training dummy variables. The moderating effects of training load and game load on each of the 6 days prior were estimated from the coefficients for the corresponding variables by multiplying them by a load equal to 2 within-subject SDs of the load on each day. The within-subject SDs were calculated by rescaling each player’s load to a mean of zero before grouping the data for each of the 6 days; days on which training did not occur were treated as missing, not zero. The effect of a difference in load of 2 SDs represents the difference in soreness after typically low and typically high game or training loads.

Magnitudes of effects were evaluated via standardization. For this purpose, a between-subjects SD representing the typical variation in soreness between players on any given day was derived as the square root of the sum of the variances of the random effects in the model. The effects were divided by this SD and their magnitudes interpreted with the following scale: <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; and >1.2, large. Uncertainty in the effects was expressed as 90% confidence limits. Inferences about magnitudes were mechanistic: If the confidence interval overlapped thresholds for substantial positive and negative values (± 0.2 standardized units), the effect was deemed unclear; effects were otherwise deemed clear.

Results

Perceptual soreness responses peaked immediately postgame, then decreased gradually (Figure 1). Games of greater intensity, as determined by additional game load, promoted a clear small increase of up to 0.5 units in general soreness and calf, groin, and quadriceps soreness during the 72 hours postgame, with little further effect thereafter (Figure 1). Training load contributed small amounts of ~0.4 units to the general soreness profile in the following training week, and additional training load promoted further small increases in soreness up to ~0.4 units in the 4 days after any training session (Figure 2).

Similar effects of training load were observed for hamstring, calf, groin, and quadriceps muscle soreness, but there was little effect of training on the soreness of the other muscle groups (Table 1).

![Figure 1](image1.png) — General muscle soreness in the 6 days after a game (black circles) and the additional soreness associated with a 2-SD difference in game load (white boxes). Values are means, bars are between-players SDs. Soreness responses of specific muscle groups showed similar time lines and magnitudes of change (lines without symbols). The effects of game load on soreness were clear for all measures of muscle soreness for all days postgame (range of confidence limits 0.05–0.11).

![Figure 2](image2.png) — Contribution to general muscle soreness in the 6 days after a training session due to the mean training load (black boxes) and a 2-SD difference in training load (white boxes). The effects were clear for all measures (confidence limits 0.04–0.09).
Soreness Responses in Australian Football

All effects in this study had sufficiently low uncertainty to be clear. For the 3-year observation period, there were 2568 responses to the soreness questionnaire. Average weekly game load, training load, and general muscle soreness were 790 ± 182, 229 ± 98, and 3.1 ± 1.3, respectively. There was no substantial difference in the average yearly game load between years. The combined training and game loads (mean ± SD) during the precompetition and early- and late-competition seasons across the analysis period were 1138 ± 274, 967 ± 187, and 1041 ± 124, respectively. Main training sessions over the study period were on days 2 and 4 before the game; due to scheduling and player requirements some sessions were on other days, but those sessions were consistent in load with main sessions (Figure 3). Typical error measures for the reliability of the RPE and muscle-soreness scales were 0.95(14%); 90% confidence limits 0.82–1.16, and 0.51(25%); ± 0.20, respectively.

Discussion

Game loads from Australian Football promote muscle-soreness responses in players that dissipate over the remainder of a weekly competition cycle. The contribution to this soreness from games that are harder, from a perceptual load perspective, is small early in the week and practically nonexistent by the end of the week. The contribution to soreness from training load is also small at the beginning of the week, and by the second training session this contribution is negligible, even when training loads are increased. It would appear from the analysis of these data that increasing the training load in any given training session by up to one-half during the week following a game will have no substantial contribution to soreness responses in the days following the training session. To our knowledge, this is the first attempt to statistically quantify the changes in perceptual soreness responses in team sport after competition by combining the weekly demands of games and training.

Differences between days for muscle-soreness responses during the week following competition showed small immediate improvements in the first days of the week. This improvement continued for 3 days after a game, which supports the findings of previous physical

Table 1 Changes in Soreness Responses in the Week Following Competition Due to Additional Game Load

