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Variability of physical performance and player match loads in professional rugby union

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ABSTRACT

Objectives: To examine the within- and between-player variability of physical performance and player match loads in professional rugby union.
Design: A single cohort, observational study.
Methods: Physical match performance data were collected from 28 male, professional, English Championship players over 15 competitive matches. Using microsensors, the variables selected for analysis were total distance, low-speed running distance, high-speed running distance, very high-speed running distance, total impacts, repeated high-intensity efforts, body load (PlayerLoad^{TM}), and low velocity (<7.2 km h^{-1}) body load. Ratings of perceived exertion represented match internal loads. Variability was quantified using the coefficient of variation, with the meaningful interpretation of change in physical performance and match loads calculated using magnitude-based inferences.
Results: We found large between-match (within-player) variation for high-speed running distance (27.6%; ±90% confidence limits 6.9% [forwards], 20.1%; ±4.1% [backs]), very high-speed running distance (68%; ±19%, 34.1%; ±7.5%), total impacts (24.0%; ±5.9%, 36.4%; ±7.9%) and repeated high-intensity efforts (18.7%; ±4.4%, 39.5%; ±8.8%), with moderate variability for match ratings of perceived exertion (8.2%; ±1.8%, 10.8%; ±2.1%), body load (7.3%; ±1.7%, 10.0%; ±2.0%) and low velocity body load (8.9%; ±2.0%, 10.7%; ±2.1%). Threshold values for likely substantial between-match changes in high-intensity physical performance measures ranged from 21% to 76%, and were ~10% for match ratings of perceived exertion, body load and low velocity body load.
Conclusions: Within- and between-player variability of high-intensity activity in professional rugby union is large, yet ratings of perceived exertion, body load and low velocity body load appear more stable by comparison and may be interpreted with greater accuracy.

1. Introduction

By means of video-based time-motion analysis[1–3] and, more recently, microsensor technology,[4–6] the physical demands of rugby union competition have been extensively documented. Match-play is characterized by short, intermittent bouts of high-intensity activity, such as sprinting and high-speed running,[6,7] accelerations and changes of direction under high velocities,[5,7] tackling,[1,2,8] static exertions,[2,3] and repeated high-intensity efforts (RHIE)[4,9]—all of which are interspersed with longer periods of movements performed at lower intensities.[5,10] Given the physiologically taxing nature of these performance demands, high player match loads are inherent during rugby union competition.[4,5] Player match loads may relate to the totality of mechanical stress experienced during movements and collisions,[11] as well as the player's relative physiological response to the work performed (i.e. the internal load).[12,13]

Team sport performance is a multifactorial construct that is stochastic and unstable in nature,[14] meaning that within-player (between-match) variability of physical performance and resultant match loads is inherent.[15–17] During competition, influences such as the opposing team,[18] win/lose margin or frequency,[19] interchange players[19] and season phase[15,16] are likely to influence the demands of match-play and subsequent match-to-match

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variability of physical performance and player match loads. In a complex and highly structured sport such as rugby union, the variability of physical performance and player match loads are also likely to differ between-players, given the notable discrepancies in position-specific roles, technical competency and anthropometry.[10]

The variability of physical performance and player match loads have previously been reported for other football codes such as soccer,[16] rugby league,[17] and Australian Football (AFL).[15,20] Gregson et al.[16] established large between-match coefficients of variation (CV) for a variety of high speed running parameters in professional soccer, including distance covered between 19.8 and 25.2 km h^{-1} (CV = 16.2%; ±95% confidence limits [CL] 6.4%). Similar findings have recently been observed by Kempton et al.,[17] who noted large between-match variability in both high- (>15 km h^{-1}; CV = 14.6%; ±90% CL 2.2%) and very high-speed running (>21 km h^{-1}; 37%; ±6.1%) during professional rugby league competition. Moderate to high within-player variability has also been evidenced for high- (>14.4 km h^{-1}; CV = 11.7–13.8%) and very high-speed running (>19.9 km h^{-1}; CV = 15.1–20.9%) during AFL competition, yet the between-match variation of total body load appears lower in comparison (CV = 7.2–10.5%).[15] As well as this, Weston et al.[20] reported moderate within-player CVs (7.9%; ±90% CL 5.5%) in ratings of perceived exertion (RPE)—as a marker of relative internal load—following AFL match-play. Despite this, no attempts have yet been made to quantify the variability of physical performance and player match loads in rugby union.

