BMJ Open Sport & Exercise Medicine

In-match physical demands on elite Japanese rugby union players using a global positioning system

Hayato Yamamoto [ORCID],[1] Masanori Takemura,[2] Junta Iguchi,[3] Misato Tachibana,[1] Junzo Tsujita,[4] Tatsuya Hojo[1]

[1]Graduate School of Health & Sports Science, Doshisha University, Kyoto, Japan
[2]Ichihashi Clinic, Kobe, Japan
[3]Department of Health and Sports Sciences, Kyoto University of Advanced Science, Kameoka, Japan
[4]Institute of Health and Sports Medicine Science, Osaka, Japan

Correspondence to
Hayato Yamamoto;
trainer_life_22@yahoo.co.jp

ABSTRACT

Objectives Our aim of this study was to quantify the physical demands of elite rugby union players by each position as a step towards designing position-specific training programme using a Global Positioning System/accelerometer system.

Methods This study was performed as a retrospective observational study. Data were obtained from 45 official matches. The sample size used for the analysis was 298. The per-match total distances, accelerations and impacts were calculated and statistically compared for the forwards and backs and for individual positions.

Results Total distances for the forwards and backs were 5731.1±507.8 and 6392.1±646.8 m, respectively. The high-velocity running distances (>18.0 km/hour) covered by the forwards and backs were 317.4±136.9 and 715.0±242.9 m, respectively. The number of accelerations (>1.5 m/s^2) for the forwards and backs were 76.3±18.9 and 100.8±19.6 times, respectively, and the number of high impacts (>10 g) were 48.0±46.9 and 35.6±28.3 times for the forwards and backs, respectively. All characteristics were significantly different between the forwards and backs (p<0.05). The per-position characteristics were also calculated. Within the backs, scrum half (SH) and wingers (WTBs) covered high-velocity running significantly higher distance than fly-half (SH d=2.571, WTBs d=1.556) and centres (SH d=1.299, WTBs d=0.685) (p<0.05).

Conclusion By clarifying the physical demands according to the positions, it will be possible to create optimised position-specific training programmes.

INTRODUCTION

Player movements during a rugby union match consist of intermittent bouts of intense motion, requiring explosive force exertion for high-velocity activities, such as sprinting, tackling and scrummaging, with breaks comprising low-intensity activity, such as walking and jogging.[1–3] Previously, research on the physical demands on players during a rugby union match was often analysed using video-based time-motion analysis. Austin *et al* reported on the distance and speed of travel during a match, while Eaton and George reported on tackling and scrum

What are the new findings?

► The physical demands of elite rugby union players in a match in Japan were revealed.
► This finding allows comparison with overseas teams.
► Not only tha data of classification of forwards and backs, but also the distance traveled, acceleration, and impact of each position became clear.
► The idea of developing strength and conditioning programme based on the results was presented.

management.[2 4–7] However, methods using video-based time-motion analysis in rugby union can be unreliable because they are vulnerable to the subjectivity of the evaluator/analyst.[8 9] Also, video-based time-motion analysis cannot evaluate contacts such as impacts.

To improve the objectivity, Global Positioning Systems (GPS) and accelerometers have been used to analyse in-match physical demands.[10–12] Currently, there are reports on the reliability and validity of GPS units.[11–14] GPS units with built-in accelerometers can obtain data reliably and in real-time, unlike video-time analyses, and have thus been commonly used for analysing physical demands in team sports such as soccer,[15 16] field hockey,[17 18] rugby league[19 20] and Australian Football League.[21 22] On the other hand, there are few studies using GPS to analyse physical demands of contemporary rugby union play compared with other sports (soccer, rugby league and Australian football league).[8 23–26] In addition, even in the reported research, there are issues such as the lack of statistical analysis due to the small sample size, and not being analysed by individual positions in the classification of forwards and backs. Such analyses are insufficient as a study of physical demands.

Notably, there are few reports detailing the physical demands during elite rugby union matches in Japan.[27] Therefore, this study was designed to analyse the physical demands of elite rugby union players in Japan during a

match using a GPS/accelerometer system. We analysed the raw data from players who played full matches and calculated the physical demands in terms of distance travelled, accelerations and impacts. We also statistically analysed these calculations for the forward and back groups and for each individual position. We believe that these data will enable sports scientists and strength and conditioning coaches to develop improved training programme that can improve player performance and reduce the risk of injuries related to non-optimal training.

Previous studies have shown physical demands in the forwards and backs classifications, but each position is assumed to have unique characteristics beyond the forwards and backs classifications. Thus, our aim of this study was to quantify the movement (or physical) demands of elite union players by forwards and backs as well as each position using a GPS/accelerometer system. Then, by understanding of the movement (or physical) demands, it may provide valuable insight into an effective strength and conditioning training programme for each position based on game-based training approaches. We hypothesised that backs would move in faster speed zones and their mileage would be relatively longer than forwards. On the other hand, forwards would have heavier body loads because of spending more time in slower and high-intensity activities such as scrums compared with backs.

