Abstract

Objectives: To investigate the physical demands of professional rugby league match-play using microtechnology, and to compare these demands with typical training activities used to prepare players for competition. Design: Prospective cohort study. Methods: Thirty elite rugby league players participated in this study. Seven hundred and eighty-six training data sets and 104 data sets from National Rugby League matches were collected over one playing season. Movement was recorded using a commercially available microtechnology unit (minimaxX, Catapult Innovations), which provided information on speeds, distances, accelerations, physical collisions and repeated high-intensity efforts. Results: Mean distances covered during match-play by the hit-up forwards, wide-running forwards, adjustables, and outside backs were 3569 m, 5561 m, 6411 m, and 6819 m, respectively. Hit-up forwards and wide-running forwards were engaged in a greater number of moderate and heavy collisions than the adjustables and outside backs, and more repeated high-intensity effort bouts per minute of play (1 bout every 4.8–6.3 min). The physical demands of traditional conditioning, repeated high-intensity effort exercise, and skill training activities were all lower than the physical demands of competition. Conclusions: These results demonstrate that absolute distances covered during professional rugby league matches are greater for outside backs, while the collision and repeated high-intensity effort demands are higher for hit-up forwards and wide-running forwards. The specific physical demands of competitive play, especially those demands associated with collisions and repeated high-intensity efforts, were not well matched by those observed in traditional conditioning, repeated high-intensity effort exercise, and skills training activities. Further research is required to investigate whether modifications need to be made to these training activities to better prepare players for the demands of National Rugby League competition.

Keywords: Contact; Conditioning; Physical demands; Team sport; Physical preparation; GPS

1. Introduction

Time-motion analysis is of importance to applied sport scientists and strength and conditioning coaches in order to assist in the development of game-specific conditioning programs. While time-motion analysis has been used extensively in most team sports,^1^ research into the physical demands and movement patterns of rugby league match-play is limited.^2^-^4^ In a study in the early 1990s, Meir et al. investigated the

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rest ratios alone will likely result in players being underprepared for the most demanding passages of competition.\textsuperscript{2,6,7} More recently, studies have investigated the high-intensity running\textsuperscript{8} tackling,\textsuperscript{3} and repeated effort demands\textsuperscript{2} of professional rugby league match-play. Austin et al.\textsuperscript{2} filmed and coded the repeated high-intensity effort demands of professional rugby league hit-up forwards, adjustables, and outside backs during competitive match-play. Hit-up forwards were involved in significantly more repeated high-intensity effort bouts than players from other positions and had the shortest average recovery between bouts. The authors concluded that repeated high-intensity effort bouts occurred frequently during professional rugby league match-play and at critical times during the game.

Due to the labor-intensive nature of video-based time-motion analysis, most\textsuperscript{4,5} but not all\textsuperscript{7–9} studies have been limited to small sample sizes. With the introduction of global positioning system (GPS) technology, sport scientists are now able to gain information on the distances covered in low and high-intensity activities performed by athletes during training and competition,\textsuperscript{10} however, the reliability and validity of individual sprint and change of direction speed activities are relatively poor.\textsuperscript{11} Recent evidence has shown that the tri-axial accelerometers and gyroscopes embedded in these microtechnology units offer a valid\textsuperscript{12} and reliable\textsuperscript{13} means of automatically detecting the collisions and tackles that occur in rugby league. The capacity to monitor the contact load of rugby league players demonstrates the practical utility of these microtechnology units.