The quantification of within- and between-player performance variability in team sports helps to establish reference values for the smallest worthwhile change in outcome measures and permits a better understanding of meaningful between-match changes on an individual (athlete) level.[21,22] Given that playing position influences match activities within rugby union,[10,23,24] it is likely that, as in soccer[16] and AFL,[15] the variability of physical performance and player match loads are also influenced by positional demands. Separating players into positional groupings of forwards and backs explains a large proportion (~58% and ~45%, respectively) of the shared variance in match-play time-motion characteristics during rugby union competition, yet the overall similarities between these two groups are trivial.[24] Therefore, the aims of our investigation were twofold. First, we aimed to determine the within- and between-player variability of physical performance and player match loads for two distinct positional groups (forwards and backs) in rugby union. Secondly, we aimed to establish threshold values for the interpretation of between-match changes in physical performance and player match loads on an individual level.

2. Methods

Twenty-eight professional rugby union players (mean ± SD; age: 27 ± 4 years; height: 187 ± 8 cm; body mass: 101 ± 14 kg) who represented a RFU English Championship team were used in our investigation. The initial sample included 15 forwards (age: 28 ± 4 years; height: 192 ± 7 cm; body mass: 112 ± 5 kg) and 13 backs (age: 27 ± 4 years; height: 181 ± 4 cm; body mass: 88 ± 6 kg). Physical performance, and player match load data were collected from 15 matches in total during the 2012/2013 season (win: loss ratio = 4: 1, aggregate points for = 377, aggregate points against = 215). Of these fixtures, 9 matches were played at home and 6 matches were played away from home. The sample included 12 matches played in the RFU English Championship and 3 matches played in the British & Irish Cup. Ethical approval was granted via Teesside University's institutional ethics committee.

During the games, each player wore a bespoke harness carrying a microsensor (MinimaxX™ S4, Catapult Innovations, Melbourne, Australia) which contained a 10 Hz global positioning system (GPS) and a 100 Hz; tri-axial accelerometer, gyroscope and magnetometer. The measurement error (CV) in 10 HZ GPS for total distance, distance covered ≥15 km h^{-1} and distance covered >20 km h^{-1} during team sport specific movements is reported to be 1.9%, 4.7 and 10.5%, respectively.[25] The interunit reliability of the MinimaxX™ 10 Hz GPS is good for the measurement of total distance (typical error of measurement [TEM] = 1.3%) and distance covered 14–20 km h^{-1} (TEM = 4.8%),[26] but less so for distances covered >20 km h^{-1} (TEM = 11.5%).[26] The highly responsive, tri-axial accelerometers embedded within MinimaxX™ units allow for the measurement of force-dependent mechanical loads incurred from team sport specific movements and player collisions, which is beyond the scope of GPS or video-based methods in isolation.[11,20] The within- (CV = 0.91–1.05%) and between-device (CV = 1.02–1.10%) reliability of data derived from the 100 Hz, triaxel accelerometers is high.[11]

Data were downloaded post-match using Logan Plus 4.2 software (Catapult Innovations, Melbourne, Australia), with half-time and injury time excluded from further analysis. All physical performance measures were represented in absolute and relative terms, indicative of volume and intensity, respectively. Relative measures were calculated as the absolute measure divided by on-field time. We set the minimum number of games-per-player and players-per-game in each positional group at 3.[20] For the analysis of the absolute performance measures and player match loads, only players who completed the full game were included. This gave a total of 82 match observations from 6 forwards (range = 3–9 games; 35 match observations) and 8 backs (range = 3–8 games; 47 match observations). For the analysis of relative performance measures, all player observations were included regardless of field time. This gave a total of 172 match observations from 15 forwards (range = 3–12 games; 89 match observations) and 13 backs (range = 3–11 games; 83 match observations).

