Preliminary Evidence of Transient Fatigue and Pacing During Interchanges in Rugby League

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Purpose: This study aimed to quantify changes in heart rate (HR) and movement speeds in interchanged and whole-match players during 35 elite rugby league performances. Methods: Performances were separated into whole match, interchange bout 1, and interchange bout 2 and further subdivided into match quartiles. Mean percentages of peak HR (%HR_{peak}) and total and high-intensity running (> 14 km/h) meters per minute (m/min) were recorded. Results: For whole-match players, a decline in high-intensity m/min and %HR_{peak} was observed between successive quartiles (P < .05). High-intensity m/min during interchange 1 also progressively declined, although initial m/min was higher than whole match (24.2 ± 7.9 m/min vs 18.3 ± 4.7 m/min, P = .018), and %HR_{peak} did not change over match quartiles (P > .05). During interchange 2, there was a decline in high-intensity m/min from quartile 1 to quartile 3 (18 ± 4.1 vs 13.4 ± 5 m/min, P = .048) before increasing in quartile 4. Quartiles 1 and 2 also showed an increase in %HR_{peak} (85.2 ± 6.5 vs 87.3 ± 4.2%, P = .022).

Conclusions: Replacement players adopted a high initial intensity in their first match quartile before a severe decline thereafter. However, in a second bout, lower exercise intensity at the outset enabled a higher physiological exertion for later periods. These findings inform interchange strategy and conditioning for coaches while also providing preliminary evidence of pacing in team sport.

Keywords: global positioning systems, substitutions, high-intensity running

While the use of motion-analysis technology in elite rugby league has enabled a general understanding of the physical and physiological profiles of competitive match play, little is known about how players may strategize and distribute their energy expenditure during matches. For example, investigations in rugby league have broadly observed differences in movement characteristics between positional groups, with longer and relatively less intense work bouts for outside backs compared with the brief intense periods of forwards and adjustables. However, given the nature of the interchange rule permitting up to 12 substitutions (2010–11 season) during any stage of a Super League match, such findings might have been anticipated. The interchanging of forwards and adjustables on and off the field at selected stages during a match, usually after an intense activity bout, is common practice in rugby league. This rule results in a less predictable playing period for interchanged players and, in accordance with the multilevel model of pacing in team sport proposed by Edwards and Noakes, may serve to alter the ways players predetermine and adapt their physiological exertions before and during match time, respectively.

A decline in high-intensity running provides an appropriate indication of match-related fatigue in team sports, with decrements of 37% to 50% reported between the first and last 15 minutes of a soccer match. Changes in high-intensity movement are associated with deterioration in physical performance and an increase in markers of fatigue. While reports in rugby league have noted a decline of 11.5% in high-intensity movements from the first to second half or, more specifically, decrements of 30.5% from the first to final quartile of an entire match, no study to date has addressed the presence and time course of fatigue among interchanged players. Given the greater relative high-intensity distance covered in replacement substitutes than in replaced substitutes during soccer matches, it is reasonable to anticipate a similar effect in rugby league players. Furthermore, the effect of 2 repeated performance bouts on the activity profiles found in elite rugby league, particularly in players anticipating their role as interchanged players, provides an interesting model to study pacing in team sports, the presence of which has been questioned in other team sports such as Australian Football. Such findings may help elucidate the influence of playing time and the stage of match introduction on movement intensity in rugby league, since each of these factors, in combination with dynamic match-related considerations, contributes to the subconscious construction of a pacing strategy that allows for completion of the given playing period while
maintaining a tolerable level of physical discomfort. Such an investigation would also be useful for rugby league practitioners attempting to optimize the impact of players introduced at varying stages of rugby league matches. Accordingly, the aim of the current study was to compare changes in heart rate and movement intensity over progressive match quartiles and, in turn, identify characteristic pacing strategies between interchanged and whole-match players during elite Super League matches.