<table>
<thead>
<tr>
<th>Days postgame</th>
<th>General soreness (4.6 ± 0.4)</th>
<th>Hamstring (3.2 ± 0.4)</th>
<th>Calf (3.5 ± 0.4)</th>
<th>Gluteals (3.1 ± 0.4)</th>
<th>Groin (3.0 ± 0.4)</th>
<th>Quadriceps (3.0 ± 0.4)</th>
<th>Low back (3.3 ± 0.9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50 ± 0.13, 0.37, small ↑</td>
<td>0.23 ± 0.11, 0.23, small ↑</td>
<td>0.35 ± 0.12, 0.33, small ↑</td>
<td>0.12 ± 0.11</td>
<td>0.27 ± 0.11, 0.25, small ↑</td>
<td>0.27 ± 0.11, 0.26, small ↑</td>
<td>0.03 ± 0.11</td>
</tr>
<tr>
<td>2</td>
<td>0.34 ± 0.08, 0.31, small ↑</td>
<td>0.17 ± 0.07, 0.24, small ↑</td>
<td>0.28 ± 0.08, 0.26, small ↑</td>
<td>0.14 ± 0.07</td>
<td>0.28 ± 0.07, 0.27, small ↑</td>
<td>0.28 ± 0.07, 0.21, small ↑</td>
<td>0.21 ± 0.07, 0.21, small ↑</td>
</tr>
<tr>
<td>3</td>
<td>0.22 ± 0.07, 0.21, small ↑</td>
<td>0.12 ± 0.06, 0.20, small ↑</td>
<td>0.21 ± 0.07, 0.20, small ↑</td>
<td>0.12 ± 0.06</td>
<td>0.21 ± 0.06, 0.20, small ↑</td>
<td>0.13 ± 0.07</td>
<td>0.08 ± 0.06</td>
</tr>
<tr>
<td>4</td>
<td>0.12 ± 0.07</td>
<td>0.07 ± 0.07</td>
<td>0.10 ± 0.08</td>
<td>0.11 ± 0.06</td>
<td>0.11 ± 0.06</td>
<td>0.15 ± 0.07</td>
<td>0.04 ± 0.07</td>
</tr>
<tr>
<td>5</td>
<td>0.04 ± 0.08</td>
<td>-0.04 ± 0.07</td>
<td>0.03 ± 0.08</td>
<td>0.03 ± 0.07</td>
<td>0.10 ± 0.07</td>
<td>0.04 ± 0.08</td>
<td>-0.01 ± 0.07</td>
</tr>
<tr>
<td>6</td>
<td>0.00 ± 0.13</td>
<td>-0.02 ± 0.12</td>
<td>-0.08 ± 0.12</td>
<td>0.12 ± 0.11</td>
<td>0.11 ± 0.07</td>
<td>0.07 ± 0.12</td>
<td>-0.07 ± 0.11</td>
</tr>
</tbody>
</table>

Note: Values in parentheses in table heads are daily soreness 1 day postgame ± SD. Values in table are soreness change ± 90% confidence limit (CL), effect size (ES), qualitative outcome. The magnitudes of difference were classified using the criteria trivial < 0.2, small 0.2–0.6, moderate 0.6–1.2, large 1.2–2.0, and very large ≥2. A substantial increase or decrease was classified as a ≥75% likelihood of the effect being greater than or equal to the ES 0.2 reference value (small). Effects were classified as unclear if the ± 90% CL of the ES crossed the boundaries of ES ± 0.2. CLs for effects ranged from 0.06 to 0.12.
outcomes of performance and neuromuscular function being compromised ~3 days postcompetition. Immediate postgame recovery strategies such as cold-water immersion and massage,25,26 often replicated in the days following competition, could influence this outcome and reduce the soreness expected after this type of exercise. These athletes used cold- and contrast-water immersion posttraining and postgame consistently over the analysis period and also received massage 2 or 3 times per week during the training and competition period. Previous claims discount an ability of either strategy to accelerate structural or functional recovery and found that they may negatively influence the inflammatory process delaying recovery.27 In this instance it appears that consistent cold-water and massage therapies could have played a beneficial role in minimizing soreness responses. Ideally, the quantification of remedial therapies during the competition week would provide insight as to the impact of these treatments on diminishing soreness responses and improvements in function compared with no treatment. In any event, as the use of these treatments was consistent across the subject group and the analysis period, any benefit would also have been consistent within the training and competition cycles. It would also appear that some players carry over some residual muscle soreness from the previous game into the next week’s competition. A comparison of short and long weekly competition cycles against soreness and performance would provide valuable information to assess changes in game intensity with decreased recovery and preparation time.

