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# BMJ Open

## Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based comparison between the Rio 2016 and Tokyo 2020 games

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**Title**

Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based comparison between the Rio 2016 and Tokyo 2020 games

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## ABSTRACT

### Objectives

To identify the fall characteristics of athletes in wheelchair rugby and wheelchair basketball during the Tokyo 2020 Paralympic Games and compare these with those of the Rio 2016 Paralympic Games.

### Design

Cross-sectional analysis

### Primary and secondary outcome measures

We obtained video footage from the International Paralympic Committee of the Tokyo 2020 Paralympic Games that included 8 teams from each of the 18 wheelchair rugby and 10 wheelchair basketball games (men and women). The data were analyzed to evaluate the number of falls, class difference (low or high pointer), time of play during the fall, phase of play, contact with other athletes, fall direction, fall location, and the body part that first contacted the floor during the fall. These data from the Rio 2016 and Tokyo 2020 games were compared.

### Results

Overall, 430 falls (rugby, 104; men's basketball, 230; and women's basketball, 96) occurred (average per game: 5.8, 23.0, and 9.6, respectively). Significant differences were observed among the three sports regarding the class, direction, fall location, and body part point of contact. In wheelchair rugby, falls occurred mainly in high-pointers and tended to be more lateral due to contact. In wheelchair basketball, falls occurred more in female high-pointers and in male low-pointers, with more forward falls due to forward contact. Unlike in the Rio 2016 games, no difference between the events based on the presence or absence of contact was observed in the Tokyo 2020 games.

### Conclusions

The number of falls increased in Tokyo 2020 compared to Rio 2016, with no significant difference in the characteristics of falls between the Rio 2016 and Tokyo 2020 games. Only in men's wheelchair basketball, the number of falls in low pointers significantly increased in the Tokyo 2020 games when compared to that in the Rio 2016 games.

### Strengths and limitations of this study

- This is the first study to characterize the falls of athletes in wheelchair team sports using data from the Rio 2016 and Tokyo 2020 Games.
- Injuries caused by the wheelchair falls in the videos were not identified.
- To clarify the relationship between falls and injuries, further analysis of the factors that causes falls should be combined and compared with survey data on injuries.

## INTRODUCTION

The Tokyo 2020 Paralympic Games featured 4403 athletes competing in 539 events in 22 sports, making it the largest Paralympic Games in history and drawing increasing attention to the Paralympic Games. Hence, with the increase in the number of athletes, the level of competition is expected to improve, and sports injuries are also expected to increase[1]. A total of 441 athletes sustained as many as 510 injuries during the 14 days of competition at the Rio 2016 Paralympics, with 61 athletes injured during their participation in wheelchair rugby (WR) and wheelchair basketball (WB); this translated to 14.9 and 12.8 injuries per 1000 athlete days, respectively [2]. Furthermore, contact team sports such as WR and WB have a higher incidence of acute injuries than fencing and tennis (61%, 65%, and 42%, 37%, respectively)[3]. In these two wheelchair team sports, many falls commonly occur. Regarding the incidence of falls at the Rio 2016 Paralympics, 359 falls occurred in three disciplines (WR, men's WB, and women's WB). The rate of falls was the highest for MWB, followed by WWB and WR[4]. However, no other study has clarified the characteristics of falls in each sport. Moreover, the relationship between sports injury characteristics and the occurrence of falls in wheelchair team sports has not yet been presented. In the case of wheelchair sports, falls can result in head impacts and emergencies such as concussions, and research in the area of concussions has received increasing attention[5,6]. Therefore, understanding the causes of falls during games is essential in considering the prevention of injury occurrence in these team sports, and more data needs to be collected. One way to analyze the occurrence of falls in wheelchair-related sports is to use video recordings of games.

By retrospectively analyzing the video recordings of the games, which is an effective method that has been used previously to interpret injury occurrence in healthy individuals,[7-9] the occurrence and characteristics of these wheelchair-related sport injuries can be identified. The analysis of anterior cruciate ligament injuries helped researchers to understand the change of dynamic alignment during injury and plan preventive measures,[7] which is why we used this method to investigate the incidence of falls in WR and WB games at the Rio 2016 Paralympic Games[4].

WR and WB players also include individuals with quadriplegia, paraplegia, and amputations. Overall, WR players have more severe functional impairments than WB players, especially those affecting the extremities, such as cervical spinal cord injury (tetraplegia), multiple amputations, polio, cerebral palsy, and other neurological diseases[10]. WR players are classified based on their hand, arm, shoulder, and trunk functions, with disability levels ranging from 0.5 (lowest physical function) to 3.5(highest physical function), and are placed into seven categories based on their level of disability[11]. WB players must

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6 have a permanent physical disability with reduced function of the lower extremities, which  
7 includes paralysis of the lower extremities, musculoskeletal disorders, spina bifida,  
8 amputation, and childhood paralysis[11]. These athletes are classified from 1.0 (lowest  
9 physical function) to 4.5 (highest physical function)[12]. Performance and injury rates vary  
10 greatly by class[13,14], and fall rates are expected to vary as well. However, no analysis of  
11 fall incidence by class has been reported.  
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15 At the Rio 2016 Paralympics, the incidence of falls and the duration of competition,  
16 the presence of contact, the direction of the fall, and the initial site of contact had different  
17 characteristics in the three events[4]. Meanwhile, we have not been able to clarify the  
18 incidence of falls for each class. In addition, five years have passed since the Rio 2016  
19 Paralympics, and the incidence of falls is expected to be different due to the improvement of  
20 athletic performance. Moreover, the Tokyo 2020 Paralympics was held under special  
21 circumstances, with the games being postponed for one year due to the COVID-19 pandemic.  
22 Therefore, new characteristics of fall occurrence different from those of the Rio 2016  
23 Paralympics may emerge, and accumulation of data will be crucial for injury prevention.  
24 This study aimed to investigate the number of falls and the occurrence of falls among  
25 wheelchair athletes in team sports at the 2020 Tokyo Paralympic Games, to compare the  
26 results with those at the 2016 Rio Paralympic Games, and to clarify the characteristics of  
27 major falls among the three major wheelchair team sports (WR, MWB, and W WB).  
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## METHODS

In this cross-sectional video analysis, we obtained the official match videos of the WR and WB wheelchair team competitions from the IPC's official website, and analyzed the match videos of all eight teams participating in the WR and eight teams each from the MWB and WWB that advanced to the quarterfinals of the Tokyo 2020 Paralympic Games (Fig. 1). The WR matches are played in four 8-minute periods, and the WB matches are played in four 10-minute periods. Three physiotherapists with expertise in para-sports systematically analyzed the videos for fall mechanism and play circumstances. The videos were repeated as needed and displayed at normal speed, slow speed, or in still images. To record the number of falls, duration of play at the time of the fall, phase of play (offense or defense), contact with another player, direction of the fall, location of the fall (backcourt, frontcourt, or key or paint area), and the body part that first made contact with the floor, we modified a standard form similar to the one used in previous video analyses[4,15]. In order to record all falls, contact with the floor was considered to be necessary. Additionally, the fall data obtained from the IPC official website of the Rio 2016 Paralympic Games and used in our previous study, from a total of 18 WR and 10 WB match videos of men (MWB) and women (WWB), including eight teams in one event, were also used in this analysis[4].

Data regarding player information (age, sex, and functional classification) were used from the IPC website (Table 1). Regarding disability classification, based on previous studies, for WR,  $\geq 2.0$  were classified as high pointer and  $\leq 1.5$  and below as low pointer[16]; for WB,  $\geq 3.0$  were classified as high pointer and  $\leq 2.5$  as low pointer[17].

### Statistical analysis

For all categorical variables, results that were consistent with the ratings of two out of three observers were reported. A good agreement among the three observers for all variables was considered when two or more observers were in agreement for all categorical items and the kappa coefficient was  $>0.8$ . A one-way analysis of variance was used to compare the mean incidence of falls for each of the three wheelchair sports games. Follow-up analyses were conducted using Bonferroni's post hoc test, if necessary. For the comparison of categorical variables, Pearson's  $X^2$  test or Fisher's exact test was used. The Fisher's exact test was used instead of the  $X^2$  test when the expected number was  $<5$ . All statistical analyses were performed using IBM SPSS version 27.0 (IBM Japan, Tokyo, Japan). A p-value  $<0.05$  considered statistically significant.

### Patient and public involvement

This study was conducted without patient involvement. Patients were not asked to comment on the study design, consulted to derive results relevant to them, or consulted to

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5 interpret the results. Patients were also not consulted in the writing or editing of this  
6 document for readability or accuracy.  
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## RESULTS

Overall, 430 falls were recorded, of which 104 (24.2%) occurred in WR, 230 (53.5%) in MWB, and 96 (22.3%) in WWB, with the average number of falls per game being 5.8, 23.0, and 9.6, respectively. A significant difference in the number of falls was observed among the three sports ( $p<0.001$ ). Table 2 shows the characteristics of falls in the three sport groups, and significant differences in class difference ( $p<0.001$ ), direction of fall ( $p<0.001$ ), location of fall ( $p=0.019$ ), and body part first impacted ( $p<0.001$ ) were detected among the three sports. When comparing falls with and without foul play, significant differences were detected in class ( $p=0.021$ ) and whether contact occurred ( $p=0.007$ ) (Table 3).

Table 4 shows a comparison of the characteristics of falls during the Rio 2016 Paralympics and the Tokyo 2020 Paralympics. In Rio 2016, a significant difference in the tendency of falls was observed among the three groups with and without contact ( $p=0.037$ ), while in Tokyo 2020, no difference was observed ( $p=0.167$ ). In terms of the number of low pointer falls, a significant difference in the tendency of falls was observed among the three groups in both Rio 2016 and Tokyo 2020 Paralympic Games ( $p=0.003$ ,  $p<0.001$ ).