Rugby league players use a combination of traditional conditioning (i.e., high-intensity running without the ball), repeated high-intensity effort training, skills ‘drills’, and game-based training to prepare for competition.\textsuperscript{14} The benefits of each of these activities is unclear, with limited research detailing whether game-specific conditioning is superior to other methods of conditioning at improving actual match performance.\textsuperscript{15–17} Of the available research, studies have shown that game-based training results in similar (and in some cases greater) heart rate responses and perceived exertion than interval running without the ball.\textsuperscript{15–17} In addition, in elite soccer players, game-based training has been shown to generally replicate the physical demands of domestic, national, and international competition.\textsuperscript{7} However, a closer examination of the repeated-sprint demands showed that players completed significantly fewer repeated-sprint bouts when using a wide range of game-based training activities than in international competition. These results, which have been confirmed by others,\textsuperscript{10} suggest that game-based training may develop players for the overall demands of team sport competition, but with inadequate game design may not specifically prepare them for the high-intensity, repeated-sprint demands of competition. Equally, it is unclear how well traditional interval running replicates (or exceeds) the contact and repeated high-intensity effort demands (i.e., sprinting and tackling) of competition, or whether repeated high-intensity effort training matches the high-intensity running demands of match-play. While non-specific traditional interval running is used by conditioning coaches to promote adaptations in aerobic power,\textsuperscript{18} game-specific training is also needed in order to adequately prepare players for the contact and repeated high-intensity effort demands of the game. Conditioning programs that neglect these contact and repeated high-intensity effort demands may result in players being underprepared for the most demanding passages of competition.\textsuperscript{2} With this in mind, the purpose of this study was to investigate the physical demands of professional rugby league match-play using GPS and associated microtechnology (i.e., tri-axial accelerometer and gyroscope), and to compare these demands with typical training activities (i.e., traditional conditioning, repeated high-intensity effort training, skills ‘drills’, and game-based training) used to prepare players for professional rugby league competition.

### 2. Methods

Thirty-elite male rugby league players from a National Rugby League (NRL) squad [mean age, 23.6 (95% confidence intervals, 22.2–25.0) yr] participated in this study. All participants received a clear explanation of the study, including information on the risks and benefits, and written consent was obtained. All experimental procedures were approved by the Institutional Review Board for Human Investigation.

Global positioning system (GPS) analysis was completed during 124 training sessions (N=26 players, totaling 786 training appearances) and 16 matches (N=21 players, totaling 104 NRL appearances) (Table 1). Players were selected from one of four positional groups representing the hit-up forwards (i.e., props, wide-running forwards (i.e., second rows and locks), adjustables (i.e., hookers, halfbacks, five-eighths, and fullbacks), and outside backs (i.e., centres and wingers). Up to 20 players wore a GPS unit during any given training session. Training data included GPS files from hit-up forwards (N=212 files), wide-running forwards (N=225 files), adjustables (N=215 files), and outside backs (N=134 files). Match data included GPS files from hit-up forwards (N=23 files), wide-running forwards (N=23 files), adjustables (N=29 files), and outside backs (N=29 files). Players wore the same microtechnology unit for each session, and all sessions were completed during the one playing season.
Training data were collected over a 10-month period that included all pre-season and in-season skill, conditioning, repeated high-intensity effort exercise, and game-based training sessions. The players engaged in traditional conditioning activities such as maximal aerobic speed and interval training without a ball. Repeated high-intensity effort activities that included repeated sprinting and tackling were also included in the training program. Exercise-to-rest ratios based on the most demanding passages of play expected during competition were used for these drills. Game-based training/conditioning activities (e.g., small-sided training games played on a reduced-sized pitch) were used to improve physical qualities, technical skill, and decision-making. Games were often played with reduced player numbers on a large field, and were designed to achieve high running loads and a high number of repeated high-intensity efforts. Skills activities were designed to develop passing and catching ability, running lines, tackling technique, support play, defensive line speed and shape, and ball control. Recovery skill sessions and final team sessions before matches were excluded from the analysis.

While there were some differences in the intensity of training activities performed throughout the season, the types of activities in the pre-season training phase (e.g., basic skills, light and full contact tackling drills and longer interval running) were similar to the early competition and late-competition training phases (e.g., light contact tackling drills, advanced skills, and shorter repeated-sprint training).

Movement was recorded by a minimaxX GPS unit (Team 2.5, Catapult Innovations, Melbourne, Australia) sampling at 5 Hz. The GPS signal provided information on speed, distance, position, and acceleration. The GPS unit also included tri-axial accelerometers and gyroscopes sampling at 100 Hz, to provide greater accuracy on speed and acceleration, and information on physical collisions and repeated high-intensity efforts. The unit was worn in a small vest, on the upper back of the players.