Movement demands were quantified using overall total distance (TD), which was further split into arbitrary velocity bands of low-speed running distance (LSR; 0–14.9 km h^{-1}), high-speed running distance (HSR; 15.0–19.9 km h^{-1}), and very high-speed running distance (VHSR; 20.0–36.0 km h^{-1}). The association between total impacts recorded by MinimaxX™ units and video-based notation methods is reported to be most likely near perfect (r = 0.96; ±90% CL 0.04),[27] therefore, collision demands were appraised using total number of player impacts (TI) sustained during match-play. A RHIE has previously been defined as ≥3 consecutive high-speed efforts or impacts (tackle, scrum, ruck, and maul activities) occurring within 21 s.[9,28] In rugby union, the RHIE is a valid performance construct that represents the most demanding passage of play and often occurs at critical periods during a game.[9] Accordingly, a RHIE was measured as per Gabbett et al.[28] and the total number of bouts performed per game were recorded.

We used RPE (arbitrary units [AU]) as our indicator of match internal load, given the validity of this measure to accurately reflect the relative physiological stress imposed on team sport athletes during competition.[12] All players were familiar with the 10-point RPE scale (CR10)[29] and scores were provided independently ~30 min post-match. To represent the totality of mechanical loads experienced by the players during match-play, PlayerLoad™ (PL; arbitrary units [AU]) was computed as a vector magnitude derived from the root mean square of accelerations recorded in the three principal axes of movement, measured using a 100 Hz piezoelectric linearsensor (Kionix: KXP94) embedded within the microsensor units.[11] Finally, given the frequency of static exertions in rugby union,[2,3] we used the slow component of PL (PL_{SLOW}) to isolate the sum of PL accumulated at low velocities only (<7.2 km h^{-1}).

Raw data are presented as the mean ± SD. Prior to analysis, all data were log transformed to reduce the error occurring from non-uniform residuals (heteroscedasticity) that is typical from

Table 1
Descriptive data (mean ± standard deviation).

	All players	Forwards	Backs
Absolute physical performance			
TD (m)	5720 ± 680	5400 ± 520	5960 ± 690
LSR (m)	4700 ± 480	4570 ± 390	4790 ± 520
HSR (m)	720 ± 210	650 ± 160	770 ± 240
VHSR (m)	300 ± 160	180 ± 110	400 ± 130
TI (*n*)	50 ± 29	78 ± 18	28 ± 12
RHIE (*n*)	27 ± 11	25.6 ± 5.7	28 ± 13
Relative physical performance			
TD ($m\,min^{-1}$)	71.7 ± 8.7	681 ± 7.0	75.7 ± 8.7
LSR ($m\,min^{-1}$)	59.3 ± 5.6	58.1 ± 5.1	60.5 ± 5.8
HSR ($m\,min^{-1}$)	8.9 ± 3.2	7.8 ± 2.4	10.1 ± 3.5
VHSR ($m\,min^{-1}$)	3.6 ± 2.4	2.1 ± 1.5	5.1 ± 2.1
TI ($n\,min^{-1}$)	0.68 ± 0.39	0.97 ± 0.30	0.37 ± 0.17
RHIE ($n\,min^{-1}$)	0.34 ± 0.14	0.33 ± 0.10	0.35 ± 0.18
Match load			
RPE (AU)	8.2 ± 0.9	8.7 ± 0.7	7.8 ± 0.9
PL (AU)	550 ± 80	590 ± 50	520 ± 90
PL_{SLOW} (AU)	250 ± 50	290 ± 30	230 ± 40

HSR = high-speed running distance (15.0–19.9 $km\,h^{-1}$); LSR = low-speed running distance (0–14.9 $km\,h^{-1}$); PL = PlayerLoad™; PL_{SLOW} = slow component of PlayerLoad™; RHIE = repeated high-intensity effort bouts; RPE = rate of perceived exertion; TD = total distance; TI = total count of impacts. VHSR = very high-speed running distance (20–36.0 $km\,h^{-1}$).

measures of athletic performance. Subsequently, data were analyzed using a mixed effects linear model (SPSS v.21, Armonk, NY: IBM Corp), with random intercepts to estimate the within- and between-player variability. Variability was expressed using the CV (%) and CVs were presented with 90% CL as markers of uncertainty of the estimates. The smallest worthwhile change (%) in physical performance and player match loads were defined as 0.2 of the between-player SD.[22] We estimated the minimum threshold required for a substantial within-player, between-match change in physical performance and player match loads to be interpreted as 'likely' (75% chance) via the magnitude-based inference approach,[22] using a custom-made spreadsheet.[21]

3. Results

Descriptive physical performance and match load data are presented in Table 1. The within- and between-player CVs (±90% CL) for forwards and backs are displayed in Tables 2 and 3, respectively, along with the reference values for (a) the smallest worthwhile change and (b) the between-match change required to be considered likely substantial. Backs tended to show greater match-to-match variability of physical performance (except HSR and VHSR), internal load and body load in comparison with forwards. Between-player variability, the smallest worthwhile change and the threshold values for likely substantial changes in physical performance and player match loads were also greater for backs.