Table 1. Demographic characteristics of athletes who participated the matches

	Wheelchair rugby (n=92)	Men's wheelchair basketball (n=96)	Women's wheelchair basketball (n=95)
Age (years±SD)	34.0±6.4	30.5±6.1	28.9±6.6
Sex			
Male	88	96	-
Female	4	-	95
Classification (%)			
0.5	15(16)	-	-
1.0	17(18)	16(17)	15(16)
1.5	8(9)	11(11)	9(9)
2.0	18(20)	10(10)	9(9)
2.5	7(8)	14(15)	10(11)
3.0	18(20)	7(7)	19(20)
3.5	9(10)	5(5)	8(8)
4.0	-	15(16)	13(14)
4.5	-	17(18)	13(14)

Table 2. Fall characteristics of the three groups

	Wheelchair rugby (n=104)	Men's wheelchair basketball (n=230)	Women's wheelchair basketball (n=96)	<i>p</i> - value
<b>Classification (%)</b>				<b>&lt;0.001</b>
Low pointer	16(15.4)	125(54.3)	43(44.8)	
High pointer	88(84.6)	105(45.7)	53(55.2)	
<b>Playing time (%)</b>				
First quarter	29(27.9)	46(20.0)	28(29.2)	0.389
Second quarter	24(23.1)	48(20.9)	21(21.9)	
Third quarter	25(24.0)	57(24.8)	22(22.9)	

Fourth quarter	26(25.0)	79(34.3)	25(26.0)	
<b>Playing phase (%)</b>				0.154
Offence	60(57.7)	147(63.9)	68(70.8)	
Defence	44(42.3)	83(36.1)	28(29.2)	
Unidentified	-	-	-	
<b>Contact with another player (%)</b>				0.167
Contact	99(95.2)	209(90.9)	90(93.8)	
Non-contact	5(4.8)	15(6.5)	3(3.1)	
Unidentified	-	6(2.6)	3(3.1)	
<b>Direction of the fall (%)</b>				<0.001
Left	32(30.8)	27(11.7)	18(18.8)	
Right	31(29.8)	38(16.5)	15(15.6)	
Forward	27(26.0)	106(46.1)	42(43.8)	
Backward	12(11.5)	53(23.0)	16(16.7)	
Unidentified	2(1.9)	6(2.6)	5(5.2)	
<b>Location of the fall (%)</b>				0.019
Back court	40(38.5)	62(27.0)	27(28.1)	
Front court	43(41.3)	79(34.3)	34(35.4)	
Paint/key area	21(20.2)	89(38.7)	35(36.5)	
<b>Body part first in contact with the floor (%)</b>				<0.001
Hand	60(57.7)	180(78.3)	81(84.4)	
Elbow	24(23.1)	16(7.0)	2(2.1)	
Shoulder	7(6.7)	5(2.2)	1(1.0)	
Back	6(5.8)	15(6.5)	5(5.2)	
Unidentified/combined	7(6.7)	14(6.1)	7(7.3)	

Table 3. Fall characteristics of classification, contact situation and foul judgment

	No foul (n=258)	Foul (n=172)	<i>p</i> - value
<b>Classification (%)</b>			<b>0.021</b>
Low pointer	122(47.3)	62(36.0)	
High pointer	136(52.7)	110(64.0)	
<b>Contact with another player (%)</b>			<b>0.007</b>
Contact	227(88.0)	171(99.4)	
Non-contact	23(8.9)	0(0.0)	
Unidentified	8(3.1)	1(0.6)	

Table 4. The difference of fall characteristics during Tokyo 2020 and Rio 2016

Variable	Olympic	Competition	Number of falls	<i>p</i> - value
Contact with				
another player	Rio	WR	78	
		MWB	152	<b>0.037</b>
		WWB	85	
		<b>Total</b>	<b>315</b>	
	Tokyo	WR	99	0.167

		MWB	209	
		WWB	90	
		<b>Total</b>	<b>398</b>	
Low pointer	Rio	WR	17	
		MWB	65	
		WWB	30	<b>0.003</b>
		<b>Total</b>	<b>112</b>	
	Tokyo	WR	16	
		MWB	125	
		WWB	43	<b>&lt;0.001</b>
		<b>Total</b>	<b>184</b>	

## DISCUSSION

The characteristics of the number of falls occurring during the Tokyo 2020 Games among the three sports were similar to those of Rio 2016, with WB having a higher likelihood of falling than WR, especially with MWB having the highest risk of falling. Furthermore, the number of falls ranged from 5.8 to 23.0 per game, which was more than in Rio 2016 (5.3 to 17.2 per game). However, in terms of the presence or absence of contact and competition time, which tended to differ among the three events in Rio 2016, no difference was observed among the three events in Tokyo 2020. Meanwhile, a new difference was noted in the tendency of falls by class. To the best of our knowledge, this is the first study to characterize falls in wheelchair athletes playing team sports at the Paralympic Games and to compare them between Rio 2016 and Tokyo 2020.

As a result of dividing the number of fallers in each category into high and low pointers, WR (84.6%) and WWB (55.2%) tended to have a high percentage of high pointers,

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6 while MWB (54.3%) conversely tended to have a high percentage of low pointers. Low  
7 pointing includes severe trunk dysfunction in addition to upper limb dysfunction in WR and  
8 severe trunk dysfunction in WB[11,12]. Therefore, they were considered to have less  
9 dynamic movements and lower risk of falling than high pointers. Nevertheless, in the MWB,  
10 the low pointers fell more often than the high pointers. This could be due to the difference  
11 in the proportion of low pointers and high pointers in the competition. In a previous study  
12 comparing the performance of male and female WB players, it has been reported that female  
13 players performed similarly to male players with 1.5 class points lower[18]. Hence, it can be  
14 inferred that up to 2.0–2.5 of the low pointers in MWB were able to move nearly as much as  
15 the high pointers in WWB. Assuming that high pointers can move aggressively on the court  
16 and that the increased contact with the opponent and have an increased risk of falling,  
17 players >2.0 (72%) may be at risk of falling in MWB. If we assume that the athletes can move  
18 aggressively in the MWB and are at an increased risk of falling, we would expect that athletes  
19 with a  $\geq 2.0$  MWB (72%) would be at risk of falling. Meanwhile, 2.0–2.5 athletes, who are low  
20 pointers but can perform as well as female high pointers, may have fallen more frequently  
21 in the MWB because they have less residual function. In order to consider the risk of falling  
22 in MWB, it is necessary to focus on the 2.0–2.5 athletes who can perform as well as female  
23 high pointers and have less residual function among men, rather than using the general  
24 classification of low point and high point.

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34 When the incidence of falls with and without foul play was compared, the low  
35 pointer had 66.3% of falls without foul play. Meanwhile, the high pointers showed a different  
36 trend from the low pointers, with 55.3% of falls without foul play and 44.7% of falls with foul  
37 play, showing little difference in the incidence of falls with and without foul play. Moreover,  
38 despite the overwhelming prevalence of contact-type falls, there were more falls without foul  
39 play (n=258) than with foul play (n=172). In Rio 2016, the incidence of contact falls in WR was  
40 lower than in WB, but this time there was no difference in the incidence of contact falls in the  
41 three disciplines. This result may be due to an increase in falls caused by tackles without foul  
42 play in WR. At the Tokyo 2020 Games, the Paralympics were postponed for one year due to  
43 the pandemic, during which time the number of external games themselves decreased [19,20].  
44 Since no international competitions were held for about a year, it is possible that there was  
45 little experience of contact play in the games. In addition, due to the pandemic, there was a  
46 period when contact play itself was avoided, and it is possible that contact play was not  
47 satisfactory during practice. Therefore, it is expected that WRs who were allowed to make  
48 contact forward of the axle were less tolerant of contact during games, and that falls in  
49 contact increased. Since we did not observe the situation during practice, we can only  
50 speculate, but the environment of Tokyo 2020 is unique in many ways, and these factors may  
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6 have changed the situation in which falls occurred.

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8 In terms of fall direction, the WR players tended to fall more to the left, right, and  
9 front while the WB players tended to fall more to the front. The proportion of elbows and  
10 shoulders in the WR players was higher than that in the WB players, and most of the WB  
11 players fell from their hands. In WR, tackling from behind is a foul, while tackling from in  
12 front of the axle is allowed. Since the impact at contact is large, the momentum of the  
13 contacting side leads directly to a fall, and it is expected that there are many falls to the left  
14 and right. In addition, the tackled player still has the momentum of forward propulsion and  
15 falls forward as it is, so the WR is expected to have more falls to the left and right and forward.  
16 On the other hand, for WBs, contact is allowed, but not as violent contact as tackling, so even  
17 if the player loses balance due to contact, he will fall while rotating forward, which is  
18 expected to result in more forward falls. Additionally, most WR players have out-of-place  
19 injuries in their upper limbs, and their remaining trunk function is less than that of the WB  
20 players[21]. In the case of a fall, WR players may not be able to put out their hands  
21 immediately and may contact the ground from the elbow or shoulder. When the incidence  
22 of falls was divided into the backcourt, frontcourt, and paint (key) area, the incidence of falls  
23 in the key area was lower in the WR players, while the WB players tended to have more falls  
24 in the paint area. This may be due to the competition characteristics of WR, where contact in  
25 the key area is prohibited, and WB, where many players gather in the paint area under the  
26 goal. Therefore, it is necessary to understand that the occurrence of falls and the site of  
27 physical contact at the time of falls are different between WR and WB, even in the same team  
28 sports event. The incidence of injuries in WR and WB team sport events in the Paralympics  
29 did not improve in the London and Rio Paralympics (2012 and 2016, respectively)[2,3].  
30 Furthermore, a detailed analysis of the mechanisms of trauma and injury has not been  
31 reported. The fact that the trends of fall characteristics of WR and WB were similar in Rio  
32 2016 and Tokyo 2020 should be very useful data for the prevention of injury occurrence in  
33 WR and WB in the future.

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46 This study's most significant findings is that the number of MWB low pointer falls  
47 increased the most in Tokyo 2020 compared with Rio 2016. This may be due to the difference  
48 in team composition. In Rio 2016, MWB low pointers accounted for 47%[4], while in Tokyo  
49 2020, they accounted for 53%. In particular, there was a 9% decrease in the number of 3.0–3.5  
50 players and a 4% increase in the number of 2.0–2.5 players. Therefore, it is expected that the  
51 countries that remain in the MWB final tournament tend to have more opportunities for  
52 players with  $\geq 2.0$  points, who have some remaining trunk function. However, in the MWB,  
53 the players with less residual function may be required to exert more effort to keep up with  
54 the high pointers. Therefore, in order to prevent falls in the future, it will be important to  
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conduct research focusing on the details of falls (e.g., the situation at the time of the fall and the direction of the fall) in athletes with MWB between 2.0 and 2.5, as well as on measures to prevent falls during contact. It will then be important to link this research to the prevention of injury occurrence in wheelchair team sports.

### Limitations

There are several limitations to this study. First, we analyzed only official IPC videos and Internet-based IPC reports, so it is unclear whether we were able to analyze all actual falls. Nevertheless, we were able to analyze most of the falls, including those that interrupted the video. Second, we analyzed the games of the top eight teams in MWB and WWB to unify the number of teams, players, and level of competition with WR. The analysis of the 53 qualifying games excluded in our study can be used to present the characteristics of future WB falls. Last, we have not identified any injuries that occurred during the games. Therefore, whether these falls resulted in injuries or not was unknown. However, comparing Rio 2016 and Tokyo 2020, it is expected that more attention and research focus will be given to Paralympic sports injuries in the three popular team sports events of the Paralympics to clarify the differences in fall injuries between WR and WB athletes. Further research is needed to determine the differences in fall injuries between WR and WB athletes.