Data were categorized into (i) movement speed bands, corresponding to low (0–5 m s$^{-1}$) and high (>5 m s$^{-1}$) speeds; (ii) recovery between efforts, corresponding to short (<30 s), moderate (30 s to 2 min), and long (>2 min) recovery; and (iii) repeated high-intensity effort bouts. A repeated high-intensity effort bout was defined as 3 or more high acceleration (>2.79 m s$^{-2}$), high speed, or contact efforts with less than 21 s recovery between efforts. The minimaxX units have been shown to have acceptable validity and reliability for estimating longer distances at walking through to striding speeds, although large measurement errors and poor validity have been reported for the measurement of individual sprints, accelerations, and change of direction efforts. The minimaxX units have been shown to offer a valid measurement of tackles and repeated efforts commonly observed in collision sports.

Differences among positional groups and between training and match-play were compared using statistical significance testing and by using a practical approach based on the real-world relevance of the results. Firstly, differences in the physical demands (i.e., distance covered at low and high speeds, mild, moderate, and heavy collisions, and repeated high-intensity effort activity) among playing positions were compared using a one-way analysis of variance. Comparisons between the overall match demands of all playing positions and those recorded during traditional conditioning, repeated high-intensity effort exercise, game-based training, and skill training activities were also compared using a one-way analysis of variance. The source(s) of any significant differences involving multiple groups were followed up using a Tukey honestly significant difference post hoc test. The level of significance was set at $p<0.05$ and all data are reported as means and 95% confidence intervals (CI). Secondly, given the practical nature of the study, differences among playing positions, and match and training demands were also analyzed using Cohen’s effect size (ES) statistic. Effect sizes of <0.09, 0.10–0.49, 0.50–0.79, and >0.80 were considered trivial, small, moderate, and large, respectively.

### 3. Results

The mean absolute distances covered during match-play were higher for the outside backs than the hit-up forwards, wide-running forwards, and adjustables, however no differences were observed among groups for the relative distances covered per minute of match-play (Table 2). The single greatest total distance covered by a hit-up forward, wide-running forward, adjustable, and outside back was 6666 m (110 m/min), 8165 m (142 m/min), 12692 m (165 m/min), and 9561 m (124 m/min), respectively. The hit-up forwards covered less distance at low movement speeds than the wide-running forwards, adjustables, and outside backs, while the outside backs covered greater distances at high movement speeds than the other positional groups. The hit-up forwards and wide-running forwards were involved in a greater number of collisions (ES = 1.41–2.75; 0.63–2.00) and repeated high-intensity effort bouts (ES = 0.57–0.98; 0.22–0.52) per minute of match-play than the adjustables and outside backs. The single greatest frequency of collisions per minute of match-play for the hit-up forwards, wide-running forwards, adjustables, and outside backs was 2.1, 1.2, 1.3, and 0.8, respectively. The single greatest frequency of repeated high-intensity effort bouts per minute of match-play for the hit-up forwards, wide-running forwards, adjustables, and outside backs was 0.5, 0.4, 0.7, and 0.3, respectively.

The relative distance covered in traditional conditioning exceeded the relative distance covered in match-play, while repeated high-intensity effort exercise and skill activities were lower (Table 3). The collision and repeated high-intensity effort demands of traditional conditioning and skill training activities were both lower than that of competition. Game-based training exceeded the run-
ning demands of match-play. The repeated high-intensity effort demands of game-based training were similar to match-play. In addition, game-based training had similar mild, moderate, and overall collision frequency to NRL competition, but lower heavy collision demands than match-play.

4. Discussion

This study is the first to investigate the physical demands of professional rugby league match-play and training using commercially available microtechnology (i.e., GPS, accelerometers, and gyroscopes) units. In addition, this is the first study to verify whether current training practices reflect the demands of NRL competition. Consistent with some, but not all studies, the data show that absolute distances covered are greater for the adjustable, outside backs, and wide-running forwards than for the hit-up forwards. However, the relative distances covered (per minute of match-play) are similar among positional groups. Furthermore, and in agreement with others, the collision and repeated-effort demands of match-play were higher for the hit-up forwards and wide-running forwards than for the adjustable and outside backs. Neither traditional conditioning, repeated high-intensity effort exercise, nor skill activities replicated the physical demands of match-play. These data may be used by conditioning coaches to develop game- and position-specific training programs for professional rugby league players.