METHODS
Design
Data were collected using GPS units with built-in accelerometers during official matches from one team belonging to the Japan Rugby top league. The team played 14 matches in 2013 (4 wins–10 losses record), 16 matches in 2014 (6 wins–10 losses) and 15 matches in 2015 (4 wins–10 losses–one draw), that is, a total of 45 matches (14 wins–30 losses–one draw) over three seasons. As the Japan Rugby top league is the pre-eminent rugby competition in Japan, the data collected for this study can be said to be that of elite rugby union. We analysed the raw data from players who played full matches over three seasons and calculated the physical demands in terms of distance travelled, accelerations and impacts. We then statistically analysed these calculations for the forward and back groups and for each individual position.

Participants
Data were obtained from one team belonging to the Japan Rugby top league. The participants were 15 starting members in each match (n=675). However, we excluded those players who did not play the full 80 min duration (ie, those who underwent substitution for any reason). A total of 298 subjects (forwards: age 27.9±3.0 years, height 183.1±6.3 cm and body mass 100.3±7.2 kg, backs: age 27.7±2.7 years, height 173.9±7.8 cm and body mass 84.2±11.8 kg) were used in the sample analysis.

GPS unit data from the matches were collected from dedicated teams. The objectives and possible limitations of the study were explained to potential subjects. Written consent was obtained from all subjects prior to enrolment. This research was done without patient involvement.

GPS analysis
We used GPS units (SPI Pro X; GPSports Systems, Canberra, Australia) with built-in accelerometers with sampling frequencies of 5 and 100 Hz. The GPS unit was placed on the upper middle back between the scapulae of the subject using special protective vests recommended by the manufacturer. Previous studies have shown that GPS units have acceptable reliability and validity to measure movement.[11–14] Previous studies have shown the reliability of GPS units using intraclass correlation coefficient, and the results show high reliability from 0.98 to 0.99.[28]

The GPS system and accompanying software (Team AMS; GPSports Systems) can measure the total distance, distance travelled within velocity ranges ('zones'), acceleration/deceleration, impact (using the accelerometer) and heart rate when synchronised with a heart rate monitor.[29] Distance (total distance and distance travelled within velocity zones), acceleration and impact were used for analysing physical demands during a match.

Distance travelled
The total distance travelled between 'kickoff' and 'fulltime' was measured as the total distance, including both when the ball was in and out of play. The out-of-play distance was included because rugby uses a running clock, and positioning for the next play (quickly) is as important as that when the ball is in play.[29 30]

Total distance was subdivided into total distance/velocity by binning velocity into three zones (ranges): speed zone SZ-1 (0–12.0 km/hour, SZ-2 (12.1–18.0 km/hour) and SZ-3 (>18.0 km/hour). Both the absolute value of the distance travelled in each zone and percentage of the total distance were calculated. The threshold of the speed zone was set based on the previous research of rugby union.[8]

Mean velocity was calculated by dividing the total distance by 80 min.

Accelerations
Accelerations were calculated from the GPS data as velocity per unit time (m/s/s, ie, m/s^2) and binned into three zones as follows: acceleration zone (AZ)-1, 1.5–2.0 m/s^2; AZ-2, 2.0–2.5 m/s^2; AZ-3, >2.5 m/s^2. The threshold of the AZ was set based on the previous research of rugby union.[8]

Impacts
Impacts were calculated from the accelerometer data. The three-dimensional (triaxial) linear accelerometric values were collected and transformed into gravity (g) by dividing the raw value by 9.81 m/s^2. Impacts were binned into two impact zones (IZ): IZ-1 (8.1–10 g) and IZ-2 (>10 g).

Table 1 Match data for each position

| Position | n | Total distance | | | Speed zone 1 | | | | Speed zone 3 | | | |
		Mean SE	CV	95% CI	Mean SE	CV	%*	95% CI	Mean SE	CV	%*	95% CI
Forwards	**119**	**5731.1±46.7**	**8.9%**	**5625 to 5837**	**4164.5±32.4**	**8.4%**	**72.7%**	**4091 to 4238**	**317.4±12.6**	**43.2%**	**5.5%**	**289 to 346**
Props	11	5602.9±170.8†‡	9.6%	5217 to 5989	4274.5±128.3	9.5%	76.3%	3984 to 4565	211.6±34.9‡	52.1%	3.8%	133 to 291
Hooker	6	5509.6±200.8	8.2%	5055 to 5964	4244.2±100.4	5.3%	77.0%	3688 to 4471	238.5±39.8	37.3%	4.3%	18 to 328
Locks	45	5872.0±67.3§	7.6%	5720 to 6024	4215.6±62	9.8%	71.8%	3275 to 4356	339.4±18.3§	35.8%	5.8%	62 to 381
Flankers	38	5887.5±69.8§	7.2%	5730 to 6045	4118.4±43.2	6.4%	70.0%	3516 to 4216	395.9±20.8¶§	32.0%	6.7%	105 to 443
No. 8	19	5228.6±99.1	8.0%	5005 to 5453	4046.8±71	7.4%	77.4%	3347 to 4207	194.2±14.5†‡	31.8%	3.7%	51 to 227
Backs	**179**	**6392.1±48.5**	**10.1%**	**6282 to 6502**	**4363.4±30.9**	**9.4%**	**68.3%**	**3428 to 4433**	**715±18.2**	**34.0%**	**11.2%**	**164 to 756**
Scrum half	13	7014.0±94.7***††	4.7%	6800 to 7228	4103.2±74‡‡§§	6.2%	58.5%	3499 to 4271	872.9±48‡‡**	19.0%	12.4%	482 to 981
Fly-half	20	6409.4±127§§	8.6%	6122 to 6697	4536.2±66.7¶¶††§§	6.4%	70.8%	3862 to 4687	466.7±34.3¶¶***††§§	32.0%	7.3%	120 to 544
Centres	55	6110.0±79.1¶¶§§	9.5%	5931 to 6289	4264.4±43.8§§	7.5%	69.8%	3530 to 4363	654.6±23.1¶¶‡‡††	26.0%	10.7%	267 to 707
Wings	67	6248.2±71¶¶§§	9.2%	6088 to 6409	4234.6±44.1‡‡§§	8.5%	67.8%	3418 to 4334	811.4±33.9‡‡**	33.9%	13.0%	184 to 888
Full back	24	7088.9±85.6‡‡††**	5.8%	6895 to 7283	4947.0±64.2¶¶‡‡†††**	6.2%	69.8%	4236 to 5092	705.5±35.9‡‡	24.4%	10.0%	307 to 787