### CONCLUSION

As in Rio 2016, the incidence of falls was high in Tokyo 2020 with MWB having the highest number of falls, followed by WWB and WR. The direction of fall occurrence and the first site of body contact at the time of the fall in Tokyo 2020 were also similar to those in Rio 2016. However, the occurrence of falls with and without contact in Tokyo 2020 was different from that in Rio 2016. Moreover, a new finding was obtained when comparing the low and high pointers, that more falls occurred in the low pointers of MWB. Further research will be conducted to understand the mechanism of fall injuries in wheelchair athletes and to relate these results to injury research.

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6 interpretation of the data and assisted in the preparation of the manuscript; ST, SA, TT, KK,  
7 MY, RM, TA, HE, and TT performed the video analysis; MK provided advice and YU was  
8 the principal investigator. All authors have approved the final version of the manuscript and  
9 have agreed to be accountable for all aspects of the work to ensure that any questions related  
10 to the accuracy or completeness of any part of the work are properly investigated and  
11 resolved.  
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16 **PATIENT AND PUBLIC INVOLVEMENT:** Patients and/or the public were not involved in  
17 the design, or conduct, or reporting or dissemination plans of this research.  
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19  
20 **PATIENT CONSENT FOR PUBLICATION:** Not required.  
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22  
23 **ETHICS APPROVAL:** This study protocol was approved by Hiroshima University's  
24 Institutional Review Board (Study protocol ID number: E-1459).  
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27  
28 **DATA AVAILABILITY STATEMENT:** All data relevant to the study are included in the  
29 article or uploaded as supplementary information. All data generated or analysed during  
30 this study are included in this published article.  
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### Figure legend

Figure 1. Inclusion and exclusion criteria of match videos.

\*Because WR is a mixed sport, there were no women and men categories.

MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB, WB game videos for women.

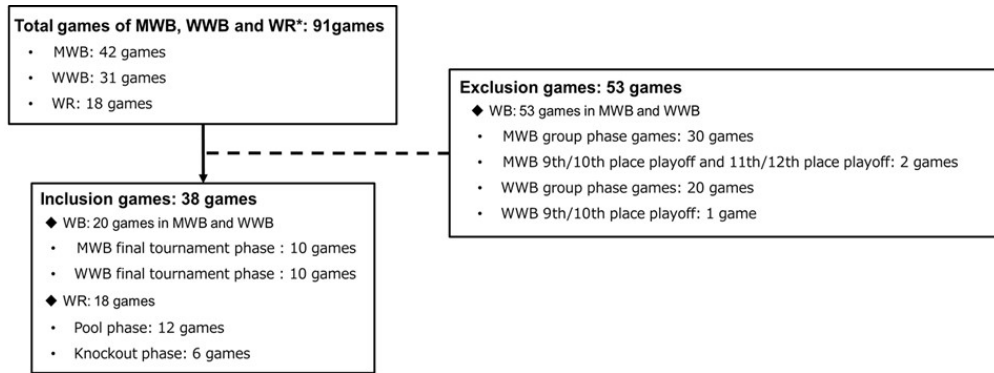


Figure 1. Inclusion and exclusion criteria of match videos. \*Because WR is a mixed sport, there were no women and men categories. MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB, WB game videos for women.

161x59mm (150 x 150 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5
		(b) Describe any methods used to examine subgroups and interactions	5
		(c) Explain how missing data were addressed	5
		(d) If applicable, describe analytical methods taking account of sampling strategy	5
		(e) Describe any sensitivity analyses	5
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	Fig1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table1
		(b) Indicate number of participants with missing data for each variable of interest	-
Outcome data	15*	Report numbers of outcome events or summary measures	Fig1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	-

		(b) Report category boundaries when continuous variables were categorized	7
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	10-13
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).



# BMJ Open

## Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based descriptive comparison between the Rio 2016 and Tokyo 2020 games

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60**1 Title**

2 Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based  
3 descriptive comparison between the Rio 2016 and Tokyo 2020 games  
4

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23 3471 words  
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## 37 **ABSTRACT**

### 38 **Objectives**

39 To identify the fall characteristics of athletes in wheelchair rugby and wheelchair basketball  
40 during the Tokyo 2020 Paralympic Games and descriptively compare these with those of  
41 the Rio 2016 Paralympic Games.

### 42 **Design**

43 Cross-sectional analysis

### 44 **Primary and secondary outcome measures**

45 We obtained video footage from the International Paralympic Committee of the Tokyo  
46 2020 Paralympic Games that included 8 teams from each of the 18 wheelchair rugby and 10  
47 wheelchair basketball games (men and women). The data were analyzed to evaluate the  
48 number of falls, class difference (low or high pointer), time of play during the fall, phase of  
49 play, contact with other athletes, fall direction, fall location, and the body part that first  
50 contacted the floor during the fall. These data from the Rio 2016 and Tokyo 2020 games  
51 were compared.

### 52 **Results**

53 Overall, 430 falls (rugby, 104; men's basketball, 230; and women's basketball, 96) occurred  
54 (average per game: 5.8, 23.0, and 9.6, respectively). Significant differences were observed  
55 among the three sports regarding the class, direction, fall location, and body part point of  
56 contact. In wheelchair rugby, falls occurred mainly in high-pointers and tended to be more  
57 lateral due to contact. In wheelchair basketball, falls occurred more in female high-pointers  
58 and in male low-pointers, with more forward falls due to forward contact. Unlike in the Rio  
59 2016 games, no difference between the events based on the presence or absence of contact  
60 was observed in the Tokyo 2020 games.

### 61 **Conclusions**

62 The number of falls increased in Tokyo 2020 compared to Rio 2016, with no significant  
63 difference in the characteristics of falls between the Rio 2016 and Tokyo 2020 games. Only  
64 in men's wheelchair basketball, the number of falls in low pointers significantly increased  
65 in the Tokyo 2020 games when compared to that in the Rio 2016 games.

### 67 **Strengths and limitations of this study**

- 68 • The analysis of wheelchair sport falls at the Tokyo 2020 Paralympic Games and the  
69 Rio 2016 Paralympic Games was conducted using official Paralympic videos  
70 available on the Internet.
- 71 • The characteristics of falls during wheelchair rugby and wheelchair basketball  
72 competitions were analyzed.

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- 73 • The data from the Tokyo 2020 Paralympic Games and the Rio 2016 Paralympic
- 74 Games were compared, and the characteristics of falls at the Tokyo Paralympic
- 75 Games were analyzed.
- 76 • No injuries due to wheelchair falls were identified in the videos.
- 77 • The relationship between falls and injuries could not be explained.

For peer review only

## 78 INTRODUCTION

79 The Tokyo 2020 Paralympic Games featured 4403 athletes competing in 539 events  
80 in 22 sports, making it the largest Paralympic Games in history and drawing increasing  
81 attention to the Paralympic Games. Hence, with the increase in the number of athletes, the  
82 level of competition is expected to improve, and sports injuries are also expected to increase  
83 [1]. A total of 441 athletes sustained as many as 510 injuries during the 14 days of competition  
84 at the Rio 2016 Paralympics, with 61 athletes injured during their participation in wheelchair  
85 rugby (WR) and wheelchair basketball (WB); this translated to 14.9 and 12.8 injuries per 1000  
86 athlete days, respectively [2]. Furthermore, contact team sports such as WR and WB have a  
87 higher incidence of acute injuries than fencing and tennis (61%, 65%, and 42%, 37%,  
88 respectively) [3]. In these two wheelchair team sports, many falls commonly occur.  
89 Regarding the incidence of falls at the Rio 2016 Paralympics, 359 falls occurred in three  
90 disciplines (WR, men's WB, and women's WB). The rate of falls was the highest for MWB,  
91 followed by WWB and WR [4]. However, no other study has clarified the characteristics of  
92 falls in each sport. Moreover, the relationship between sports injury characteristics and the  
93 occurrence of falls in wheelchair team sports has not yet been presented. In the case of  
94 wheelchair sports, falls can result in head impacts and emergencies such as concussions, and  
95 research in the area of concussions has received increasing attention [5, 6]. Therefore,  
96 understanding the causes of falls during games is essential in considering the prevention of  
97 injury occurrence in these team sports, and more data needs to be collected. One way to  
98 analyze the occurrence of falls in wheelchair-related sports is to use video recordings of  
99 games.

100 By retrospectively analyzing the video recordings of the games, which is an  
101 effective method that has been used previously to interpret injury occurrence in healthy  
102 individuals, [7-9] the occurrence and characteristics of these wheelchair-related sport injuries  
103 can be identified. The analysis of anterior cruciate ligament injuries helped researchers to  
104 understand the change of dynamic alignment during injury and plan preventive measures,  
105 [7] which is why we used this method in our previous study to investigate the incidence of  
106 falls in WR and WB games at the Rio 2016 Paralympic Games [4].

107 WR and WB players also include individuals with quadriplegia, paraplegia, and  
108 amputations. Overall, WR players have more severe functional impairments than WB  
109 players, especially those affecting the extremities, such as cervical spinal cord injury  
110 (tetraplegia), multiple amputations, polio, cerebral palsy, and other neurological diseases  
111 [10]. WR players are classified based on their hand, arm, shoulder, and trunk functions, with  
112 disability levels ranging from 0.5 (lowest physical function) to 3.5 (highest physical function),

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6 113 and are placed into seven categories based on their level of disability [11]. WB players must  
7 114 have a permanent physical disability with reduced function of the lower extremities, which  
8 115 includes paralysis of the lower extremities, musculoskeletal disorders, spina bifida,  
9 116 amputation, and childhood paralysis [11]. These athletes are classified from 1.0 (lowest  
10 117 physical function) to 4.5 (highest physical function) [12]. Performance and injury rates vary  
11 118 greatly by class [13, 14], and fall rates are expected to vary as well. However, no analysis of  
12 119 fall incidence by class has been reported.