4. Discussion

This study is the first to report the variability of physical performance and player match loads in professional rugby union competition. Our data indicate that high-intensity activity (locomotive- and impact-based) is highly variable on a match-to-match basis, highlighting the difficulties in interpreting high-intensity physical performance data for match analysis and training prescription. In comparison with high-intensity physical performance measures, TD, LSR and player match loads (RPE, PL and PL_{SLOW}) were more stable within- and between-players. These findings indicate that true between-match changes in player match loads may be interpreted with greater accuracy in comparison with high-intensity physical performance measures.

The within-player CVs for high-intensity locomotive activity reported in our investigation were slightly higher than those previously established in professional rugby league,[17] soccer[16] and AFL[15] competition. This is perhaps explained by (a) the notable differences in high-speed movement patterns evident between rugby union and other football codes,[16,20,28] (b) the differences in measurement devices and definition of speed thresholds between

Table 2
Forward players variability and interpretation of physical performance and match load measures.

	Within-player CV (%; ±90% CL)	Between-player CV (%; ±90% CL)	Smallest worthwhile change (%)	Likely substantial change (%)[a]
Absolute physical performance				
TD (m)	10.0; ±2.1	5.5; ±1.5	1.0	6.3
LSR (m)	8.7; ±1.9	2.2; ±5.3	0.4	8.7
HSR (m)	27.6; ±6.9	16.5; ±5.1	3.3	29.7
VHSR (m)	68; ±19	58; ±63	11.5	76.3
TI (*n*)	24.0; ±5.9	15; ±16	3.0	26.4
RHIE (*n*)	18.7; ±4.4	16; ±12	3.2	21.2
Relative physical performance				
TD ($m\,min^{-1}$)	10.0; ±1.4	4.2; ±3.3	0.8	10.4
LSR ($m\,min^{-1}$)	8.9; ±1.3	3.2; ±2.7	0.6	9.1
HSR ($m\,min^{-1}$)	33.4; ±5.2	19; ±10	3.8	35.8
VHSR ($m\,min^{-1}$)	64; ±11	69; ±36	13.8	75.5
TI ($n\,min^{-1}$)	31.5; ±4.9	28.1; ±6.0	4.4	34.6
RHIE ($n\,min^{-1}$)	24.7; ±3.8	24; ±11	4.7	28.4
Match load				
RPE (AU)	8.2; ±1.8	3.7; ±4.2	0.7	8.6
PL (AU)	7.3; ±1.7	6.0; ±4.9	1.2	8.2
PL_{SLOW} (AU)	8.9; ±2.0	7.7; ±5.8	1.5	10.0

CL = confidence limits; CV = coefficient of variation; HSR = high-speed running distance (15.0–19.9 $km\,h^{-1}$); LSR = low-speed running distance (0–14.9 $km\,h^{-1}$); PL = PlayerLoad™; PL_{SLOW} = slow component of PlayerLoad™; RHIE = repeated high-intensity effort bouts; RPE = rate of perceived exertion; TD = total distance; TI = total count of impacts. VHSR = very high-speed running distance (20–36.0 $km\,h^{-1}$).
[a] 75% chance.

Table 3
Back players variability and interpretation of physical performance and match load measures.