*Per cent (%) distance spent in each speed zone.
†Significantly different from locks (p<0.05).
‡Significantly different from flankers (p<0.05).
§Significantly different from No. 8 (p<0.05).
¶Significantly different from props (p<0.05).
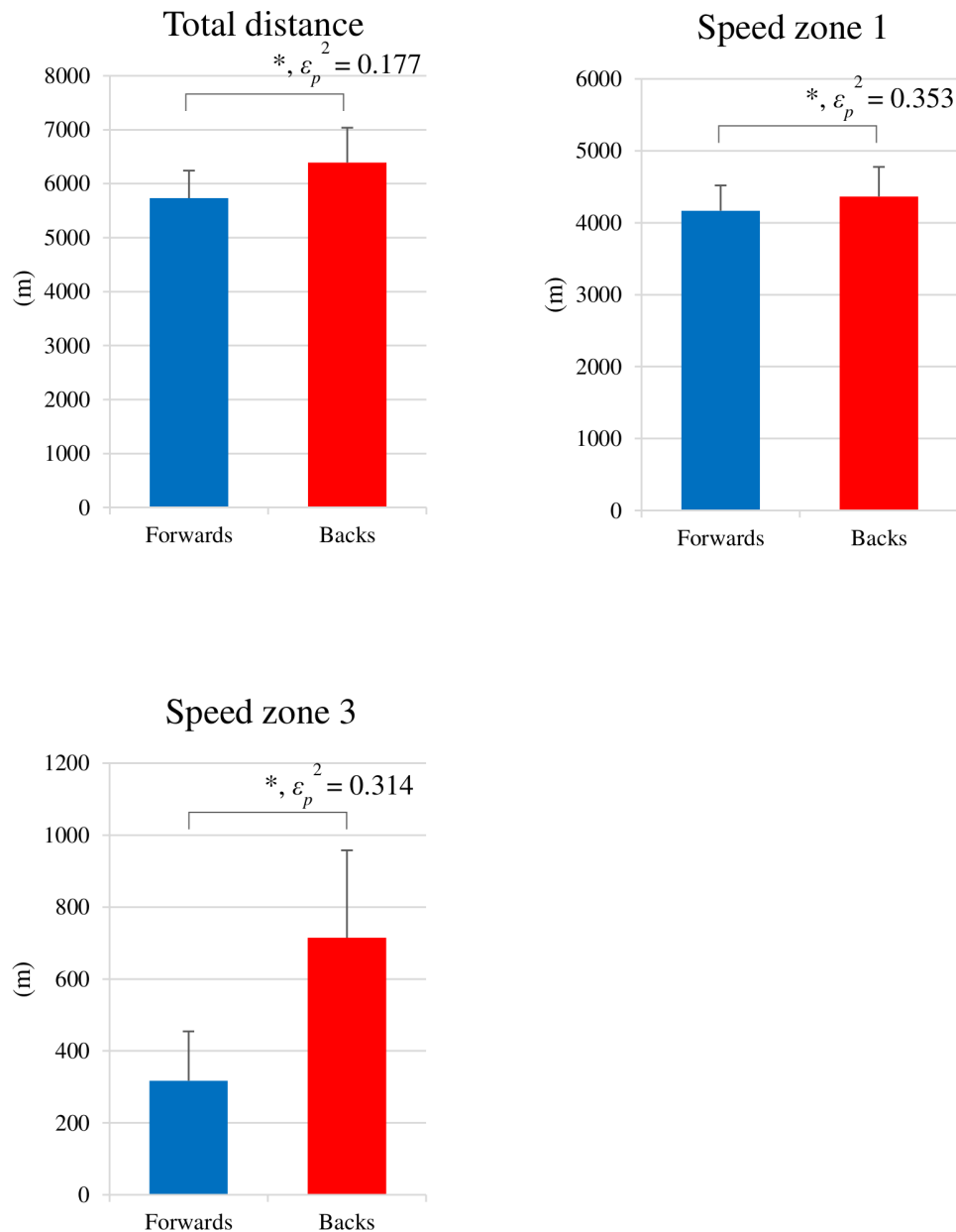**Significantly different from centres (p<0.05).
††Significantly different from wings (p<0.05).
‡‡Significantly different from fly-half (p<0.05).
§§Significantly different from full back (p<0.05).
¶¶Significantly different from scrum half (p<0.05).
CI, confidence intervals; CV, coefficient of variation; SE, standard error.