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16 120 At the Rio 2016 Paralympics, the incidence of falls and the duration of competition,  
17 121 the presence of contact, the direction of the fall, and the initial site of contact had different  
18 122 characteristics in the three events [4]. Meanwhile, in our previous study we have not been  
19 123 able to clarify the incidence of falls for each class. In addition, five years have passed since  
20 124 the Rio 2016 Paralympics, and the incidence of falls is expected to be different due to the  
21 125 improvement of athletic performance. Moreover, the Tokyo 2020 Paralympics was held  
22 126 under special circumstances, with the games being postponed for one year due to the  
23 127 COVID-19 pandemic. Therefore, new characteristics of fall occurrence different from those  
24 128 of the Rio 2016 Paralympics may emerge, and accumulation of data will be crucial for injury  
25 129 prevention. This study aimed to investigate the number of falls and the occurrence of falls  
26 130 among wheelchair athletes in team sports at the 2020 Tokyo Paralympic Games, to compare  
27 131 the results with those at the 2016 Rio Paralympic Games, and to clarify the characteristics of  
28 132 major falls among the three major wheelchair team sports (WR, MWB, and W WB).  
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## 134 METHODS

135 In this cross-sectional video analysis, we obtained the official match videos of the  
136 WR and WB wheelchair team competitions from the International Paralympic Committee's  
137 (IPC) official website, and analyzed the match videos of all eight teams participating in the  
138 WR and eight teams each from the MWB and WWB that advanced to the quarterfinals of the  
139 Tokyo 2020 Paralympic Games (Fig. 1). The WR matches are played in four 8-minute periods,  
140 and the WB matches are played in four 10-minute periods. Three physiotherapists with  
141 expertise in para-sports systematically analyzed the videos for fall mechanism and play  
142 circumstances. The videos were repeated as needed and displayed at normal speed, slow  
143 speed, or in still images. To record the number of falls, duration of play at the time of the fall,  
144 phase of play (offense or defense), contact with another player, direction of the fall, location  
145 of the fall (backcourt, frontcourt, or key or paint area), and the body part that first made  
146 contact with the floor, we modified a standard form similar to the one used in previous video  
147 analyses [4, 15]. In order to record all falls, contact with the floor was considered to be  
148 necessary. Additionally, the fall data obtained from the IPC official website of the Rio 2016  
149 Paralympic Games and used in our previous study, from a total of 18 WR and 10 WB match  
150 videos of men (MWB) and women (WWB), including eight teams in one event, were also  
151 used in this analysis [4]. Analysis of the Rio 2016 Paralympic Games data was also conducted  
152 using the same methods as for the present 2020 analysis.

153 Data regarding player information (age, sex, and functional classification) were  
154 used from the IPC website (Table 1). Regarding disability classification, based on previous  
155 studies, for WR,  $\geq 2.0$  were classified as high pointer and  $\leq 1.5$  and below as low pointer [16];  
156 for WB,  $\geq 3.0$  were classified as high pointer and  $\leq 2.5$  as low pointer [17].

### 158 Statistical analysis

159 For all categorical variables, results that were consistent with the ratings of two out  
160 of three observers were reported. A good agreement among the three observers for all  
161 variables was considered when two or more observers were in agreement for all categorical  
162 items and the kappa coefficient was  $>0.8$ . A one-way analysis of variance was used to  
163 compare the mean incidence of falls for each of the three wheelchair sports games. Follow-  
164 up analyses were conducted using Bonferroni's post hoc test, if necessary. For the  
165 comparison of categorical variables, Pearson's  $X^2$  test or Fisher's exact test was used. The  
166 Fisher's exact test was used instead of the  $X^2$  test when the expected number was  $<5$ . Adjusted  
167 residuals were used for post hoc tests. Comparisons of the incidence of falls with and without  
168 foul contact were also conducted using Pearson's chi-square test. In order to compare the  
169 characteristics of falls at the Tokyo 2020 Paralympic Games with those at the Rio 2016

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6 170 Paralympic Games, descriptive comparisons were also made between the results from the  
7 171 2020 and 2016 Games regarding the presence of contact with other athletes, and the  
8 172 percentage of low pointer falls. All statistical analyses were performed using IBM SPSS  
9 173 version 27.0 (IBM japan, Tokyo, Japan). A p-value <0.05 considered statistically significant.

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12 174 **Patient and public involvement**

13 175 This study was conducted without patient involvement. Patients were not asked to  
14 176 comment on the study design, consulted to derive results relevant to them, or consulted to  
15 177 interpret the results. Patients were also not consulted in the writing or editing of this  
16 178 document for readability or accuracy.  
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## 180 RESULTS

181 Overall, 430 falls were recorded, of which 104 (24.2%) occurred in WR, 230 (53.5%)  
182 in MWB, and 96 (22.3%) in WWB, with the average number of falls per game being 5.8,  
183 23.0, and 9.6, respectively. There was a significant difference in the mean number of falls,  
184 occurring only between MWB and the other events (WR and WWB) ( $p<0.001$ ). Table 2  
185 shows the characteristics of falls in the three sport groups, and significant differences in  
186 class difference ( $p<0.001$ ), direction of fall ( $p<0.001$ ), location of fall ( $p=0.019$ ), and body part  
187 first impacted ( $p<0.001$ ) were detected among the three sports. When comparing falls with  
188 and without foul play, significant differences were detected in class ( $p=0.021$ ) and whether  
189 contact occurred ( $p=0.007$ ) (Table 3).  
190 Table 4 shows a comparison of the characteristics of falls during the Rio 2016 Paralympics  
191 and the Tokyo 2020 Paralympics. In Rio 2016, a significant difference in the tendency of  
192 falls was observed among the three groups with and without contact ( $p=0.037$ ), while in  
193 Tokyo 2020, no difference was observed ( $p=0.167$ ). In terms of the number of low pointer  
194 falls, a significant difference in the tendency of falls was observed among the three groups  
195 in both Rio 2016 and Tokyo 2020 Paralympic Games ( $p=0.003$ ,  $p<0.001$ ).

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Table 1. Demographic characteristics of athletes who participated the matches

	Wheelchair rugby (n=92)	Men's wheelchair basketball (n=96)	Women's wheelchair basketball (n=95)
Age (years±SD)	34.0±6.4	30.5±6.1	28.9±6.6
Sex			
Male	88	96	-
Female	4	-	95
Classification (%)			
0.5	15(16)	-	-
1.0	17(18)	16(17)	15(16)
1.5	8(9)	11(11)	9(9)
2.0	18(20)	10(10)	9(9)
2.5	7(8)	14(15)	10(11)
3.0	18(20)	7(7)	19(20)
3.5	9(10)	5(5)	8(8)
4.0	-	15(16)	13(14)
4.5	-	17(18)	13(14)

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Table 2. Fall characteristics of the three groups

	Wheelchair rugby (n=104)	Men's wheelchair basketball (n=230)	Women's wheelchair basketball (n=96)	<i>p</i> - value
<b>Classification (%)</b>				<b>&lt;0.001</b>
Low pointer	16(15.4) <sup>†</sup>	125(54.3) <sup>*</sup>	43(44.8)	
High pointer	88(84.6) <sup>*</sup>	105(45.7) <sup>†</sup>	53(55.2)	
<b>Playing time (%)</b>				
First quarter	29(27.9)	46(20.0)	28(29.2)	0.389
Second quarter	24(23.1)	48(20.9)	21(21.9)	
Third quarter	25(24.0)	57(24.8)	22(22.9)	
Fourth quarter	26(25.0)	79(34.3)	25(26.0)	

<b>Playing phase (%)</b>				0.154
Offence	60(57.7)	147(63.9)	68(70.8)	
Defence	44(42.3)	83(36.1)	28(29.2)	
Unidentified	-	-	-	
<b>Contact with another player (%)</b>				0.167
Contact	99(95.2)	209(90.9)	90(93.8)	
Non-contact	5(4.8)	15(6.5)	3(3.1)	
Unidentified	-	6(2.6)	3(3.1)	
<b>Direction of the fall (%)</b>				<0.001
Left	32(30.8)*	27(11.7) <sup>†</sup>	18(18.8)	
Right	31(29.8)*	38(16.5)	15(15.6)	
Forward	27(26.0) <sup>†</sup>	106(46.1)*	42(43.8)	
Backward	12(11.5) <sup>†</sup>	53(23.0)*	16(16.7)	
Unidentified	2(1.9)	6(2.6)	5(5.2)	
<b>Location of the fall (%)</b>				0.019
Back court	40(38.5)*	62(27.0)	27(28.1)	
Front court	43(41.3)	79(34.3)	34(35.4)	
Paint/key area	21(20.2) <sup>†</sup>	89(38.7)*	35(36.5)	
<b>Body part first in contact with the floor (%)</b>				<0.001
Hand	60(57.7) <sup>†</sup>	180(78.3)	81(84.4)*	
Elbow	24(23.1)*	16(7.0) <sup>†</sup>	2(2.1) <sup>†</sup>	
Shoulder	7(6.7)*	5(2.2)	1(1.0)	
Back	6(5.8)	15(6.5)	5(5.2)	
Unidentified/combined	7(6.7)	14(6.1)	7(7.3)	

198 • Values are expressed as the number of falls (% of total falls) for each group.

199 • \* Significantly higher among the three events (p<0.05)

200 • <sup>†</sup>Significantly lower among the three events (p<0.05)

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Table 3. Fall characteristics according to foul judgement

	No foul (n=258)	Foul (n=172)	<i>p</i> - value
<b>Classification (%)</b>			<b>0.021</b>
Low pointer	122(47.3)*	62(36.0) <sup>†</sup>	
High pointer	136(52.7) <sup>†</sup>	110(64.0)*	
<b>Contact with another player (%)</b>			<b>0.007</b>
Contact	227(88.0) <sup>†</sup>	171(99.4)*	
Non-contact	23(8.9)*	0(0.0) <sup>†</sup>	
Unidentified	8(3.1)	1(0.6)	

202 • Values are expressed as the number of falls (% of total falls) for each group.

203 • \*Significantly higher in foul judgment ( $p < 0.05$ )

204 • <sup>†</sup>Significantly lower in foul judgment ( $p < 0.05$ )

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Table 4. The difference of fall characteristics during Tokyo 2020 and Rio 2016

Variable	Paralympic	Competition	Number of falls	<i>p</i> - value	
Contact with another player (%)	Rio	WR	78(24.8) <sup>†</sup>	<b>0.037</b>	
		MWB	152(48.3)		
		WWB	85(27.0)		
		<b>Total</b>	<b>315</b>		
	Tokyo	WR	99(24.9)		0.167
		MWB	209(52.5)		
WWB		90(22.6)			
	<b>Total</b>	<b>398</b>			
Low pointer (%)	Rio	WR	17(15.2) <sup>†</sup>	<b>0.003</b>	
		MWB	65(58.0)*		
		WWB	30(26.8)		
		<b>Total</b>	<b>112</b>		

Tokyo	WR	16(8.7) <sup>†</sup>	
	MWB	125(67.9)*	
	WWB	43(23.4)	<0.001
	<b>Total</b>	<b>184</b>	

206 • Values are expressed as the number of falls (% of total falls) for each Paralympic Games.