### Methods

#### Participants
After consent from the club to conduct the research and ethical approval from the Faculty of Applied Health Sciences Ethics Committee, 18 elite male players (age 24.4 ± 3.3 y, body mass 95.2 ± 6.6 kg, height 183.4 ± 5.7 cm) from an English Super League club consented to participate in the current study. The study conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

#### Design
Heart rate and movement characteristics were analyzed during 14 Super League matches (35 individual performances) over the 2010 and 2011 seasons using portable GPS devices (SPI-Pro, 5Hz, GPSports, Canberra, Australia) and an in-built 6-g accelerometer (100 Hz). All matches took place in the evening between approximately 6 and 10 PM at 1 of 2 grounds in the Northwest of England. The mean temperature for all matches was 8.4°C ± 5.1°C. Players continued with normal training and match-day preparations throughout the testing period.

#### Procedure
The fitting of GPS and heart-rate monitors followed the guidelines detailed in a previous study. Throughout the testing period, a mean of 8 ± 1 (range 5–12) satellites was determined as available for signal transmission using Team AMS software. Using a specific software application (http://www.trimble.com/planningsoftware_ts.asp), a geographical point (station) was established based on latitude and longitude coordinates of the home grounds where matches took place. The mean horizontal dilution of precision was recorded at 1.2 ± 0.1 over 10-minute intervals during match periods and ranged from 0.73 to 2.22 for all recorded matches, which is in accordance with studies evaluating match demands using GPS systems and indicates optimal conditions for satellite transmissions. Of the 14 matches analyzed, 10 were won and 4 were lost, with a mean score deficit of 19 ± 16 points.

Performances were subcategorized into 3 distinct performance types, each representative of a continuous performance bout. These were whole matches (players starting and finishing on the field of play), interchange bout 1 (players either replacing others or being replaced by others for their first playing bout), and interchange bout 2 (players replacing others or being replaced by others for a second playing bout). Each player analyzed took part in 1 to 4 matches, with 11 players (n = 19) completing whole matches and 12 players (n = 16) completing bout 1, of which 7 players completed a second bout (n = 9). The descriptive statistics of match periods, relative quartile periods, and time of introduction to the match are provided in Table 1. Whole-match players consisted of 7 backs (3 wingers, 1 full back, 2 centers, and 1 scrum half) and interchanged players consisted of 11 forwards (3 prop forwards, 5 second rowers, 2 hookers, and 1 loose forward).

There were no players taking part in both whole matches and interchanged matches in the current analysis. All players were deemed injury free at the time of testing by a qualified physiotherapist and physician, and players being interchanged due to injury were discarded from the analysis. All bout 1 interchanges took place during the first half, and all bout 2 interchanges took place in the second half. While players being interchanged had no prior knowledge of exactly when they would be interchanged, they were aware of their tactical role as interchangeable players. Any performance in which more than 70% of the respective half had been completed was discarded from the analysis based on typical interchange bouts and recommendations in which performances >70% of match time have been regarded as representative of whole matches.

### Table 1 Total Pitch Time, Playing Quartiles, and Time of Introduction in Whole Match, Interchange Bout 1, and Interchange Bout 2, Mean ± SE

<table>
<thead>
<tr>
<th></th>
<th>Whole match (n = 19)</th>
<th>Interchange 1 (n = 16)</th>
<th>Interchange 2 (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pitch time (min)</td>
<td>84.5 ± 3.4</td>
<td>20.2 ± 3.9</td>
<td>22.5 ± 11.0</td>
</tr>
<tr>
<td>Quartile time (min)</td>
<td>21.1 ± 0.2</td>
<td>5.1 ± 1.0</td>
<td>5.6 ± 2.7</td>
</tr>
<tr>
<td>Introduction time (min)</td>
<td>0 ± 0</td>
<td>12.1 ± 6.0</td>
<td>10.4 ± 6.3</td>
</tr>
<tr>
<td>Warm-up percent of peak heart rate</td>
<td>74.5 ± 4.0*</td>
<td>67.2 ± 2.7</td>
<td>68.3 ± 4.4</td>
</tr>
</tbody>
</table>