Of particular interest to practitioners will be the contribution of these soreness changes and training loads with respect to injury risk. During the early- and late-competition training phases of a rugby league season, increases in training load of 175 to 620 and 145 to 410 intensity-minutes (respectively) resulted in no further increase in injury incidence compared with the preseason phase, when increases between 155 and 590 would increase injury risk.28 Those training loads are substantially higher than those presented herein, which may be related to the differences in physical contact between sports, as well as longer training sessions. Recent injury-risk data describe previous injury and age as dominant risk factors for soft-tissue injury, particularly hamstring injury in Australian Football.29 Although the Hamstring Outcome Score test has questions related to soreness, this along with performance and strength tests, anthropomorphic characteristics, and clinical findings does not predict risk for hamstring injury.30 Hamstring soreness has previously been found as a predisposing factor to muscle injury in soccer,31 but we observed that hamstring soreness was not the highest of responses and was not influenced by additional game load as heavily as calf, groin, and quadriceps muscle groups. Further work is required to determine any relationship between muscle soreness and injury risk.

The current analysis was undertaken over a period where Australian Football game interchanges increased by 22 per year on average. Performance indicators from Australian Football League GPS data indicate that estimated game intensity increased by 17% in the period from 2005 to 2010, with little difference from 2008 to 2010.32 Although average running velocity increased by 8.4% from 2005 to 2008,32 there was only a small increase from 2008 to 2010, with no difference from 2009 to 2010.32 So it would appear that average weekly running velocity in Australian Football competition was largely unchanged over the study period; however, the nature of the running demands may have affected game intensity. Acceleration characteristics, continual (steady-state, >8 km·h⁻¹) running, and long continual efforts had small to moderate increases from 2008 to 2010.32 We recognize that these are average data from organizations that chose to submit data and that the athletes in this study compose a small sample of that analysis; however, we feel that these demands would be experienced by the majority of players. Injury data show an increase in the incidence of injuries since 2007 and in the prevalence of injuries overall since 2003.34 This included hamstring strains, which were claimed to be the most significant; however, the increase in new injury incidence for hamstrings since 2007 was 0.5% and decreased by 1.1% from 2009 to 2010.34 Recently, Orchard et al35 concluded from an analysis of player interchange rates and hamstring injury that increasing the amount of individual rest during a game may have a protective effect against hamstring injury. It remains to be investigated if there is a link between playing time (rotations), soreness responses, and soft-tissue injury, as the influence of game demands on soreness are small for most muscle groups and changes in soft-tissue injury are small and variable between years. The soreness associated with the running demands of Australian Football after competition could be classified as delayed-onset muscle soreness (DOMS). The eccentric loads associated with the volume and type of running in a game promote the perceptual responses observed in this study. Previous research has demonstrated that repeat-sprint exercise applicable to team-sport demands elevated DOMS for 72 hours after exercise.31 A single soccer game showed less response, with DOMS peaking at 24 hours,32 while DOMS peaked after a single basketball game but was similar to baseline at 24 hours.37 It is more likely that the initial outcomes seen here are acute responses related to the demands of competition rather than a typical DOMS profile, as the responses are greatest immediately after a game, whereas DOMS is typically most severe at ~72 hours. Even when additional game load occurs, the profile changes are small and occur consistently in general muscle soreness and calf and groin soreness over the 72 hours postgame.

A limitation of the current analysis is that the study cohort represented only 1 of the 16 teams in the Australian Football League over the study period; other teams may have had different training and game loads. There was also no examination of blood markers of muscle damage. There is evidence from Australian Football that creatine kinase is useful for quantifying muscle damage based on relationships between elevated concentrations and

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high to low performers in fast running, accelerations, and decelerations; however, these observations were not from elite players, and the use of creatine kinase in these scenarios has been questioned previously. Other markers such as circulating fatty-acid-binding protein and myoglobin, have faster appearance and clearance rates and have been used successfully during Australian Football contact trials, college-level American football, and basketball. These and similar markers should be included in future studies to increase the knowledge of interactions between game loads, muscle damage, and perceptual responses of muscle soreness in Australian Football and other contact team sports. Many organizations may not have access to biochemical analysis; therefore, quantifying soreness responses with the approach described herein has practical application.

**Practical Application**

The perceptual responses of elite players to combined weekly game and training load shows that soreness of several main locomotive muscle groups is elevated in the immediate days after competition, and these increases will take until the end of the subsequent week to dissipate. Additional game load and additional training load have only a small impact on increasing these daily soreness responses within a 3-day period immediately after a game or training session. Practitioners should consider that elevated training loads on main training days appear tolerable, as the additional training load has a small further impact on the small soreness responses related to training. Future studies should combine injury and GPS or accelerometer data to determine whether compounding soreness correlates with injury prevalence and muscle damage, particularly if a player’s game time and game load change from previous years.

**References**

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