207 • \* Significantly higher among the three events (p<0.05)

208 • <sup>†</sup>Significantly lower among the three events (p<0.05)

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## 210 DISCUSSION

211 The characteristics of the number of falls occurring during the Tokyo 2020 Games  
 212 among the three sports were similar to those of Rio 2016, with WB having a higher likelihood  
 213 of falling than WR, especially with MWB having the highest risk of falling. Furthermore, the  
 214 number of falls ranged from 5.8 to 23.0 per game, which was more than in Rio 2016 (5.3 to  
 215 17.2 per game). However, in terms of the presence or absence of contact and competition  
 216 time, which tended to differ among the three events in Rio 2016, no difference was observed  
 217 among the three events in Tokyo 2020. Meanwhile, a new difference was noted in the  
 218 tendency of falls by class. To the best of our knowledge, this is the first study to characterize  
 219 falls in wheelchair athletes playing team sports at the Paralympic Games and to descriptively  
 220 compare them between Rio 2016 and Tokyo 2020.

221 As a result of dividing the number of fallers in each category into high and low  
 222 pointers, WR (84.6%) and WWB (55.2%) tended to have a high percentage of falls among  
 223 high pointers, while MWB (54.3%) conversely tended to have a high percentage of falls  
 224 among low pointers. Low pointing includes severe trunk dysfunction in addition to upper  
 225 limb dysfunction in WR and severe trunk dysfunction in WB [11, 12]. Therefore, less dynamic  
 226 than high pointers, they avoided playing with the risk of falling, and as a result, estimated  
 227 that the number of falls was lower. Nevertheless, in the MWB, the low pointers fell more  
 228 often than the high pointers. This could be due to the difference in the proportion of low  
 229 pointers and high pointers in the competition. In a previous study comparing the  
 230 performance of male and female WB players, it has been reported that female players  
 231 performed similarly to male players with 1.5 class points lower [18]. Hence, it can be inferred  
 232 that up to 2.0–2.5 of the low pointers in MWB were able to move nearly as much as the high  
 233 pointers in WWB. Assuming that high pointers can move aggressively on the court and that

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6 234 the increased contact with the opponent and have an increased risk of falling, players >2.0  
7 235 (72%) may be at risk of falling in MWB. If we assume that the athletes can move aggressively  
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9 236 in the MWB and are at an increased risk of falling, we would expect that athletes with a  $\geq 2.0$   
10 237 MWB (72%) would be at risk of falling. Meanwhile, 2.0–2.5 athletes, who are low pointers  
11 238 but can perform as well as female high pointers, may have fallen more frequently in the  
12 239 MWB because they have less residual function. In order to consider the risk of falling in MWB,  
13 240 it is necessary to focus on the 2.0–2.5 athletes who can perform as well as female high pointers  
14 241 and have less residual function among men, rather than using the general classification of  
15 242 low point and high point.

16 243         When the incidence of falls with and without foul play was compared, the low  
17 244 pointer had 66.3% of falls without foul play. Meanwhile, the high pointers showed a different  
18 245 trend from the low pointers, with 55.3% of falls without foul play and 44.7% of falls with foul  
19 246 play, showing little difference in the incidence of falls with and without foul play. Moreover,  
20 247 despite the overwhelming prevalence of contact-type falls, there were more falls without foul  
21 248 play (n=258) than with foul play (n=172). In Rio 2016, the incidence of contact falls in WR was  
22 249 lower than in WB, but this time there was no difference in the incidence of contact falls in the  
23 250 three disciplines. This result may be due to an increase in falls caused by tackles without foul  
24 251 play in WR. At the Tokyo 2020 Games, the Paralympics were postponed for one year due to  
25 252 the pandemic, during which time the number of external games themselves decreased [19,  
26 253 20]. Since no international competitions were held for about a year, it is possible that there  
27 254 was little experience of contact play in the games. In addition, due to the pandemic, there  
28 255 was a period when contact play itself was avoided, and it is possible that contact play was  
29 256 not satisfactory during practice. Therefore, it is expected that WRs who were allowed to  
30 257 make contact forward of the axle were less tolerant of contact during games, and that falls  
31 258 in contact increased. Since we did not observe the situation during practice, we can only  
32 259 speculate, but the environment of Tokyo 2020 is unique in many ways, and these factors may  
33 260 have changed the situation in which falls occurred.

34 261         In terms of fall direction, the WR players tended to fall more to the left, right, and  
35 262 front while the WB players tended to fall more to the front. The proportion of elbows and  
36 263 shoulders in the WR players was higher than that in the WB players, and most of the WB  
37 264 players fell from their hands. In WR, tackling from behind is a foul, while tackling from in  
38 265 front of the axle is allowed. Since the impact at contact is large, the momentum of the  
39 266 contacting side leads directly to a fall, and it is expected that there are many falls to the left  
40 267 and right. In addition, the tackled player still has the momentum of forward propulsion and  
41 268 falls forward as it is, so the WR is expected to have more falls to the left and right and forward.  
42 269 On the other hand, for WBs, contact is allowed, but not as violent contact as tackling, so even  
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6 270 if the player loses balance due to contact, he will fall while rotating forward, which is  
7 271 expected to result in more forward falls. Additionally, most WR players have out-of-place  
8 272 injuries in their upper limbs, and their remaining trunk function is less than that of the WB  
9 273 players [21]. In the case of a fall, WR players may not be able to put out their hands  
10 274 immediately and may contact the ground from the elbow or shoulder. When the incidence  
11 275 of falls was divided into the backcourt, frontcourt, and paint (key) area, the incidence of falls  
12 276 in the key area was lower in the WR players, while the WB players tended to have more falls  
13 277 in the paint area. This may be due to the competition characteristics of WR, where contact in  
14 278 the key area is prohibited, and WB, where many players gather in the paint area under the  
15 279 goal. Therefore, it is necessary to understand that the occurrence of falls and the site of  
16 280 physical contact at the time of falls are different between WR and WB, even in the same team  
17 281 sports event. The incidence of injuries in WR and WB team sport events in the Paralympics  
18 282 did not improve in the London and Rio Paralympics (2012 and 2016, respectively) [2, 3].  
19 283 Furthermore, a detailed analysis of the mechanisms of trauma and injury has not been  
20 284 reported. The fact that the trends of fall characteristics of WR and WB were similar in Rio  
21 285 2016 and Tokyo 2020 should be very useful data for the prevention of injury occurrence in  
22 286 WR and WB in the future.

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31 287 This study's most significant finding is that the number of MWB low pointer falls  
32 288 increased the most in Tokyo 2020 compared with Rio 2016. This may be due to the difference  
33 289 in team composition. In Rio 2016, MWB low pointers accounted for 47% [4], while in Tokyo  
34 290 2020, they accounted for 53%. In particular, there was a 9% decrease in the number of 3.0–3.5  
35 291 players and a 4% increase in the number of 2.0–2.5 players. Therefore, it is expected that the  
36 292 countries that remain in the MWB final tournament tend to have more opportunities for  
37 293 players with  $\geq 2.0$  points, who have some remaining trunk function. However, in the MWB,  
38 294 the players with less residual function may be required to exert more effort to keep up with  
39 295 the high pointers. Therefore, in order to prevent falls in the future, it will be important to  
40 296 conduct research focusing on the details of falls (e.g., the situation at the time of the fall and  
41 297 the direction of the fall) in athletes with MWB between 2.0 and 2.5, as well as on measures to  
42 298 prevent falls during contact. It will then be important to link this research to the prevention  
43 299 of injury occurrence in wheelchair team sports.

### 300 **Limitations**

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301 There are several limitations to this study. First, we analyzed only official IPC  
302 videos and Internet-based IPC reports, so it is unclear whether we were able to analyze all  
303 actual falls. Nevertheless, we were able to analyze most of the falls, including those that  
304 interrupted the video. Second, we analyzed the games of the top eight teams in MWB and  
305 WWB to unify the number of teams, players, and level of competition with WR. The analysis

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6 306 of the 53 qualifying games excluded in our study can be used to present the characteristics  
7 307 of future WB falls. Third, the players were not directly involved in this study, and the results  
8 308 were only obtained from the videos. A more detailed and accurate analysis could be  
9 309 conducted by directly surveying the players who fell. Lastly, we have not identified any  
10 310 injuries that occurred during the games. This is because the video and data used for this  
11 311 analysis did not provide data on whether an injury had occurred, whether the player was  
12 312 treated by a doctor, or whether the player left the game injured after the fall. Therefore,  
13 313 whether these falls resulted in injuries or not was unknown. However, comparing Rio 2016  
14 314 and Tokyo 2020, it is expected that more attention and research focus will be given to  
15 315 Paralympic sports injuries in the three popular team sports events of the Paralympics to  
16 316 clarify the differences in fall injuries between WR and WB athletes. Further research is  
17 317 needed to determine the differences in fall injuries between WR and WB athletes.  
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## 319 CONCLUSION

26 320 As in Rio 2016, the incidence of falls was high in Tokyo 2020 with MWB having the  
27 321 highest number of falls, followed by WWB and WR. The direction of fall occurrence and the  
28 322 first site of body contact at the time of the fall in Tokyo 2020 were also similar to those in Rio  
29 323 2016. However, the occurrence of falls with and without contact in Tokyo 2020 was different  
30 324 from that in Rio 2016. Moreover, a new finding was obtained when comparing the low and  
31 325 high pointers, that more falls occurred in the low pointers of MWB. Further research will be  
32 326 conducted to understand the mechanism of fall injuries in wheelchair athletes and to relate  
33 327 these results to injury research.  
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338 provided editing and comments for revision; NM, JS, and RS contributed to the analysis and  
339 interpretation of the data and assisted in the preparation of the manuscript; ST, SA, TT, KK,  
340 MY, RM, TA, HE, and TT performed the video analysis; MK and AS provided advice and  
341 YU was the principal investigator. All authors have approved the final version of the  
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6 342 manuscript and have agreed to be accountable for all aspects of the work to ensure that any  
7 343 questions related to the accuracy or completeness of any part of the work are properly  
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9 344 investigated and resolved.

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11 346 **PATIENT AND PUBLIC INVOLVEMENT:** Patients and/or the public were not involved in  
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13 347 the design, or conduct, or reporting or dissemination plans of this research.

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16 349 **PATIENT CONSENT FOR PUBLICATION:** Not required.

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19 351 **ETHICS APPROVAL:** This study protocol was approved by Hiroshima University's  
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21 352 Institutional Review Board (Study protocol ID number: E-1459). The same Review Board  
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23 353 waived the need for obtaining informed consent from the athletes.

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26 355 **DATA AVAILABILITY STATEMENT:** All data relevant to the study are included in the  
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28 356 article or uploaded as supplementary information. All data generated or analysed during  
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30 357 this study are included in this published article.

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22 422

23 423 **Figure legend**

24 424 Figure 1. Inclusion and exclusion criteria of match videos.

25 425 \*Because WR is a mixed sport, there were no women and men categories.

26 426 MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB,

27 427 WB game videos for women.