Total distance

Speed zone 1

Speed zone 3

Figure 1 Match data per position (forwards and backs). *Significantly different (p<0.05).

Classification of positions

Rugby union consists of 10 positions: five forwards positions (props (PRs), hooker (HO), locks (LOs), flankers (FLs), eight-man/number eight (No. 8)) and five backs positions (scrum-half (SH), fly-half (FH), centres (CTBs), wings (WTBs) and full back (FB)). Analyses were performed on the combined data of the forwards or backs positions as well as on each individual position.

Statistical analysis

Data were delineated as mean±SE. The coefficient of variation (CV) was also calculated to compare the variability of the data for each parameter.

First, the homogeneity of variance was tested using Bartlett's test. As most did not satisfy these conditions, non-parametric Kruskal-Wallis hypothesis test was used to compare variables between forwards and backs as well

as among individual positions. When differences were significant, multiple comparisons were made using Steel-Dwass test. Epsilon partial squared (ε_p^2) and Cohen's d were calculated as effect size. Statistical significance was set at $p<0.05$. 'R' was used for statistical analysis.

Samples measured in this study were similar to those in previous researches, and players participated in multiple matches. The methodology used was adopted from previous research.[23]

RESULTS
Distance travelled

The total distance covered per match by the forwards and backs was significantly different ($p<0.05$, $\varepsilon_p^2=0.177$) (table 1 and figure 1). Of the forwards, LOs ($d=1.484$) and FLs ($d=1.559$) covered significantly longer distances than

Table 2 Match data per position for acceleration and impact

Position	n	AZ-1–AZ-3			AZ-3			IZ-1 and IZ-2			IZ-2		
		Mean SE	CV	95% CI	Mean SE	CV	95% CI	Mean SE	CV	95% CI	Mean SE	CV	95% CI
Forwards	**119**	**76.3±1.7**	**24.8%**	**72 to 80**	**22.8±0.8**	**38.8%**	**21 to 25**	**202.3±14.5**	**77.8%**	**170 to 235**	**48±4.3**	**97.8%**	**38 to 58**
Props	11	61.5±4.9*	25.2%	50 to 73	13.2±1.5*†	36.7%	10 to 17	192.4±17.6	28.9%	153 to 232	40.5±7	54.3%	25 to 56
Hooker	6	62.8±6.6	23.4%	26 to 78	16.5±2.2	29.6%	4 to 21	197.2±24.7	28.1%	60 to 253	20.5±5.1	56.0%	to 8 to 32
Locks	45	81.0±2.1‡	17.5%	49 to 86	24.6±1.1 ‡§	29.9%	8 to 27	225.4±36	106.1%	to 322 to 307	57±10.1	117.0%	to 96 to 80
Flankers	38	86.4±2.9§‡	20.4%	46 to 93	27.9±1.4‡§	29.9%	9 to 31	181.8±11	36.6%	29 to 207	42.6±3.8	54.6%	11 to 51
No. 8	19	57.9±2.9†*	21.5%	29 to 65	15.7±1.2*†	31.2%	4 to 18	196±17.9	38.7%	20 to 236	50.2±8.5	72.1%	34 to 69
Backs	**179**	**100.8±1.5**	**19.5%**	**56 to 104**	**39±0.7**	**25.2%**	**17 to 41**	**171.9±6.3**	**48.9%**	**to 19 to 186**	**35.6±2.1**	**79.7%**	**to 29 to 40**
Scrum half	13	122.3±3.5¶**††‡‡	9.9%	94 to 130	39.2±2.3	20.6%	20 to 44	138.1±31.4**	78.7%	to 118 to 209	26.6±7.6	99.2%	to 36 to 44
Fly-half	20	94.5±5§§	22.9%	44 to 106	37.8±2.5	29.4%	12 to 44	145.9±14.9**	44.6%	to 5 to 180	35.6±6	73.9%	to 25 to 49
Centres	55	97.7±2§§	15.4%	63 to 102	39.4±1.3	24.2%	18 to 42	217.9±11.2¶††§§	37.6%	31 to 243	42.4±4.8	83.2%	to 38 to 53
Wings	67	100.8±2.8§§	22.2%	50 to 107	40.9±1.2‡‡	24.0%	19 to 44	149.5±8**	43.4%	2 to 168	31.3±2.7	71.3%	to 20 to 38
Full back	24	101.5±3§§	14.1%	68 to 108	33.3±1.6††	22.8%	16 to 37	168.5±18.9	53.9%	to 41 to 211	36.5±5.1	66.6%	to 20 to 48