Note: Time of introduction is expressed relative to the beginning of the first (bout 1) or second half (bout 2). Percent of peak heart rate was recorded in the warm-up for whole-match players and in the 5 min before game entry for interchange players. *Different (P < .001) from each of the interchange bouts.
A digital watch was synchronized with Greenwich Mean Time and used to record the start and end of each half, as signaled by the referee. These times were later used to truncate the raw GPS data file. The time of interchanged players was recorded live and used to further truncate raw data. Consequently, only time spent actively on the pitch was analyzed. Data for all players were split into even quartiles using Team AMS software, regardless of the overall playing period (see Table 1 for mean quartile duration). All data were downloaded to a computer using SPI Ezy V2.1 (GPSports, Canberra, Australia) and analyzed using Team AMS version 2.1 software (GPSports).

**Match-Related Variables**

The total distance covered relative to match time (m/min) and high-intensity distance covered relative to match time (>14 km/h) were recorded from selected players based on the speed categories used in analyses of rugby league. Studies have shown moderate to good reliability using the speed categories used in analyses of rugby league.\(^2,10\) The total distance covered relative to match time (m/min) and high-intensity distance covered relative to match time (m/min, high-intensity m/min, and %HR peak during interchange bouts 1 or 2 (n = 8) was also recorded in the 5 minutes before playing, which accounted for the approximate warm-up period. HR peak values were obtained before data collection, defined as the highest value reached during the Yo-Yo Intermittent Recovery Test 1.\(^6\) A mean range of 16.9 ± 1.1 was reached by players participating in the study.

**Statistical Analysis**

Changes in m/min, high-intensity m/min, and %HR peak during the game were analyzed using separate mixed-design factorial analyses of variance (ANOVA) to compare type of playing bout (whole match, interchange bout 1, and interchange bout 2) by match quartile (quartiles 1, 2, 3, and 4). Assumptions of sphericity were assessed using the Mauchly test of sphericity, with any violations adjusted by use of the Greenhouse-Geisser correction. When significant interaction effects were observed, a paired-samples \(t\) test with a Bonferroni adjustment was used to determine the location of the differences between match quartiles by playing bout. Differences between interchange bouts 1 and bout 2 in %HR peak 5 minutes before match period were assessed using paired \(t\) tests, while differences between the whole match and interchange bouts 1 or 2 were assessed using an independent \(t\) test.

**Results**

### High-Intensity Running m/min

There was a main effect of match quartile on high-intensity running m/min \((F_{3,123} = 23.653, P < .001)\), with post hoc tests showing differences \((P < .001)\) between quartiles in each quartile comparison aside from quartiles 2 and 3 \((16.2 ± 4.8 vs 15.3 ± 5.9 m/min, P = .100)\) and quartiles 3 and 4 \((15.3 ± 5.9 vs 12.9 ± 4.9 m/min, P = .132)\). While no main effect was apparent for playing bout \((F_{2,41} = 0.903, P = .413)\), there was an interaction found between match quartile and playing bout on high-intensity m/min \((F_{6,123} = 5.428, P < .001)\), with paired \(t\) tests showing a drop in high-intensity m/min \((P = .041)\) between quartile 1 \((18.3 ± 4.7 m/min)\) and quartile 4 \((14.6 ± 5.8 m/min)\) for players completing a whole match. For interchange bout 1, there was a decrease in high-intensity m/min between quartiles 1 and 2 \((24.2 ± 7.9 vs 17.6 ± 6 m/min, P < .001)\), quartiles 1 and 3 \((24.2 ± 7.9 vs 16.4 ± 8.3 m/min, P < .001)\), quartiles 1 and 4 \((24.2 ± 7.9 vs 10.8 ± 5.7 m/min, P < .001)\), quartiles 2 and 4 \((17.6 ± 6 vs 10.8 ± 5.7 m/min, P < .001)\), and quartiles 3 and 4 \((16.4 ± 8.3 vs 10.8 ± 5.7 m/min, P < .001)\). For interchange bout 2, the only difference occurred between quartiles 1 and 3 \((18 ± 4.1 vs 13.4 ± 5 m/min, P = .048)\).