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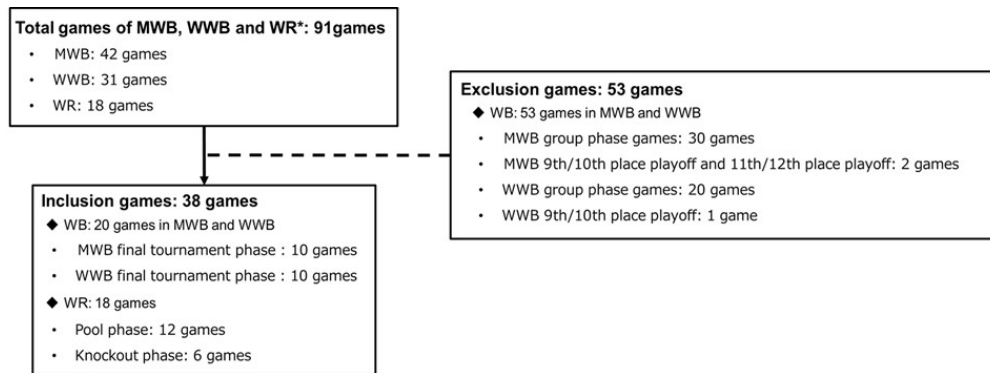


Figure 1. Inclusion and exclusion criteria of match videos. \*Because WR is a mixed sport, there were no women and men categories. MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB, WB game videos for women.

161x59mm (150 x 150 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5
		(b) Describe any methods used to examine subgroups and interactions	5
		(c) Explain how missing data were addressed	5
		(d) If applicable, describe analytical methods taking account of sampling strategy	5
		(e) Describe any sensitivity analyses	5
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	Fig1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table1
		(b) Indicate number of participants with missing data for each variable of interest	-
Outcome data	15*	Report numbers of outcome events or summary measures	Fig1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	-

		(b) Report category boundaries when continuous variables were categorized	7
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	10-13
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).



# BMJ Open

## Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based descriptive comparison between the Rio 2016 and Tokyo 2020 games

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**Title**

Analysis of wheelchair falls in team sports at the Paralympic Games: Video-based descriptive comparison between the Rio 2016 and Tokyo 2020 games

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**Word count**

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## 37 ABSTRACT

### 38 Objectives

39 To identify the fall characteristics of athletes in wheelchair rugby and wheelchair basketball  
40 during the Tokyo 2020 Paralympic Games and descriptively compare these with those of  
41 the Rio 2016 Paralympic Games.

### 42 Design

43 Cross-sectional analysis

### 44 Primary and secondary outcome measures

45 We obtained video footage from the International Paralympic Committee of the Tokyo  
46 2020 Paralympic Games that included 8 teams from each of the 18 wheelchair rugby and 10  
47 wheelchair basketball games (men and women). The data were analyzed to evaluate the  
48 number of falls, class difference (low or high pointer), time of play during the fall, phase of  
49 play, contact with other athletes, fall direction, fall location, and the body part that first  
50 contacted the floor during the fall. These data from the Rio 2016 and Tokyo 2020 games  
51 were compared.

### 52 Results

53 Overall, 430 falls (rugby, 104; men's basketball, 230; and women's basketball, 96) occurred  
54 (average per game  $\pm$  standard deviation:  $5.8\pm 3.1$ ,  $23.0\pm 5.4$ , and  $9.6\pm 5.0$ , respectively).  
55 Significant differences in class, direction, fall location, and body part point of contact  
56 between the three sports were observed. In wheelchair rugby, falls occurred mainly in  
57 high-pointers and tended to be more lateral due to contact. In wheelchair basketball, falls  
58 occurred more in female high-pointers and in male low-pointers, with more forward falls  
59 due to forward contact. Unlike in the Rio 2016 games, no difference between the events  
60 based on the presence or absence of contact was observed in the Tokyo 2020 games.

### 61 Conclusions

62 The number of falls increased in Tokyo 2020 compared to Rio 2016, with no significant  
63 difference in the characteristics of falls between the Rio 2016 and Tokyo 2020 games. Only  
64 in men's wheelchair basketball, the number of falls in low pointers significantly increased  
65 in the Tokyo 2020 games when compared to that in the Rio 2016 games.

### 67 Strengths and limitations of this study

- 68 • The analysis of wheelchair sport falls at the Tokyo 2020 Paralympic Games and the  
69 Rio 2016 Paralympic Games was conducted using official Paralympic videos  
70 available on the Internet.
- 71 • The characteristics of falls during wheelchair rugby and wheelchair basketball  
72 competitions were analyzed by three physiotherapists to ensure consistency.

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- 73 • Data from the Tokyo 2020 Paralympic Games and Rio 2016 Paralympic Games  
74 were analyzed using video-based descriptive comparisons.
- 75 • To match the number of teams in wheelchair rugby and wheelchair basketball, it  
76 was not possible to include data of the 53 wheelchair basketball qualifying games  
77 in the analysis.
- 78 • This video analysis cannot explain the relationship between falls and injuries.

For peer review only

## 79 INTRODUCTION

80 The Tokyo 2020 Paralympic Games featured 4403 athletes competing in 539 events  
81 in 22 sports, making it the largest Paralympic Games in history and drawing increasing  
82 attention to the Paralympic Games. Hence, with the increase in the number of athletes, the  
83 level of competition is expected to improve, and sports injuries are also expected to increase  
84 [1]. A total of 441 athletes sustained as many as 510 injuries during the 14 days of competition  
85 at the Rio 2016 Paralympics, with 61 athletes injured during their participation in wheelchair  
86 rugby (WR) and wheelchair basketball (WB); this translated to 14.9 and 12.8 injuries per 1000  
87 athlete days, respectively [2]. Furthermore, contact team sports such as WR and WB have a  
88 higher incidence of acute injuries than fencing and tennis (61% 65%, 42%, and 37%,  
89 respectively) [3]. In these two wheelchair team sports, many falls are common. Regarding  
90 the incidence of falls at the Rio 2016 Paralympics, 359 falls occurred in three disciplines (WR,  
91 men's WB [MWB], and women's WB [WWB]). The rate of falls was the highest for MWB,  
92 followed by WWB and WR [4]. However, no other study has clarified the characteristics of  
93 falls in each sport. Moreover, the relationship between sports injury characteristics and the  
94 occurrence of falls in wheelchair team sports has not yet been presented. In the case of  
95 wheelchair sports, falls can result in head impacts and emergencies such as concussions, and  
96 research in the area of concussions has received increasing attention [5, 6]. Therefore,  
97 understanding the causes of falls during games is essential in considering the prevention of  
98 injury occurrence in these team sports, and more data needs to be collected. One way to  
99 analyze the occurrence of falls in wheelchair-related sports is to use video recordings of  
100 games.

101 By retrospectively analyzing the video recordings of the games, which is an  
102 effective method that has been used previously to interpret injury occurrence in healthy  
103 individuals, [7-9] the occurrence and characteristics of these wheelchair-related sport injuries  
104 can be identified. The analysis of anterior cruciate ligament injuries helped researchers to  
105 understand the change of dynamic alignment during injury and plan preventive measures,  
106 [7] which is why we used this method in our previous study to investigate the incidence of  
107 falls in WR and WB games at the Rio 2016 Paralympic Games [4].

108 WR and WB players also include individuals with quadriplegia, paraplegia, and  
109 amputations. Overall, WR players have more severe functional impairments than WB  
110 players, especially those affecting the extremities, such as cervical spinal cord injury  
111 (tetraplegia), multiple amputations, polio, cerebral palsy, and other neurological diseases  
112 [10]. WR players are classified based on their hand, arm, shoulder, and trunk functions, with  
113 disability levels ranging from 0.5 (lowest physical function) to 3.5 (highest physical function)  
114 and are placed into seven categories based on their level of disability [11]. WB players must

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6 115 have a permanent physical disability with reduced function of the lower extremities, which  
7 116 includes paralysis of the lower extremities, musculoskeletal disorders, spina bifida,  
8 117 amputation, and childhood paralysis [11]. These athletes are classified from 1.0 (lowest  
9 118 physical function) to 4.5 (highest physical function) [12]. Performance and injury rates vary  
10 119 greatly by class [13, 14], and fall rates are expected to vary as well. However, no analysis of  
11 120 fall incidence by class has been reported.

12 121 At the Rio 2016 Paralympics, the incidence of falls and the duration of competition,  
13 122 the presence of contact, the direction of the fall, and the initial site of contact had different  
14 123 characteristics in the three events [4]. Meanwhile, in our previous study we have not been  
15 124 able to clarify the incidence of falls for each class. In addition, five years have passed since  
16 125 the Rio 2016 Paralympics, and the incidence of falls is expected to be different due to the  
17 126 improvement of athletic performance. Moreover, the Tokyo 2020 Paralympics was held  
18 127 under special circumstances, with the games being postponed for one year due to the  
19 128 coronavirus disease 2019 pandemic. Therefore, new characteristics of fall occurrence  
20 129 different from those of the Rio 2016 Paralympics may emerge, and accumulation of data will  
21 130 be crucial for injury prevention. This study aimed to investigate the number of falls and the  
22 131 occurrence of falls among wheelchair athletes in team sports at the 2020 Tokyo Paralympic  
23 132 Games, to compare the results with those at the 2016 Rio Paralympic Games, and to clarify  
24 133 the characteristics of major falls among the three major wheelchair team sports (WR, MWB,  
25 134 and WWB).

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## 136 METHODS

137 In this cross-sectional video analysis, we obtained the official match videos of the  
138 WR and WB wheelchair team competitions from the International Paralympic Committee's  
139 (IPC) official website, and analyzed the match videos of all eight teams participating in the  
140 WR and eight teams each from the MWB and WWB that advanced to the quarterfinals of the  
141 Tokyo 2020 Paralympic Games (Fig. 1). The WR matches are played in four 8-minute periods,  
142 and the WB matches are played in four 10-minute periods. Three physiotherapists with  
143 expertise in para-sports systematically analyzed the videos for fall mechanism and play  
144 circumstances. The videos were repeated as needed and displayed at normal speed, slow  
145 speed, or in still images. To record the number of falls, duration of play at the time of the fall,  
146 phase of play (offense or defense), contact with another player, direction of the fall, location  
147 of the fall (backcourt, frontcourt, or key or paint area), and the body part that first made  
148 contact with the floor, we modified a standard form similar to the one used in previous video  
149 analyses [4, 15]. In order to record all falls, contact with the floor was considered to be  
150 necessary. Additionally, the fall data obtained from the IPC official website of the Rio 2016  
151 Paralympic Games and used in our previous study from a total of 18 WR and 10 WB match  
152 videos of men (MWB) and women (WWB), including eight teams in one event, were also  
153 used in this analysis [4]. Analysis of the Rio 2016 Paralympic Games data was also conducted  
154 using the same methods in this present 2020 analysis.