*Significantly different from flankers (p<0.05).
†Significantly different from locks (p<0.05).
‡Significantly different from No. 8 (p<0.05).
§Significantly different from props (p<0.05).
¶Significantly different from fly-half (p<0.05).
**Significantly different from centres (p<0.05).
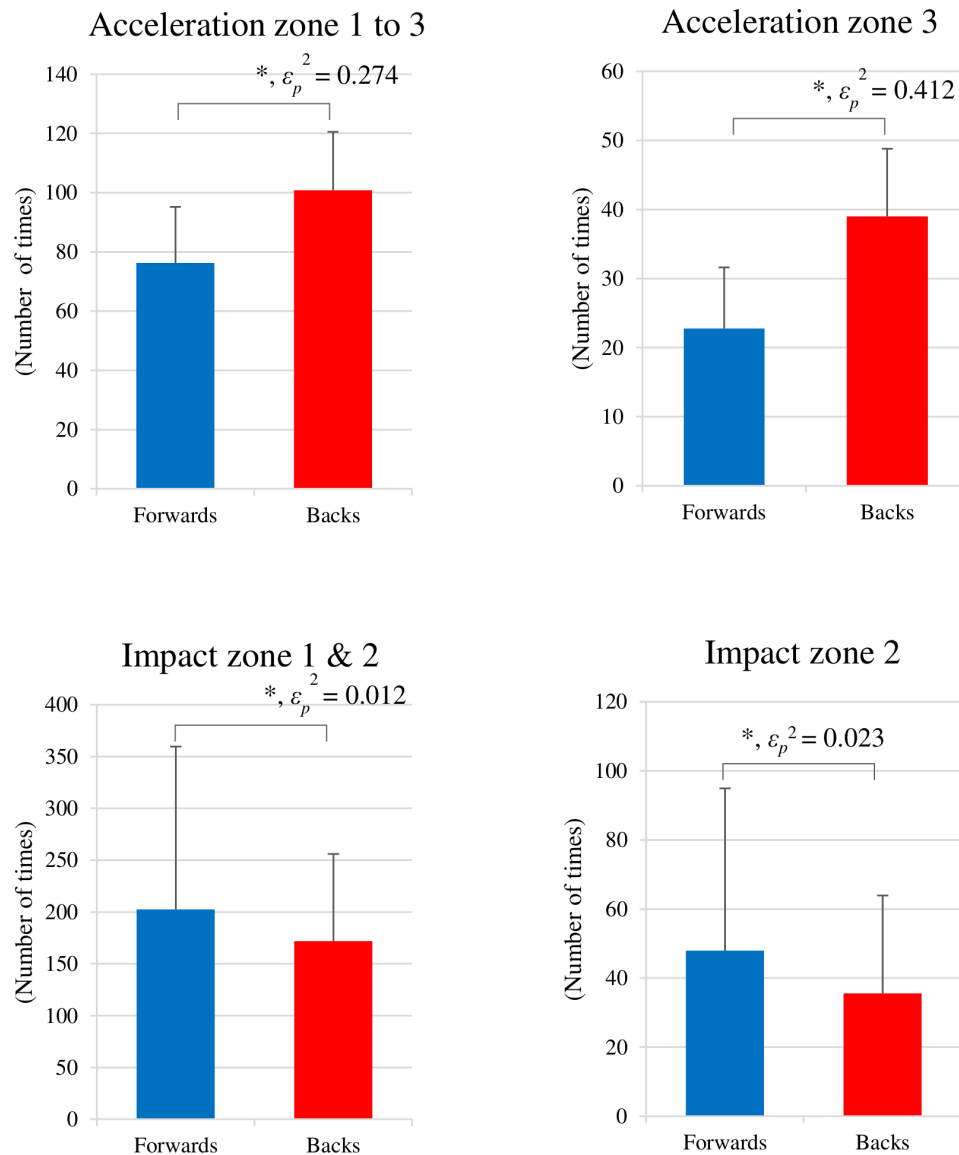††Significantly different from wings (p<0.05).
‡‡Significantly different from full back (p<0.05).
§§Significantly different from scrum half (p<0.05).
¶¶Significantly different from hooker (p<0.05).
AZ, acceleration zone; CI, confidence intervals; CV, coefficient of variation; IZ, impact zone; SE, standard error.

Acceleration zone 1 to 3

Acceleration zone 3

Impact zone 1 & 2

Impact zone 2

Figure 2 Match data per position (forwards and backs). *Significantly different (p<0.05).

No. 8 (p<0.05, respectively). Of the backs, SH covered significantly longer distances than WTBs (d=1.633) and CTBs (d=1.915) (p<0.05). In addition, the distance covered by FB was significantly longer than that by FH (d=1.395), WTBs (d=1.680) and CTBs (d=1.945) (p<0.05) (table 1).

The distances covered in SZ-3 by the forwards and backs were also significantly different (p<0.05, ε_p^2=0.314) (table 1 and figure 1). Of the forwards, LOs (PRs d=1.101, No. 8 d=1.507) and FLs (PRs d=1.551, No. 8 d=2.023) covered significantly longer distances than PRs and No. 8 (p<0.05). Of the backs, significant differences were found between SH and WTBs compared with FH (SH d=2.571, WTBs d=1.556) and CTBs (SH d=1.299, WTBs d=0.685), and between CTBs and FB compared with FH (p<0.05), with the former being greater than the latter in both the cases (table 1).

The backs covered significantly longer distances in SZ-1 than the forwards (p<0.05, ε_p^2=0.353) (table 1 and

figure 1). The forwards' results did not differ significantly according to position, but FH and FB covered significantly longer distances than SH (FH d=1.580, FB d=2.980), WTBs (FH d=0.422, FB d=2.133) and CTBs (FH d=0.887, FB d=2.169) (p<0.05) (table 1).