During quartile 1, between-groups comparisons of playing bouts by match quartile showed a superior level of high-intensity running during interchange bout 1 \((24.2 ± 7.9 m/min)\) compared with both whole-match performances \((18.3 ± 4.7 m/min, P = .018)\) and interchange bout 2 \((18 ± 4.1 m/min, P = .046)\). No other pairwise differences were apparent. Data showing changes in high-intensity m/min are shown in Figure 1.

### Total m/min

While there was a significant main effect for match quartile on the total m/min \((F_{3,123} = 6.177, P < .001)\), no main effects for playing bout \((F_{2,41} = 3.077, P = .06)\) or interaction effects \((F_{6,123} = 1.839, P = .09)\) were apparent (Figure 2). Post hoc tests showed differences between quartile 1 and quartile 4 \((97 ± 2.1 vs 88.2 ± 2.7 m/min, P = .003)\).
Figure 1 — High-intensity running over incremental quartiles of relative playing periods in performances over a whole match (n = 19) or performing as an interchanged player (bout 1, n = 16, or bout 2, n = 9). * Significantly different from quartile 2. ** Significantly different from quartile 3. *** Significantly different from quartile 4. * Significantly different from interchange bout 1. Symbols correspond to the order of the data legend: I1 indicates interchange bout 1; I2, interchange bout 2; WM, whole match.

Figure 2 — A profile of total meters per minute over incremental quartiles of relative playing periods in players completing a whole match (n = 19) or performing as an interchanged player (bout 1, n = 16, or bout 2, n = 9).
HR

The %HR<sub>peak</sub> recorded in the 5 minutes before taking the field was not different (P = .530) between players performing in both interchange bout 1 (67.2% ± 2.7%) and interchange bout 2 (68.3% ± 4.4%). Players completing a whole match demonstrated higher %HR<sub>peak</sub> compared with each interchange playing bout (P < .001; Table 1) during the warm-up; however, this was followed by an approximately 5-minute period of passive recovery in a moderately heated dressing room before the start of the match. As shown in Figure 3, during the playing bout there were no main effects found for match quartile on the %HR<sub>peak</sub> (F<sub>1.5,63.3</sub> = 2.032, P = .150), but a main effect for playing bout (F<sub>1,20.5</sub> = 4.367, P = .019) was found, with differences occurring between interchange bout 2 and whole match (87.9% ± 4.9% vs 82.9% ± 4.4%, P = .033).

An interaction effect was demonstrated between match quartile and playing bout (F<sub>3.1,63.3</sub> = 4.139, P = .01), with post hoc analysis showing a rise in %HR<sub>peak</sub> between quartiles 1 and 2 (85.2% ± 6.5% vs 87.3% ± 4.2%, P = .022) for interchange bout 2; however, no pairwise differences in %HR<sub>peak</sub> were found for interchange bout 1. In contrast, a consistent decline in %HR<sub>peak</sub> was shown for whole-match performances, with differences occurring between quartiles 1 and 3 (85.8% ± 4.9% vs 81.7% ± 4.5%, P = .004), quartiles 1 and 4 (85.8% ± 4.9% vs 79.9% ± 7%, P = .022), quartiles 2 and 3 (84.3% ± 4.1% vs 81.7% ± 4.5%, P = .005), and quartiles 2 and 4 (84.3% ± 4.1% vs 79.9% ± 7%, P = .018).

As presented in Figure 3, comparisons between playing bouts by match quartile showed differences in %HR<sub>peak</sub> during quartile 3 between whole match (81.7% ± 4.5%) and both interchange bout 1 (87.3% ± 4.2%, P = .020) and bout 2 (86.3% ± 5.4%, P = .025) performances. During quartile 4, only 1 difference in %HR<sub>peak</sub> was shown between whole match and interchange bout 2 (79.9% ± 7% vs 90.3% ± 2.9%, P = .003).