	Within-player CV (%; ±90% CL)	Between-player CV (%; ±90% CL)	Smallest worthwhile change (%)	Likely substantial change (%)[a]
Absolute physical performance				
TD (m)	10.8; ±2.1	6.7; ±4.7	1.3	11.6
LSR (m)	10.1; ±2.0	6.1; ±4.4	1.2	10.9
HSR (m)	20.1; ±4.1	32; ±19	6.3	25.6
VHSR (m)	34.1; ±7.5	19; ±17	3.9	36.6
TI (*n*)	36.4; ±7.9	39; ±22	6.8	41.7
RHIE (*n*)	39.5; ±8.8	47; ±31	9.4	47.2
Relative physical performance				
TD ($m\,min^{-1}$)	10.1; ±1.5	6.7; ±3.3	1.3	7.7
LSR ($m\,min^{-1}$)	8.7; ±1.3	5.0; ±2.6	1.0	9.3
HSR ($m\,min^{-1}$)	23.2; ±3.6	31; ±14	6.1	28.4
VHSR ($m\,min^{-1}$)	44.4; ±7.5	34; ±20	6.9	49.4
TI ($n\,min^{-1}$)	35.8 ±5.8	32; ±15	6.4	40.7
RHIE ($n\,min^{-1}$)	42.9; ±7.2	62; ±31	12.4	53.5
Match load				
RPE (AU)	10.8; ±2.1	6.6; ±4.6	1.3	11.7
PL (AU)	10.0; ±2.0	17.6; ±9.6	3.5	13.1
PL_{SLOW} (AU)	10.7; ±2.1	14.4; ±8.1	2.9	13.2

CL = confidence limits; CV = coefficient of variation; HSR = high-speed running distance (15.0–19.9 $km\,h^{-1}$); LSR = low-speed running distance (0–14.9 $km\,h^{-1}$); PL = PlayerLoad™; PL_{SLOW} = slow component of PlayerLoad™; RHIE = repeated high-intensity effort bouts; RPE = rate of perceived exertion; TD = total distance; TI = total count of impacts. VHSR = very high-speed running distance (20–36.0 $km\,h^{-1}$).
[a] 75% chance.

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our research and others,[16,17] and (c) our relatively smaller sample size in comparison with some of these previous investigations. Despite this, similar patterns are evident between our data and those of others in the variability player movement patterns.[15,17] We provide further evidence to suggest that an increase in running speed causes an increase in the between-match variation of distance covered at such speeds during team sport competition. Absolute and relative expressions of TI and RHIE generally had the highest between-match CVs in our investigation. Ultimately, these data suggest several repeated measures are required to identify a true between-match change in a player's physical performance (HSR, TI and RHIE) in rugby union.

RPE, PL and PL_{SLOW} showed lower between-match variability in comparison with the majority of physical performance measures. This is somewhat of concern when attempting to comprehend the dose-response nature of match-play in rugby union, given that physical performance is the main determinant of the internal load.[12,13] One plausible explanation for this may be that our tool for assessing internal load (RPE; CR10 scale)[29] lacked the sensitivity to capture the magnitude of between-match variation in physical performance. A potential solution to this issue could be the use of a more precise scale for the weighting of perceived match intensity (e.g. CR100 centiMax).[29] Furthermore, the precision in scaling exertion signals may be enhanced by differentiating global RPE into central (e.g. 'lungs') and peripheral (e.g. 'muscle') mediators,[20] which may further the understanding of the relationships between internal loads and physical performance (external loads) during team sport competition.[13]

Consistent with research in soccer[16] and AFL,[15] there was an effect of positional group on the variability of physical match performance in our investigation. Backs recorded larger CVs for all performance measures (except HSR and VHSR) in comparison with forwards, both within- and between-players, suggesting that the time-motion characteristics of forwards are more uniform (between-players) in comparison with backs.[3,6] This may be due to the differences in positional roles and playing styles that have previously been reported between subgroups of backs.[8,23,24] Accordingly, consideration should be given when comparing between players within similar positional groups and may further reinforce the need for intra-positional player divisions beyond forwards and backs in both training and recovery interventions.[6,24] For example, players who characteristically work closer to the ball perform more consecutive high-intensity effort bouts in comparison with peripheral players,[9,23] which may explain the large degree of between-player variability in TI and RHIE amongst backs in our investigation (CV = 32–62%). Coaches may wish to acknowledge this information when designing and structuring appropriate training and conditioning sessions that aim to replicate match demands.