155 Data regarding player information (age, sex, and functional classification) were  
156 used from the IPC website (Table 1). Regarding disability classification, based on previous  
157 studies, for WR,  $\geq 2.0$  was classified as high pointer and  $\leq 1.5$  as low pointer [16]; for WB,  $\geq 3.0$   
158 were classified as high pointer and  $\leq 2.5$  as low pointer [17].

### 160 Statistical analysis

161 For all categorical variables, results that were consistent with the ratings of two out  
162 of three observers were reported. A good agreement among the three observers for all  
163 variables was considered when two or more observers were in agreement for all categorical  
164 items and the kappa coefficient was  $>0.8$ . A one-way analysis of variance was used to  
165 compare the mean incidence of falls for each of the three wheelchair sports games. Follow-  
166 up analyses were conducted using Bonferroni's post hoc test, if necessary. For the  
167 comparison of categorical variables, Pearson's  $X^2$  test or Fisher's exact test was used. Fisher's  
168 exact test was used instead of the  $X^2$  test when the expected number was  $<5$ . Adjusted  
169 residuals were used for post hoc tests. Comparisons of the incidence of falls with and without  
170 foul contact were also conducted using Pearson's chi-square test. In order to compare the  
171 characteristics of falls at the Tokyo 2020 Paralympic Games with those at the Rio 2016

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6 172 Paralympic Games, descriptive comparisons were also made between the results from the  
7 173 2020 and 2016 Games regarding the presence of contact with other athletes, and the  
8 174 percentage of low pointer falls. All statistical analyses were performed using IBM SPSS  
9 175 version 27.0 (IBM Japan, Tokyo, Japan). A p-value <0.05 was considered statistically  
10 176 significant.

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13 177 **Patient and public involvement**

14 178 This study was conducted without patient involvement. Patients were not asked to  
15 179 comment on the study design, consulted to derive results relevant to them, or consulted to  
16 180 interpret the results. Patients were also not consulted in the writing or editing of this  
17 181 document for readability or accuracy.  
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**183 RESULTS**

184 Overall, 430 falls were recorded, of which 104 (24.2%) occurred in WR, 230 (53.5%)  
185 in MWB, and 96 (22.3%) in WWB, with an average number of falls per game of  $5.8 \pm 3.1$ ,  
186  $23.0 \pm 5.4$ , and  $9.6 \pm 5.0$ , respectively. There was a significant difference in the mean number of  
187 falls between only MWB and the other events (WR and WWB) ( $p < 0.001$ ). Table 2 shows the  
188 characteristics of falls in the three sport groups. Significant differences in class difference  
189 ( $p < 0.001$ ), direction of fall ( $p < 0.001$ ), location of fall ( $p = 0.019$ ), and body part first impacted  
190 ( $p < 0.001$ ) were detected among the three sports. When comparing falls with and without  
191 foul play, significant differences were detected in class ( $p = 0.021$ ) and whether contact  
192 occurred ( $p = 0.007$ ) (Table 3).

193 Table 4 shows a comparison of the characteristics of falls during the Rio 2016 Paralympics  
194 and the Tokyo 2020 Paralympics. In Rio 2016, a significant difference in the tendency of  
195 falls was observed among the three groups with and without contact ( $p = 0.037$ ), while in  
196 Tokyo 2020, no difference was observed ( $p = 0.167$ ). In terms of the number of low pointer  
197 falls, a significant difference in the tendency of falls was observed among the three groups  
198 in both Rio 2016 and Tokyo 2020 Paralympic Games ( $p = 0.003$ ,  $p < 0.001$ ).

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Table 1. Demographic characteristics of athletes who participated in the matches

	Wheelchair rugby (n=92)	Men's wheelchair basketball (n=96)	Women's wheelchair basketball (n=95)
Age (years±SD)	34.0±6.4	30.5±6.1	28.9±6.6
Sex			
Male	88	96	-
Female	4	-	95
Classification (%)			
0.5	15 (16)	-	-
1.0	17 (18)	16 (17)	15 (16)
1.5	8 (9)	11 (11)	9 (9)
2.0	18 (20)	10 (10)	9 (9)
2.5	7 (8)	14 (15)	10 (11)
3.0	18 (20)	7 (7)	19 (20)
3.5	9 (10)	5 (5)	8 (8)
4.0	-	15 (16)	13 (14)
4.5	-	17 (18)	13 (14)

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Table 2. Fall characteristics of the three groups

	Wheelchair rugby (n=104)	Men's wheelchair basketball (n=230)	Women's wheelchair basketball (n=96)	<i>p</i> - value
<b>Classification (%)</b>				<b>&lt;0.001</b>
Low pointer	16 (15.4) <sup>†</sup>	125 (54.3) <sup>*</sup>	43 (44.8)	
High pointer	88 (84.6) <sup>*</sup>	105 (45.7) <sup>†</sup>	53 (55.2)	
<b>Playing time (%)</b>				
First quarter	29 (27.9)	46 (20.0)	28 (29.2)	0.389
Second quarter	24 (23.1)	48 (20.9)	21 (21.9)	
Third quarter	25 (24.0)	57 (24.8)	22 (22.9)	
Fourth quarter	26 (25.0)	79 (34.3)	25 (26.0)	

10

<b>Playing phase (%)</b>				0.154
Offence	60 (57.7)	147 (63.9)	68 (70.8)	
Defence	44 (42.3)	83 (36.1)	28 (29.2)	
Unidentified	-	-	-	
<b>Contact with another player (%)</b>				0.167
Contact	99 (95.2)	209 (90.9)	90 (93.8)	
Non-contact	5 (4.8)	15 (6.5)	3 (3.1)	
Unidentified	-	6 (2.6)	3 (3.1)	
<b>Direction of the fall (%)</b>				<0.001
Left	32 (30.8)*	27 (11.7) <sup>†</sup>	18 (18.8)	
Right	31 (29.8)*	38 (16.5)	15 (15.6)	
Forward	27 (26.0) <sup>†</sup>	106 (46.1)*	42 (43.8)	
Backward	12 (11.5) <sup>†</sup>	53 (23.0)*	16 (16.7)	
Unidentified	2 (1.9)	6 (2.6)	5 (5.2)	
<b>Location of the fall (%)</b>				0.019
Back court	40 (38.5)*	62 (27.0)	27 (28.1)	
Front court	43 (41.3)	79 (34.3)	34 (35.4)	
Paint/key area	21 (20.2) <sup>†</sup>	89 (38.7)*	35 (36.5)	
<b>Body part first in contact with the floor (%)</b>				<0.001
Hand	60 (57.7) <sup>†</sup>	180 (78.3)	81 (84.4)*	
Elbow	24 (23.1)*	16 (7.0) <sup>†</sup>	2 (2.1) <sup>†</sup>	
Shoulder	7 (6.7)*	5 (2.2)	1 (1.0)	
Back	6 (5.8)	15 (6.5)	5 (5.2)	
Unidentified/combined	7 (6.7)	14 (6.1)	7 (7.3)	

201 • Values are expressed as the number of falls (% of total falls) for each group.

202 • \* Significantly higher among the three events (p<0.05)

203 • <sup>†</sup>Significantly lower among the three events (p<0.05)

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Table 3. Fall characteristics according to foul judgement

	No foul (n=258)	Foul (n=172)	<i>p</i> - value
<b>Classification (%)</b>			<b>0.021</b>
Low pointer	122 (47.3)*	62 (36.0)†	
High pointer	136 (52.7)†	110 (64.0)*	
<b>Contact with another player (%)</b>			<b>0.007</b>
Contact	227 (88.0)†	171 (99.4)*	
Non-contact	23 (8.9)*	0 (0.0)†	
Unidentified	8 (3.1)	1 (0.6)	

205 • Values are expressed as the number of falls (% of total falls) for each group.

206 • \*Significantly higher in foul judgment ( $p < 0.05$ )

207 • †Significantly lower in foul judgment ( $p < 0.05$ )

208

209 Table 4. The difference of fall characteristics during Tokyo 2020 and Rio 2016

Variable	Olympic	WR	MWB	WWB	<i>p</i> - value
<b>Contact with another player (%)</b>	Rio (total=315)	78 (24.8)†	152 (48.3)	85 (27.0)	<b>0.037</b>
	Tokyo (total=398)	99 (24.9)	209 (52.5)	90 (22.6)	0.167
<b>Low pointer (%)</b>	Rio (total=112)	17 (15.2)†	65 (58.0)*	30 (26.8)	<b>0.003</b>
	Tokyo (total=184)	16 (8.7)†	125 (67.9)*	43 (23.4)	<b>&lt;0.001</b>

210 • Values are expressed as the number of falls (% of total falls) for each Paralympic Games.

211 • \* Significantly higher rate among the three events ( $p < 0.05$ )

212 • † Significantly lower rate among the three events ( $p < 0.05$ )

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## 214 DISCUSSION

215 The characteristics of the number of falls occurring during the Tokyo 2020 Games  
 216 among the three sports were similar to those of Rio 2016, with WB having a higher likelihood

of falling than WR; MWB had the highest risk of falling. Furthermore, the number of falls ranged from 5.8 to 23.0 per game, which was more than in Rio 2016 (5.3 to 17.2 per game). However, in terms of the presence or absence of contact and competition time, which tended to differ among the three events in Rio 2016, no difference was observed among the three events in Tokyo 2020. Meanwhile, a new difference was noted in the tendency of falls by class. To the best of our knowledge, this is the first study to characterize falls in wheelchair athletes playing team sports at the Paralympic Games and to descriptively compare them between Rio 2016 and Tokyo 2020.

As a result of dividing the number of fallers in each category into high and low pointers, WR (84.6%) and WWB (55.2%) tended to have a high percentage of falls among high pointers, while MWB (54.3%) conversely tended to have a high percentage of falls among low pointers. Low pointing includes severe trunk dysfunction in addition to upper limb dysfunction in WR and severe trunk dysfunction in WB [11, 12]. Therefore, less dynamic than high pointers, they avoided playing with the risk of falling, and as a result, estimated that the number of falls was lower. Nevertheless, in the MWB, the low pointers fell more often than the high pointers. This could be due to the difference in the proportion of low pointers and high pointers in the competition. In a previous study comparing the performance of male and female WB players, it has been reported that female players performed similarly to male players with a point  $\geq 1.5$  [18]. Hence, it can be inferred that up to 2.0–2.5 of the low pointers in MWB were able to move nearly as much as the high pointers in WWB. Assuming that high pointers can move aggressively on the court and that the increased contact with the opponent increases the risk of falling, players with a point  $> 2.0$  (72%) may be at risk of falling in MWB. If we assume that the athletes can move aggressively in the MWB and are at an increased risk of falling, we would expect that athletes with a point  $\geq 2.0$  would be at risk of falling in MWB (72%). Meanwhile, athletes with 2.0–2.5 points (low pointers) who can perform as well as female high pointers may have fallen more frequently in the MWB because they have less residual function. In order to consider the risk of falling in MWB, it is necessary to focus on the athletes with 2.0–2.5 points who can perform as well as female high pointers and have a less residual function among men, rather than using the general classification of low pointer and high pointer.