The CV of the total distance showed a small value; moreover, it indicated a large value as the moving speed increased (table 1).

Acceleration

The number of accelerations for the forwards and backs was significantly different (p<0.05, ε_p^2=0.274) (table 2 and figure 2). Of the forwards, LOs (PRs d=1.315, No. 8 d=1.731) and FLs (PRs d=1.505, No. 8 d=1.868) were required to accelerate many more times than that by PRs and No. 8; SH (FH d=1.591, CTBs d=1.806, WTBs d=1.196, FB d=1.568) had to accelerate many times than that by other backs (p<0.05) (table 2).

Table 3 Application to training for each forwards position

Position	Results	Physical demands during the match	Application to training
Props (PRs)	Number of impact: high (compared with backs)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Focus on contact fitness training compared with backs. Weight training aimed at weight gain due to muscle hypertrophy compared with backs.
Hooker (HO)	Number of impact: high (compared with backs)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Focus on contact fitness training compared with backs. Weight training aimed at weight gain due to muscle hypertrophy compared with backs.
Locks (LOs)	AZ-3 and SZ-3: high (compared with PRs and HO)	Ability to repeat large acceleration and move at high speed (such as sprint).	Focus on speed and agility training and repeated sprint ability training compared with PRs and HO.
	Number of impact: high (compare within forwards)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Compared with other forwards, focus more on contact fitness training.
Flankers (FLs)	AZ-3 and SZ-3: high (compared with PRs and HO)	Ability to repeat large acceleration and move at high speed (such as sprint).	Focus on speed and agility training and repeated sprint ability training compared with PRs and HO.
	Number of impact: high (compared with backs)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Focus on contact fitness training compared with Backs. Weight training aimed at weight gain due to muscle hypertrophy compared with backs.
No. 8	Number of impact: high (compared with backs)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Focus on contact fitness training compared with backs. Weight training aimed at weight gain due to muscle hypertrophy compared with backs.

AZ, acceleration zone; SZ, speed zone.

The number of accelerations in AZ-3 was significantly higher for the backs than for the forwards ($p<0.05$, $\varepsilon_p^2=0.412$) (table 2). Of the forwards, LOs (PRs $d=1.834$, No. 8 $d=1.428$) and FLs (PRs $d=2.158$, No. 8 $d=1.787$) had significantly higher number of accelerations than PRs and No. 8 ($p<0.05$); of the backs, FB had significantly lower accelerations than WTBs (FB $d=0.867$) ($p<0.05$) (table 2).

Impacts

The number of impacts was significantly higher for the forwards than for the backs ($p<0.05$, $\varepsilon_p^2=0.012$) (table 2 and figure 2). There were no significant differences among the forwards, whereas CTBs had a significantly higher number of impacts than SH (CTBs $d=0.830$), FH (CTBs $d=0.973$) and WTBs (CTBs $d=0.926$) ($p<0.05$) (table 2).

For the high-force (IZ-2) zone, there was a significant difference between the forwards and backs ($p<0.05$, $\varepsilon_p^2=0.023$) (table 2 and figure 2) but none between any individual positions (table 2).

DISCUSSION

This study analysed the physical demands of elite rugby union players in Japan based on data from a team belonging to Japan Rugby top league. Knowledge of the physical demands during a match can help sports scientists and strength and conditioning coaches create optimised training programme aimed at improving competitiveness and possibly avoiding injury.

We only analysed the players who played for the complete duration of the match (80 min) without being substituted. In previous research, data for substituted players were included by extrapolating full match data from the partial-match ones.[7] However, because this technique cannot account for fatigue or performance degradation during an actual match, they are not likely to be an accurate evaluation of the physical demands of a full match. In addition, previous research has stated that the appropriateness of extrapolating data to provide full match data information is questionable.[23]

As hypothesised, in terms of the total distance travelled and speed (mean velocity over the 80 min match), the forwards showed significantly lower values than the backs (5731 and 6392 m, 71.6 and 79.9 m/min, respectively). The differences averaged to 660 m and 8 m/min per match. In terms of SZ-3, backs covered 715 m and forwards covered 317 m; the per cent SZ-3 for the backs was 11.2% and for the forwards was 5.5%. The total distance is a measure of the overall amount of exercise, whereas SZ-3 indicates exercise intensity. Therefore, our data suggested that the backs had higher load and intensity during a match. Notably, in SZ-1, the significant