The mean distances covered during match-play by the hit-up forwards, wide-running forwards, and adjustable, and outside backs were 3569 m, 5561 m, 6411 m, and 6819 m, respectively. Due to differences in playing time, the relative distances covered were similar among the hit-up forwards (94 m/min), wide-running forwards (96 m/min), adjustable (101 m/min), and outside backs (93 m/min). These relative distances are slightly lower than distances previously estimated from video tracking (106 m/min) of professional rugby league competition, and may reflect the combined error associated with GPS and video-based tracking technologies, differences in physical qualities or playing styles of the teams analyzed, or rule changes, most notably the increase from one to two referees since the previous study was published. Outside backs covered greater distances at lower movement speeds, and performed more high-speed running (8.0 m/min) than the hit-up forwards (6.2 m/min), wide-running forwards (7.2 m/min), and adjustable (6.9 m/min) positional groups. While some of the differences in high-speed running may be explained by the greater playing time in this positional group, centres and wingers are often required to lead the kick-chase (i.e., where attacking teams kick the ball into the opposition team’s territory and then aim to restrict the opposition team’s gains in field position) and along with the fullback, are predominantly responsible for kick-returns. The 2.5-fold greater absolute high-speed running distance

| Table 2: Distance covered, repeated high-intensity effort, and collision demands of different positional groups during National Rugby League competition. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Hit-up forwards | Wide-running forwards | Adjustable | Outside backs |
| Time (min)      | 38.0 (33.6–42.5) | 58.5 (51.6–65.3) | 64.1 (55.7–72.4) | 73.5 (68.1–79.0) |
| Low-speed distance (m) | 3334 (2892–3776) | 5143 (4541–5746) | 5974 (5138–6811) | 6235 (5753–6718) |
| High-speed distance (m) | 235 (185–285) | 418 (355–481) | 436 (365–508) | 583 (532–633) |
| Total distance (m) | 3569 (3088–4051) | 5561 (4916–6207) | 6411 (5513–7310) | 6819 (6302–7336) |
| Relative distance (m/min) | 94 (89–98) | 96 (91–101) | 101 (94–108) | 93 (89–98) |

**Collisions**

| Effort recovery (s) | 6.4 (5.7–7.1) | 5.6 (4.9–6.2) | 4.7 (4.1–5.4) | 5.5 (4.7–6.4) |
| Mean effort duration (s) | 2.1 (1.9–2.3) | 1.8 (1.6–2.0) | 1.6 (1.4–1.7) | 1.5 (1.3–1.7) |
| Efforts per bout (no.) | 6.2 (5.3–7.1) | 5.5 (4.6–6.4) | 5.5 (4.5–6.4) | 5.3 (4.5–6.1) |
| Total (no.) | 42 (35–48) | 45 (38–52) | 34 (28–40) | 28 (23–32) |

**Repeated high-intensity efforts**

| Bouts (no.) | 8.0 (5.9–10.1) | 9.9 (7.3–12.5) | 8.6 (5.8–11.4) | 8.5 (6.5–10.4) |
| Efforts per bout (no.) | 6.2 (5.3–7.1) | 5.5 (4.6–6.4) | 5.5 (4.5–6.4) | 5.3 (4.5–6.1) |
| Mean effort duration (s) | 2.1 (1.9–2.3) | 1.8 (1.6–2.0) | 1.6 (1.4–1.7) | 1.5 (1.3–1.7) |
| Maximum effort duration (s) | 6.0 (4.9–7.2) | 5.6 (4.9–6.2) | 4.7 (4.1–5.4) | 5.5 (4.7–6.4) |
| Effort recovery (s) | 6.4 (5.7–7.1) | 5.9 (5.1–6.8) | 5.9 (4.9–7.0) | 5.9 (5.1–6.6) |
| Bouts frequency (no/min) | 1.09 (0.96–1.22) | 0.76 (0.69–0.84) | 0.58 (0.45–0.71) | 0.38 (0.32–0.43) |

Global positioning system (GPS) analysis was completed during 16 matches (N=21 players, totaling 104 NRL appearances). Repeated high-intensity efforts: 3 or more maximal acceleration sprint efforts, very-high speed sprint efforts, and/or tackle efforts with less than 21 s between efforts. Data are means (and 95% confidence intervals).