When the incidence of falls with and without foul play was compared, the low pointers had 66.3% of falls without foul play. Meanwhile, the high pointers showed a different trend from the low pointers, with 55.3% of falls without foul play and 44.7% of falls with foul play, showing little difference in the incidence of falls with and without foul play. Moreover, despite the overwhelming prevalence of contact-type falls, there were more falls without foul play ( $n=258$ ) than with foul play ( $n=172$ ). In Rio 2016, the incidence of contact

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6 253 falls in WR was lower than in WB, but this time there was no difference in the incidence of  
7 254 contact falls in the three disciplines. This result may be due to an increase in falls caused by  
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9 255 tackles without foul play in WR. At the Tokyo 2020 Games, the Paralympics were postponed  
10 256 for one year due to the pandemic, during which time the number of external games  
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12 257 themselves decreased [19, 20]. Since no international competitions were held for about a year,  
13 258 it is possible that there was little experience of contact play in the games. In addition, due to  
14  
15 259 the pandemic, there was a period when contact play itself was avoided, and it is possible  
16 260 that contact play was not satisfactory during practice. Therefore, it is expected that WRs who  
17  
18 261 were allowed to make contact forward of the axle were less tolerant of contact during games,  
19 262 and that falls in contact increased. Since we did not observe the situation during practice, we  
20  
21 263 can only speculate, but the environment of Tokyo 2020 is unique in many ways, and these  
22 264 factors may have changed the situation in which falls occurred.

23  
24 265 In terms of fall direction, the WR players tended to fall more to the left, right, and  
25 266 front while the WB players tended to fall more to the front. The proportion of elbows and  
26 267 shoulders in the WR players was higher than that in the WB players, and most of the WB  
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28 268 players fell from their hands. In WR, tackling from behind is a foul, while tackling from in  
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30 269 front of the axle is allowed. Since the impact at contact is large, the momentum of the  
31 270 contacting side leads directly to a fall, and it is expected that there are many falls to the left  
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33 271 and right. In addition, the tackled player still has the momentum of forward propulsion and  
34 272 falls forward as it is, so the WR is expected to have more falls to the left and right and forward.  
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36 273 On the other hand, for WBs, contact is allowed, but not as violent contact as tackling;  
37 274 therefore, even if the player loses balance due to contact, he will fall while rotating forward,  
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39 275 which is expected to result in more forward falls. Additionally, most WR players have out-  
40 276 of-place injuries in their upper limbs, and their remaining trunk function is less than that of  
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42 277 the WB players [21]. In the case of a fall, WR players may not be able to put out their hands  
43 278 immediately and may contact the ground from the elbow or shoulder. When the incidence  
44  
45 279 of falls was divided into the backcourt, frontcourt, and paint (key) area, the incidence of falls  
46 280 in the key area was lower in the WR players, while the WB players tended to have more falls  
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48 281 in the paint area. This may be due to the competition characteristics of WR, where contact in  
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50 282 the key area is prohibited, and WB, where many players gather in the paint area under the  
51 283 goal. Therefore, it is necessary to understand that the occurrence of falls and the site of  
52 284 physical contact at the time of falls are different between WR and WB, even in the same team  
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54 285 sports event. The incidence of injuries in WR and WB team sport events in the Paralympics  
55 286 did not improve in the London and Rio Paralympics (2012 and 2016, respectively) [2, 3].  
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57 287 Furthermore, a detailed analysis of the mechanisms of trauma and injury has not been  
58 288 reported. The fact that the trends of fall characteristics of WR and WB were similar in Rio  
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289 2016 and Tokyo 2020 should be very useful data for the prevention of injury occurrence in  
290 WR and WB in the future.

291 This study's most significant finding is that the number of MWB low pointer falls  
292 increased more in Tokyo 2020 compared with Rio 2016. This may be due to the difference in  
293 team composition. In Rio 2016, MWB low pointers accounted for 47% [4], while in Tokyo  
294 2020, they accounted for 53%. In particular, there was a 9% decrease in the number of players  
295 with a with 3.0–3.5 points and a 4% increase in the number of players with 2.0–2.5 points.  
296 Therefore, it is expected that the countries that remain in the MWB final tournament tend to  
297 have more opportunities for players with  $\geq 2.0$  points, who have some remaining trunk  
298 function. However, in the MWB, the players with less residual function may be required to  
299 exert more effort to keep up with the high pointers. Therefore, in order to prevent falls in the  
300 future, it will be important to conduct research focusing on the details of falls (e.g., the  
301 situation at the time of the fall and the direction of the fall) in athletes with MWB between  
302 2.0 and 2.5, as well as on measures to prevent falls during contact. It will then be important  
303 to link this research to the prevention of injury occurrence in wheelchair team sports.

#### 304 **Limitations**

305 There are several limitations to this study. First, we analyzed only official IPC  
306 videos and Internet-based IPC reports, so it is unclear whether we were able to analyze all  
307 actual falls. Nevertheless, we were able to analyze most of the falls, including those that  
308 interrupted the video. Second, we analyzed the games of the top eight teams in MWB and  
309 WWB to unify the number of teams, players, and level of competition with WR. The analysis  
310 of the 53 qualifying games excluded in our study can be used to present the characteristics  
311 of future WB falls. Third, the players were not directly involved in this study, and the results  
312 were only obtained from the videos. A more detailed and accurate analysis could be  
313 conducted by directly surveying the players who fell. Lastly, we did not identify any injuries  
314 that occurred during the games. This is because the video and data used for this analysis did  
315 not provide data on whether an injury had occurred, whether the player was treated by a  
316 doctor, or whether the player left the game injured after the fall. Therefore, whether these  
317 falls resulted in injuries or not was unknown. However, comparing Rio 2016 and Tokyo 2020,  
318 it is expected that more attention and research focus will be given to Paralympic sports  
319 injuries in the three popular team sports events of the Paralympics to clarify the differences  
320 in fall injuries between WR and WB athletes. Further research is needed to determine the  
321 differences in fall injuries between WR and WB athletes.

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#### 323 **CONCLUSION**

324 As in Rio 2016, the incidence of falls in Tokyo 2020 was high, with MWB having the

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6 325 highest number of falls, followed by WWB and WR. The direction of fall occurrence and the  
7 326 first site of body contact at the time of the fall in Tokyo 2020 were also similar to those in Rio  
8 327 2016. However, the occurrence of falls with and without contact in Tokyo 2020 was different  
9 328 from that in Rio 2016. Moreover, a new finding was obtained when comparing the low and  
10 329 high pointers: more falls occurred in the low pointers of MWB. Further research will be  
11 330 conducted to understand the mechanism of fall injuries in wheelchair athletes and to relate  
12 331 these results to injury research.

13 332

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16 335

17 336 **COMPETING INTERESTS: None declared.**

18 337

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20 339 commercial, or not-for-profit sectors.

21 340

22 341 **AUTHOR CONTRIBUTIONS:** KF designed the study and wrote the paper; all authors  
23 342 revised the manuscript; NM, JS, and RS contributed to the analysis and interpretation of the  
24 343 data and assisted in the preparation of the manuscript; ST, SA, TT, KK, MY, RM, TA, HE,  
25 344 and TT performed the video analysis; MK and AS provided advice, and YU was the principal  
26 345 investigator. All authors have approved the final version of the manuscript and have agreed  
27 346 to be accountable for all aspects of the work to ensure that any questions related to the  
28 347 accuracy or completeness of any part of the work are properly investigated and resolved.

29 348

30 349 **PATIENT AND PUBLIC INVOLVEMENT:** Patients and/or the public were not involved in  
31 350 the design, or conduct, or reporting or dissemination plans of this research.

32 351

33 352 **PATIENT CONSENT FOR PUBLICATION:** Not required.

34 353

35 354 **ETHICS APPROVAL:** This study protocol was approved by Hiroshima University's  
36 355 Institutional Review Board (Study protocol ID number: E-1459). The same Review Board  
37 356 waived the need for obtaining informed consent from the athletes.

38 357

358 **DATA AVAILABILITY STATEMENT:** All data relevant to the study are included in the  
359 article or uploaded as supplementary information. All data generated or analyzed during  
360 this study are included in this published article.

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6 426 **Figure legend**

7 427 Figure 1. Inclusion and exclusion criteria of match videos.

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9 428 \*Because WR is a mixed sport, there were no women and men categories.

10 429 MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB,

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12 430 WB game videos for women.

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For peer review only

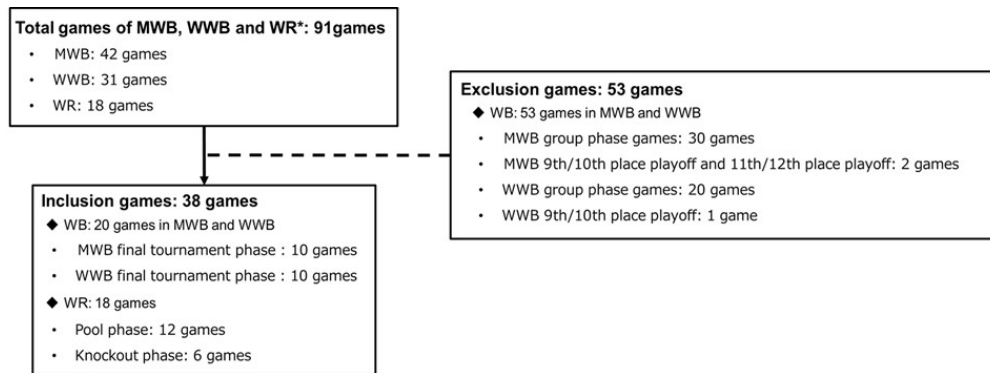


Figure 1. Inclusion and exclusion criteria of match videos. \*Because WR is a mixed sport, there were no women and men categories. MWB, WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB, WB game videos for women.

161x59mm (150 x 150 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5
		(b) Describe any methods used to examine subgroups and interactions	5
		(c) Explain how missing data were addressed	5
		(d) If applicable, describe analytical methods taking account of sampling strategy	5
		(e) Describe any sensitivity analyses	5
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	Fig1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table1
		(b) Indicate number of participants with missing data for each variable of interest	-
Outcome data	15*	Report numbers of outcome events or summary measures	Fig1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	-

		(b) Report category boundaries when continuous variables were categorized	7
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10-11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	10-13
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).