Table 4 Application to training for each backs position

Position	Results	Physical demands during the match	Application to training
Scrum half (SH)	Total distance , Number of accelerations: high (compared with all positions)	Running fitness ability that can cover many travel distances during match. Resistance of lower limbs that can withstand muscle cramps caused by many travel distances and many acceleration times.	Focus on running fitness training among all positions.
	AZ-3 and SZ-3: high (compared with all positions)	Ability to repeat large acceleration and move at high speed (such as sprint).	Focus on speed and agility training and repeated sprint ability training.
Fly-half (FH)	Total distance and SZ-3: high (compared with forwards)	Running fitness that can cover many travel distances during match. Ability to repeat high speed movement (repeated sprint ability).	Focus on running fitness training compared with backs. Focus on speed and agility training and repeated sprint ability training compared with forwards.
Centres (CTBs)	Number of impact: high (compare within backs)	Ability to repeat contacts (contact fitness). Physical to win at contact (increase of skeletal muscle mass, improvement of maximum strength and power).	Compared with other backs, focus on contact fitness training. Weight training aimed at weight gain due to muscle hypertrophy compared with other backs.
Wings (WTBs)	SZ-3: high (compared with all positions)	Improvement of maximum speed. Improvement of repeated sprint ability.	Focus on speed & agility training and repeated sprint ability training.
Full back (FB)	Total distance: high (compared with all positions)	Running fitness that can cover many travel distances during match. Resistance of lower limbs that can withstand muscle cramps caused by many travel distances and many acceleration times.	Focus on running fitness training among all positions.

AZ, acceleration zone; SZ, speed zone.

difference in the distance travelled was not present when the percentage of the total distance was considered. Thus, the difference in endurance-related and activity-related physical demands between forwards and backs during a match is related to the amount of SZ-3. However, SZ-3 was uniformly defined for all positions, although forwards are likely to have a lower maximum speed and require a greater effort to reach SZ-3. Adjusting the speed zones for position and taking maximum speed into account would enable a more detailed analysis of exercise intensity.

When comparing the results of previous studies of European professional teams with those of this study, the total distance is effectively equivalent.[23 25] Despite Japan's national team holding a lower rank than other national teams competing in the rugby World Cup, the total work levels are very similar. This seems to indicate that it is impossible to sufficiently evaluate team ability by work alone. Thus, accelerations and impacts were also analysed.

Backs recorded significantly higher total and AZ-3-specfic accelerations than the forwards. In particular, AZ-3, which mainly represents sprints, was considerably different (0.29 and 0.49 bouts/min for forwards and backs, respectively). Thus, the backs are required to perform intense accelerations more often during a match. It should be noted that the maximal acceleration possible for the forwards is likely to be lower than that

for the backs, which could have resulted in a bias in the results.[8]

Impacts, in contrast to accelerations, resulted in a significantly higher result for the forwards than for the backs which is consistent with our hypothesis. Impacts occur when a tackle is made and when any physical shock is applied to the body. For instance, situations related to competition for the ball, such as breakdowns and contact with the ground, also register as impacts. As expected, the forwards are required to absorb a high number of impact loads. Thus, it is necessary for forwards to increase their fitness so that players can repeat contacts. In addition, it is necessary to increase muscle hypertrophy for players to prevent injury from high-impact collision.

Within the forwards, distance of SZ-3 and the number of times of AZ-3 for LOs and FLs were significantly higher than those for the other positions. Our data indicate that LOs and FLs are required to increase their maximum speed and repeat-sprint ability compared with the other forwards.

Notably, the data for No. 8 was different than those from previous study.[23] In the previous study, No. 8 was similar to LOs in terms of total distance; however, in the present study, No. 8 had lower total distance than LOs. The No. 8 data for this study were obtained from players with relatively heavy weight (over 120 kg). Therefore, the No. 8 data in this study may have been greatly influenced

by the characteristics of that specific player. In order to measure the physical demands of No. 8, additional research is needed with a larger player population to better clarify the results.

In addition, LOs had higher impact values than those of the other forward positions for IZ-2 (57 times). Thus, LOs should be considered to be in a position that requires above-average physical strength (relative to other forwards as well as backs) to repeatedly engage in contact while maintaining the sprinting ability mentioned earlier.

Within the backs, the total distance by SH and FB was ≥7000 m, which is approximately 600–900 m higher than that for other backs. The CV of the total distance by SH and FB was approximately 5%, which was lower than that of other positions and indicated that SH and FB move constantly for over 7000 m per match. SH also performed significantly more SZ-3 (873 m; 12.4%) and significantly greater acceleration (122 times). SH must always move quickly to the rack during an attack and pass the ball. It is considered that the total distance and the number of accelerations showed a high value due to this characteristic. FB is the most rearward position and must cover a large space during attacks and defenses. It is considered that the total distance has increased due to this characteristic. Also, since these characteristics of SH and FB are not greatly affected by wins and losses and match result, CV also showed a small value.

Regarding the backs, WTBs recorded over 800 m of SZ-3 and had the highest AZ-3 scores. Thus, WTBs need to be able to sprint repeatedly and require training for improving their maximum speed. On the other hand, CTBs deal with higher impact loads than other backs. When creating a training programme for CTBs, it is necessary to incorporate more contact fitness with repeated tackles and down-up operations.

This study objectively visualised the physical demands of rugby union matches and supported the empirical observations coaches had identified through their experiences. Overall, the interpretation of data obtained from the GPS unit is yet to be undertaken, and the new possibilities for analysis with the use of GPS units that this invites are unlimited. Additional research is required to qualitatively analyse the data obtained from the GPS units.

CONCLUSION

Differences in the type of physical demands on the forwards and backs were demonstrated, indicating the necessity for specialised training according to the role of the players as well as their specific positions. SH and FB should be provided training programme with high load, but SH additionally should be given more high-intensity exercise (eg, repeated sprint). Guidelines can be developed according to these results to optimise training programme for each position. Finally, other ideas on how to implement this in actual sports are shown in tables 3 and 4.