* Significantly different (p<0.05) from hit-up forwards.
† Significantly different (p<0.05) from wide-running forwards.
‡ Significantly different (p<0.05) from adjustable.

This study may be used by conditioning coaches to develop game- and position-specific training programs for professional rugby league players.
in this positional group, coupled with the fact that, unless injured, these players are generally required to play the entire match, emphasizes the importance of high speed running in outside backs. Conditioning coaches should prioritize the development of prolonged, high-intensity running ability in this positional group.

The most significant differences among playing positions were the high-intensity collision and repeated effort demands of match-play. Consistent with the findings of others, the hit-up forwards and wide-running forwards performed a greater absolute amount of moderate and heavy collisions than the adjustables and outside backs, and were consequently engaged in significantly more collisions per minute of match-play. Hit-up forwards and wide-running forwards were involved in a collision approximately every 2 min. Hit-up forwards, wide-running forwards, adjustables, and outside backs performed a heavy collision every 2.5, 3.3, 5, and 5 min, respectively. While there were no differences among positions for the absolute number of repeated high-intensity effort bouts performed in a match, the hit-up forwards and wide-running forwards performed more repeated high-intensity effort bouts per minute of play. Hit-up forwards completed on average, one repeated high-intensity effort bout every 4.8 min, while the wide-running forwards performed on average, one repeated high-intensity effort bout every 6.3 min. Conversely, repeated high-intensity effort bouts occurred on average every 7.7 min and 9.1 min for the adjustables and outside backs, respectively. Collisions and tackles are widely acknowledged as the most demanding aspect of rugby league match-play. In addition, research from our laboratory has recently shown that repeated high-intensity effort exercise (sprinting and tackling) is associated with greater heart rate and perceived exertion and poorer sprint performance than repeated-sprint exercise alone, demonstrating that the addition of tackling significantly increases the physiological response to repeated-sprint exercise and has the potential to reduce physical performance. These findings, coupled with the repeated high-intensity effort demands, suggest that repeated sprinting and physical collisions are necessary to adequately prepare hit-up forwards and wide-running forwards for the demands of competition, while repeated high-speed sprinting is critical for outside backs.

A novel aspect of this study was the comparison of group means with the most extreme demands for each positional group.

Table 3: Distance covered, repeated high-intensity effort, and collision demands of National Rugby League matches, traditional conditioning activities, repeated high-intensity effort activities, game-based training activities, and skill training activities.

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<th>NRL competition</th>
<th>Traditional conditioning</th>
<th>Repeated high-intensity effort</th>
<th>Game-based training</th>
<th>Skills</th>
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<tr>
<td>Time (min)</td>
<td>59.7 (55.6–63.8)</td>
<td>12.8 (10.7–14.9)</td>
<td>43.6 (36.8–50.5)</td>
<td>12.6 (11.8–13.4)</td>
<td>77.8 (76.6–78.9)</td>
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<td>Low-speed distance (m)</td>
<td>5279 (4901–5658)</td>
<td>1011 (779–1243)</td>
<td>3295 (3022–3567)</td>
<td>1474 (1371–1577)</td>
<td>4203 (4138–4267)</td>
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<tr>
<td>High-speed distance (m)</td>
<td>429 (391–467)</td>
<td>1069 (932–1206)</td>
<td>405 (283–528)</td>
<td>261 (235–288)</td>
<td>214 (206–222)</td>
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<tr>
<td>Total distance (m)</td>
<td>5709 (5299–6118)</td>
<td>2080 (1775–2385)</td>
<td>3700 (3344–4056)</td>
<td>1708 (1601–1816)</td>
<td>4423 (4357–4490)</td>
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<tr>
<td>Relative distance (m/min)</td>
<td>96 (93–99)</td>
<td>164 (160–169)</td>
<td>91 (84–99)</td>
<td>137 (133–141)</td>
<td>58 (57–59)</td>
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Global positioning system (GPS) analysis was completed during 124 training sessions (N = 26 players, totaling 786 training appearances) and 16 matches (N = 21 players, totaling 104 NRL appearances). Repeated high-intensity efforts: 3 or more maximal acceleration sprint efforts, very-high speed sprint efforts, and/or tackle efforts with less than 21 s between efforts. Data are means (and 95% confidence intervals).