Discussion

The current study is the first to demonstrate the influence of the interchange rule on match running performance in elite Super League rugby. A key finding of the current study is the marked dependency of high-intensity running on the nature of the playing bout. For example, consistent with reports in rugby league<sup>10</sup> and soccer,<sup>6</sup> the high-intensity running of players completing a whole match was shown to differ (~21%) only between quartile 1 (18.3 ± 4.7 m/min) and quartile 4 (14 ± 4.6 m/min), reflecting a subtle and progressive decline in high-intensity movement throughout the match quartiles. In contrast, performances during the first interchange (bout 1) show a comparatively larger amount (P < .05) of high-intensity...
running during the first quartile, followed by a stepwise decline in performance between all playing quartiles apart from quartile 2 to quartile 3. Such observations during interchange bout 1 appear consistent with the effect of transient fatigue, wherein players demonstrate a stark decline in high-intensity running immediately after a period of peak exertion. In rugby league, players completing briefer interchange periods are used tactically by coaches as higher-intensity “impact” players and arrive at the field in a relatively more rested state than their noninterchanged counterparts, which was demonstrated by the lower recordings of %HRpeak in the 5 minutes before entering the field of play compared with values recorded during match play. This appears to result in players’ beginning the first relative quartile of a match at unsustainable exercise intensities, subsequently leading to lower amounts of high-intensity running at later stages of the match. Studies investigating fatigue in rugby league match play have not considered the potential influence of the interchange in this manner.

A second notable finding of our study is the performance from the second interchange bouts, in which high-intensity movement did not differ (P > .05) from a whole-match profile during any match quartile. Furthermore, the only decrement in high-intensity performance was demonstrated between quartiles 1 and 3, which did not continue (P > .05) between quartiles 3 and 4. Indeed, while no difference occurred between quartiles 3 and 4 for high-intensity running during interchange bout 2, a marginal increase was apparent between these periods. Furthermore, during interchange 2, no differences (P < .05) were found between these later match quartiles and quartile 1. Our findings are consistent with the “end spurt” phenomenon, which represents one of a variety of pacing strategies in which athletes (typically endurance based) increase running speed toward the end of a race after conservative exertions during earlier stages. It has been suggested that pacing in team sports might not occur in such a manner and that the continual decline in performance, as observed herein for the players completing a whole match, is more typical. However, the potential differences in movement patterns between players completing a whole match compared with those playing for shorter preempted bouts, particularly during secondary bouts in which experienced players have an approximate understanding of the endpoint, have not been considered. This is important since pacing strategies are part of a preconceived, conscious or subconscious design, set by the athlete to ensure optimal completion of the bout, and will be guided by knowledge of the exercise task. Indeed, the fact that a true endpoint could be vaguely understood in team sport, owing to factors such as extra time, does not detract from the microstrategies employed by an athlete to respond appropriately to match demands. Indeed, the variability in %HRpeak observed in bout 2 interchange performance throughout the match quartiles could reflect such an occurrence (see Figure 3). Moreover, the up-regulation of %HRpeak during the third and fourth quartiles in interchange bout 2 is in contrast to the other playing bouts where a continual decline is observed and represents the reserved high-intensity running capacity among these players. Therefore, our findings suggest that players performing a second interchange bout will preserve high-intensity running in a preemptive attempt to produce an end spurt in the final quartiles of performance. However, the effect of pacing should be considered alongside the variety of pacing strategies that can be adopted by an athlete. Indeed, players completing a whole match appear to pace their efforts according to a different strategy, one that limits fatigue and ensures completion of the match in a reasonable physical state.