ORCID iD
Hayato Yamamoto http://orcid.org/0000-0002-2578-2526

REFERENCES

1 Nicholas CW. Anthropometric and physiological characteristics of rugby Union football players. *Sports Med* 1997;23:375–96.
2 Austin D, Gabbett T, Jenkins D. The physical demands of super 14 rugby Union. *J Sci Med Sport* 2011;14:259–63.
3 Austin D, Gabbett T, Jenkins D. Repeated high-intensity exercise in professional rugby Union. *J Sports Sci* 2011;29:1105–12.
4 Deutsch MU, Kearney GA, Rehrer NJ. Time – motion analysis of professional rugby union players during match-play. *J Sports Sci* 2007;25:461–72.
5 Eaton C, George K. Position specific rehabilitation for rugby union players. Part I: empirical movement analysis data. *Physical Therapy in Sport* 2006;7:22–9.
6 McLean DA. Analysis of the physical demands of international rugby Union. *J Sports Sci* 1992;10:285–96.
7 Roberts SP, Trewartha G, Higgitt RJ, *et al*. The physical demands of elite English rugby Union. *J Sports Sci* 2008;26:825–33.
8 Cunniffe B, Proctor W, Baker JS, *et al*. An evaluation of the physiological demands of elite rugby Union using global positioning system tracking software. *J Strength Cond Res* 2009;23:1195–203.
9 Dobson BP, Keogh JWL. Methodological issues for the application of time-motion analysis research. *Strength Cond J* 2007;29:48–55.
10 Coutts AJ, Duffield R. Validity and reliability of GPs devices for measuring movement demands of team sports. *J Sci Med Sport* 2010;13:133–5.
11 Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPs for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *J Sports Sci* 2012;30:121–7.
12 Jennings D, Cormack S, Coutts AJ, *et al*. The validity and reliability of GPs units for measuring distance in team sport specific running patterns. *Int J Sports Physiol Perform* 2010;5:328–41.
13 Petersen C, Pyne D, Portus M, *et al*. Validity and reliability of GPs units to monitor cricket-specific movement patterns. *Int J Sports Physiol Perform* 2009;4:381–93.
14 Waldron M, Worsfold P, Twist C, *et al*. Concurrent validity and test–retest reliability of a global positioning system (GPs) and timing gates to assess sprint performance variables. *J Sports Sci* 2011;29:1613–9.
15 Gregson W, Drust B, Atkinson G, *et al*. Match-to-match variability of high-speed activities in premier League soccer. *Int J Sports Med* 2010;31:237–42.
16 Scott BR, Lockie RG, Knight TJ, *et al*. A comparison of methods to quantify the in-season training load of professional soccer players. *Int J Sports Physiol Perform* 2013;8:195–202.
17 Jennings D, Cormack SJ, Coutts AJ, *et al*. Gps analysis of an international field hockey tournament. *Int J Sports Physiol Perform* 2012;7:224–31.

18 Macutkiewicz D, Sunderland C. The use of GPs to evaluate activity profiles of elite women hockey players during match-play. *J Sports Sci* 2011;29:967–73.

19 Gabbett TJ, Jenkins DG, Abernethy B. Physical demands of professional rugby League training and competition using microtechnology. *J Sci Med Sport* 2012;15:80–6.

20 Kempton T, Sirotic AC, Coutts AJ. Between match variation in professional rugby League competition. *J Sci Med Sport* 2014;17:404–7.

21 Colby MJ, Dawson B, Heasman J, *et al*. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res* 2014;28:2244–52.

22 Wisbey B, Montgomery PG, Pyne DB, *et al*. Quantifying movement demands of AFL football using GPs tracking. *J Sci Med Sport* 2010;13:531–6.

23 Cahill N, Lamb K, Worsfold P, *et al*. The movement characteristics of English Premiership rugby union players. *J Sports Sci* 2013;31:229–37.

24 Coughlan GF, Green BS, Pook PT, *et al*. Physical game demands in elite rugby Union: a global positioning system analysis and possible implications for rehabilitation. *J Orthop Sports Phys Ther* 2011;41:600–5.

25 Jones MR, West DJ, Crewther BT, *et al*. Quantifying positional and temporal movement patterns in professional rugby Union using global positioning system. *Eur J Sport Sci* 2015;15:488–96.

26 McLaren SJ, Weston M, Smith A, *et al*. Variability of physical performance and player match loads in professional rugby Union. *J Sci Med Sport* 2016;19:493–7.

27 Yamamoto H, Takemura M, Kaya M, *et al*. Physical demands of elite rugby Union match-play using global positioning system. *Football Sci* 2017;14:15–23.

28 Bataller-Cervero AV, Gutierrez H, DeRentería J, *et al*. Validity and reliability of a 10 Hz GPs for assessing variable and mean running speed. *J Hum Kinet* 2019;67:17–24.

29 Yamamoto H, Takemura M, Tachibana M, *et al*. Game analysis of rugby Union using GPs. *Jpn J Biomecha Sports Exer* 2017;21:25–9.

30 Furukawa T, Washiya K, Koyanagi R, *et al*. Practical applications and possibility of GPs technology in rugby coaching. *Jpa J Coaching Studies* 2013;26:187–96.