It is often the role of practitioners to compare match performances within-players, to evaluate the demands of training with those of match-play and to assess the effectiveness of certain performance interventions.[17,28] Therefore, an understanding of true between-match changes is pertinent.[15,20] With this in mind, we present for the first time a guide for the interpretation of physical performance and player match loads in rugby union. This template may be particularly useful to those responsible for the management of training loads and subsequent training prescription or planning of recovery.[13] Similar to the research conducted by Weston et al.[20] our data suggests that a ~10% between-match change in internal player match load (RPE) may be considered likely substantial in rugby union players. This threshold may also be applied to PL and PL_{SLOW}., representing the totality of mechanical stress (i.e. external force) experienced by players and that accumulated at low velocities, respectively. Practitioners may wish to use this data to make informed decisions surrounding the frequency, intensity, duration and composition of training and recovery activates in the days following match-play; which may be tailored on an individual level. Between-match changes required to be considered meaningful in high-intensity physical performance (HSR, VHSR TI, RHIE) are, however, far greater than player match loads (21–76%) and may therefore be interpreted with less accuracy. Given that the stimulus for exercise-induced adaptations is the relative physiological stress imposed on the athlete,[12] we advocate the usefulness of RPE as a practical and effective overall measure of internal match load in rugby union. With the somewhat gestalt nature of RPE in mind,[13] we encourage future research to explore the applications of differential ratings of perceived exertion to rugby union and also to other team sports.[20]

While our data provides a start point for the comprehension of performance variability in rugby union, there are general limitations apparent which are worthy of acknowledgment and that may guide future research. Our sample prevented any further examination of the variability in physical performance and player match loads beyond that of forwards and backs comparison. Therefore, we encourage future research to provide a re-examination of our methods using a larger sample sizes, which we speculate may be able to explain some of the high variability that exists in physical performance by further dividing playing positions into sub-groups that poses greater shared variance in time-motion parameters (e.g. 'front row', 'inside backs', etc.).[24] As well as playing position, the opposing team, season phase, environmental conditions, player proximity to ball, live points difference, and both the magnitude and frequency of other time-motion characteristics including technical skill measures have the potential to influence the variability of time-motion characteristics in team sports,[15,16] yet we did not quantify such parameters. We would advise for future work to explore these factors in relation to the variability of physical performance and player match loads during rugby union competition.

GPS devices (10 Hz) have previously reported a typical error (CV) of 10.5% (90% confidence interval 9.0% to 12.5%) for the measurement of VHSR distance (>20 km h^{-1}) during team sport specific movements.[25] While caution should be taken when interpreting match-play data obtained at these speeds, the signal (variability) evidenced within- (34–68%) and between-players (19–69%) for VHSR in our data are still far greater than the measurement noise reported for 10 Hz GPS devices. It may therefore be assumed that the true within- and between-player variability of VHSR in rugby union likely to be very high, however accurate quantification of these premises is currently beyond the measurement potential of GPS devices or video-based methods. Finally, despite the development of highly responsive internal motion sensors, there is no technology available at present which offers the ability to isolate and measure both the frequency and magnitude of static exertions incurred during activities such as rucks, mauls, scrums and lineouts. Inevitably, this poses as a universal limitation to those striving to provide an accurate and holistic representation of match demands in rugby union and should be taken into consideration when interpreting relevant research.

5. Conclusion

This investigation is the first study to examine the variability of physical performance and player match loads in rugby union. Our data further highlights the difficulties associated with the interpretation of physical performance data in team sports, given the large degree of between-match variation observed in high-intensity activity. Player match loads such as RPE, PL and PL_{SLOW} appear more stable in comparison with physical performance and may be interpreted with greater accuracy. Playing position influences the magnitude of variability in physical performance and player match loads during rugby union competition, therefore, it would appear that some of the variability within- and between-players can be explained by player characteristics, positional demands, and tactical roles. Future research should consider larger data sets so that individual playing positions can be analyzed in greater depth.

Practical implications

- Due to the highly variable nature of high-intensity activity in rugby union, interpretation of physical match performance data (running and collisions) is challenging.
- A ~10% between-match change in player match loads (rate of perceived exertion or PlayerLoad™) may be considered likely substantial. Measures of player match load, therefore, may be more reliable and useful for the interpretation of meaningful between-match changes.
- Reference values for meaningful between-match changes in player match load data may be useful to inform acute adaptations to the post-match training or recovery schedule.
- High between-player variability in physical match performance would suggest that coaches and practitioners should consider dividing forwards and backs into smaller subgroups during training and recovery interventions.

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