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* Significantly different (p < 0.05) from NRL competition.
† Significantly different (p < 0.05) from traditional conditioning.
‡ Significantly different (p < 0.05) from repeated high-intensity effort activities.
§ Significantly different (p < 0.05) from game-based training.
group. The greatest total distances covered by the hit-up forwards, wide-running forwards, adjustables, and outside backs were 87%, 47%, 98%, and 40% greater than the mean value for each positional group. Furthermore, during the most intense passages of match-play, the hit-up forwards performed over 2 collisions each minute, while the adjustables were engaged in a repeated high-intensity effort bout every 1.4 min. These findings suggest that reporting mean values alone may underestimate the most intense physical demands of competition. Consequently, conditioning programs that are based on these mean values will likely result in players being underprepared for the most demanding passages of competition.2

In the present study, traditional conditioning (i.e., running without the ball) exceeded the running demands of National Rugby League competition, but had lower contact and repeated effort demands than competition. Furthermore, repeated high-intensity effort training exhibited lower running demands, and heavy contact demands of competition, with the duration of efforts in repeated high-intensity effort bouts also not specific to those performed in competition. The running, collision, and repeated high-intensity effort demands of skill training were all lower than competition. In contrast, game-based training offered the most specific form of conditioning, exceeding the running demands, and providing comparable mild, moderate, and overall collision and repeated high-intensity effort demands to match-play. These findings demonstrate that game-based training offers a highly-specific form of conditioning for professional rugby league players. It has been shown that the magnitude of fatigue-induced reductions in skill in response to game-specific repeated high-intensity exercise is reduced in rugby league players with higher maximal aerobic power.28 Given these findings, it should be recognized that traditional conditioning (e.g., high-intensity interval running and maximal aerobic speed training) promotes adaptations that allow players to perform the other physical demands (e.g., tackling, collisions, and repeated high-intensity efforts) and skills of rugby league.28 Equally, the ability to efficiently perform and recover from repeated high-intensity effort exercise, permits players to participate in the high-intensity running components (e.g., the kick-chase) of match-play.20 While replicating the physical demands of competition may facilitate the transfer of physical qualities to the competitive environment, it should also be acknowledged that exposure to excessive amounts of highly intense and monotonous training (e.g., persistent game-based training) in a non-periodized program could potentially result in injury, illness, fatigue, and/or overtraining.30 Nonetheless, the specific physical demands of competitive play, especially those demands associated with collisions and repeated high-intensity efforts, were not well matched by those observed in traditional conditioning, repeated high-intensity effort exercise, and skills training activities, suggesting that modifications may need to be made to these training activities to better prepare players for the demands of National Rugby League competition.

5. Conclusion

In conclusion, the results of this study demonstrate that absolute distances covered during professional rugby league matches are greater for outside backs, while the collision and repeated high-intensity effort demands are higher for hit-up forwards and wide-running forwards. The greatest total distances covered by the hit-up forwards, wide-running forwards, adjustables, and outside backs were 87%, 47%, 98%, and 40% greater than the mean value for each positional group, respectively. Although these findings may be used by conditioning coaches to develop game- and position-specific training programs for professional rugby league players, it should be noted that the data were collected from one NRL club. Consequently, the results may be influenced by the playing roster and individual coaching philosophies and may not be generalizable to all rugby league clubs. Further studies, on a larger sample are required to verify these findings.

Practical implications

- Exposure to repeated high-intensity effort exercise (in the form of repeated sprinting and tackling) should occur within the conditioning programs of hit-up forwards and wide-running forwards.
- Conditioning programs for outside backs should focus on the development of prolonged, high-intensity running ability.
- Neither traditional conditioning, repeated high-intensity effort exercise, nor skill training activities match the specific physical demands of rugby league match-play, while game-based training offers the most specific form of conditioning.

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References