Match fatigue, identified by a reduction in high-intensity running over progressive match quartiles, is mediated by both central and peripheral factors. Peripheral mechanisms such as substrate depletion, hydrogen ion accumulation, and potassium imbalance have been suggested as potential causes of fatigue and may also act to stimulate groups III and VI muscle afferents, leading to subsequent inhibition of motoneurons at the spinal level. In addition, centrally mediated fatigue mechanisms that act to maintain homeostasis have been proposed. Such mechanisms involve continual modification of exercise intensity in response to integrated peripheral cues and are regulated through both feed-forward and feedback control loops, ensuring bodily homeostasis. For example, the lower intensity of whole-match players during the opening match quartile may relate to factors such as excessive warm-up strategies, thus altering the movement intensity and subsequent approach to match play. Additional parameters such as the evolving nature of the task and an athlete’s experience of such are further integrated by the brain to form a physical performance strategy that will enable the athlete to complete the task without threatening any singular physiological system. Although speculative, such models may explain the contrasting match running profiles between players performing bouts of different duration, particularly between the equally matched playing periods of interchange bouts 1 and 2. It is our contention that the marked differences between these playing bouts may partly relate to factors such as the prior tactical understanding of the players. For example, players during interchange bout 1 are expected to create an impact on the match owing to their relatively superior physical state, thus compelling them to begin at a higher intensity of exercise than in a longer playing bout. This decision must be controlled in accordance with knowledge of an endpoint that is less discrete during bout 1, where players are often replaced if the average match pace is not maintained (Figure 1). In contrast, due to the limited-interchange rule, bout 2 performances in the current study each represented the final playing period for a player in the second half of a match. In most cases, the players were required to complete the remaining playing period, which could be constantly monitored via the stadium clock. It is in bout 2 performances that a conservation of exertion is most notable.

In contrast to continuous, closed-loop endurance events where an athlete competes alone, the current
results should be considered from the context of team sport, in which the object of performance is not to finish first at a given time point. Our findings suggest that an “all out” strategy is adopted during initial playing bouts, compared with a more evenly paced, conservative strategy in bout 2, where the overall amount of total or high-intensity m/min running performed remains unchanged. Therefore, the form of the pacing strategy adopted serves a more important purpose in rugby league and is highly dependent on the nature of the playing bout. Furthermore, owing to the stochastic nature of team sport, individual variability in pacing strategy may also be observed. For example, 1 out of the 16 bout 1 performances demonstrated an increase in high-intensity m/min in quartile 4 compared with quartile 1. While this should not detract from the mean differences we have shown between different playing bouts, such an occurrence may be the result of random match scenarios or simply the pacing method adopted by a given player in that instance. Indeed, factors such as between-matches variability and sample size should be considered as potential threats to the interpretation of changes in movement patterns during team-sport performance. However, the variance of each dependent measure that was established in the current article was consistently lower than the mean changes demonstrated between playing bouts or across quartiles. Authors may also wish to adopt the use of a nomogram presented by Atkinson and Nevill\textsuperscript{30} to estimate the sample size required to detect changes in performance. For example, in the most extreme case of the current study, a CV of 15.1% was evident for high-intensity running minutes in whole-match players. To detect a 21% change between quartiles 1 and 4 in these players, a sample size of 10 would be required, which is fewer than the players (n = 11) and performances (n = 19) that were sampled.

**Practical Applications**

The current results provide valuable information for coaches when considering the optimal timing of interchange performances to avoid different playing quartiles and provide preliminary evidence of pacing in team sport. Future research should consider the presence of different pacing strategies and the influence of factors such as task knowledge and experience on team-sport performance.

**Conclusions**

The current study is the first to highlight the difference between the fatigue profiles of whole-match and interchange performances, with players in their first bout showing a higher initial intensity in the first relative quartile of play, followed by a severe performance decline. Players completing a second replacement bout appear more likely to begin at a lower, maintainable intensity similar to whole-match performances, while also conserving their physiological exertion for later match periods. These results have significance for the optimization of interchanges and the specificity of conditioning among elite rugby league players and provide preliminary evidence of pacing in team sport. Future research should consider the presence of different pacing strategies and the influence of factors such as task knowledge and experience on team-sport performance.

**References**


