BMJ Open

Analysis of team-sport wheelchair falls during the Rio 2016 Summer Paralympic Games: a video-based cross-sectional observational study

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To cite: Sasadai J, Maeda N, Shimizu R, *et al*. Analysis of team-sport wheelchair falls during the Rio 2016 Summer Paralympic Games: a video-based cross-sectional observational study. *BMJ Open* 2020;**10**:e033088. doi:10.1136/bmjopen-2019-033088

► Prepublication history for this paper is available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2019-033088).

Received 19 July 2019
Revised 17 February 2020
Accepted 20 February 2020

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ABSTRACT

Objectives To present the fall characteristics of athletes playing wheelchair rugby (WR) and wheelchair basketball (WB) using official videos from the Rio 2016 Paralympic Games and compare the key fall characteristics among the team wheelchair sports event.

Methods Eighteen WR and 10 WB game videos for men (MWB) and women (WWB), including 8 teams per sport, were obtained from the official International Paralympic Committee of the Rio 2016 Paralympic Games. The videos were analysed to assess the number of falls, playing time of fall, playing phase, contact with other athletes, the direction of the fall and the body part first in contact with the floor during the fall.

Results In total, 359 falls (96 for WR, 172 for MWB and 91 for WWB) occurred with a mean of 5.3, 17.2 and 9.1 falls per match, respectively ($p<0.05$). Significant differences among the three sports were detected in the playing time ($p=0.011$), presence of contact ($p=0.037$), direction ($p<0.001$) and body part first in contact with the floor ($p<0.001$). For WR, the falls were primarily lateral and caused by contact, occurring in the second half of the match. WB falls tended to be in the first half for women and the second half for men. Most falls were contact falls in the forward direction.

Conclusion By observing the situational details, we described that a number of falls due to contact occurred during these team sports events, especially MWB. In addition, each sport exhibited characteristics attributable to differences in gender, degree of impairment and game rules. The directions of the falls and characteristics of the affected body parts indicate differences in impairments depending on the sport. A fall to the side or back may indicate a risk of injury.

Strengths and limitations of this study

- This is the first study to describe the fall characteristics of wheelchair athletes during popular wheelchair team sports at the Paralympic Games.
- We analysed the official videos of the Paralympic Games, which are publicly available on the Internet, focussing on the falls of wheelchair athletes during wheelchair rugby and wheelchair basketball matches.
- We cannot confirm that all wheelchair falls during the 2016 Paralympic Games were captured or analysed.
- We could not confirm that any injuries were sustained from the wheelchair falls captured on the videos.
- To clarify the relationship between falls and injuries, it is necessary to combine the results of video analysis with injury survey data and compare them.

INTRODUCTION

The Paralympic Games is the third-largest sporting event in the world after the Olympic Games and FIFA World Cup.[1] The Tokyo 2020 Paralympic Games will feature 540 medal events of 22 sports, in which and 4400 athletes will be competing.[2] Wheelchair athletes who participate in wheelchair sports events comprise a majority of the Paralympic competitors. Wheelchair sports are those that have been modified according to the abilities of athletes with lower limb and trunk impairments. The competitions are diverse, ranging from non-contact sports such as wheelchair tennis to contact sports like wheelchair rugby (WR) and wheelchair basketball (WB), and combat sports like wheelchair fencing. It was announced recently that over 10 wheelchair sports have been added to the official list of competitions for the Paralympic Games.[3]

With increasing competition levels, an increase in sports injuries may follow. Previous surveys on sports injuries of impaired athletes showed that 510 injuries were incurred by 441 athletes during the 14 day games event. These injury cases included 61 athletes who had participated in WR and WB and incurred 14.9 and 12.8 injuries per 1000 athlete days at the Rio 2016 Paralympic Games.[4] Additionally, a survey on the winter competitions reports 142 injuries with an injury rate of 20.9 injuries per 1000 athlete days.[5] Furthermore, the number

of acute injuries during contact team sports such as WR and WB is higher than fencing and tennis (61%, 65%, and 42%, 37%, respectively).[6] It is common for many falls to occur in these two wheelchair team sports, however, no study has characterised the falls in each sport. Moreover, the relationship between the sports injury characteristics of team wheelchair sports and the occurrence of wheelchair falls has not been presented yet. Furthermore, there are recent reports showing a lack of measures to prevent injuries to competitors, including wheelchair athletes during the Paralympic Games.[7] In the case of wheelchair sports, a fall may cause a head impact and may result in concussion or other medical emergencies. Therefore, careful attention would be needed to understand the causes of falls. One method to analyse the occurrence of wheelchair associated sports injuries is to view the video records of the competition.

With sports becoming popular among impaired athletes and the demand for the Paralympic Games increasing, research on sports injuries of impaired athletes gained research attention. The International Paralympic Committee (IPC) published epidemiological studies on sports injuries occurring during the recent Paralympic Games events.[4 8] The IPC report shows that acute injuries during the Para Alpine ski were decreased to less than half in the[5] PyeongChang 2018 Paralympic Winter Games compared with that in the Sochi 2014 Paralympic Winter Games.[9] However, these studies did not describe the causes of sports injuries or their prevention methods available.

Games videos is an effective method to characterise sports injuries, and it was applied to interpret the occurrence of injuries in able-bodied athletes.[10 11] Even anterior cruciate ligament injuries were analysed to understand the changing dynamic alignments, which can aid in planning prevention methods.[10]

WR and WB, two popular competitive team wheelchair sports, are part of the competitions in the Paralympic Games.[12] These indoor wheelchair team sports both require intense movements and are performed on wooden floor surfaces. Since the official WR rules permit contact between wheelchairs, wheelchairs are designed to be strong and heavy, whereas, the WB rules prohibit charging and holding. Therefore, wheelchairs for WB are light and mobile.

WR and WB athletes comprise quadriplegic and paraplegic persons, as well as amputees. Overall, WR athletes exhibit more severe dysfunction than WB athletes, particularly impairments that affect all four limbs such as cervical spinal cord injuries (tetraplegia), multiple amputations, polio, cerebral palsy and other neurological disorders.[3] WR athletes are classified based on their functionality of hands, arms, shoulders and trunk, with seven player classifications from 0.5 to 3.5 according to decreasing impairment levels.[13] WB players must have a permanent physical disability associated with reduced lower limb functionality, including paraplegia, musculoskeletal conditions, spina bifida, amputation and poliomyelitis.[3] These athletes are assigned classifications from 1.0 (least physical function) to 4.5 (most physical function).[14]

Since WR and WB are team sports, collisions between wheelchairs and falls from wheelchairs occur frequently during the games. Moreover, these two sports had a combined high incidence rate of acute injuries, that accounted for 70% of the total injuries in the Paralympic Games.[6] Wheelchair users with traumatic spinal cord injuries are most prone to falls while playing wheelchair sports, with injuries occurring once every four times.[15] Hollander *et al* reported that 9 out of 100 injuries, which occurred during the WB World Championships 2018 were traumatic injuries due to falls.[16] In this previous study, gender differences were compared, and falls caused the 8 out of 42 injuries reported in women. Therefore, there can be different characteristics of falls for men and women in the same sport. Moreover, falling can cause contusions, fractures and concussions in wheelchair athletes, which reaffirms the need for effective fall prevention methods. Falls can be caused by contact with others, losing one's balance, shock-relieving or they could be completely unexpected. Not all may cause injuries, but they can occur differently during each sport and their characteristics may differ according to those of the sports. However, so far, no study has analysed the characteristics of wheelchair falls or compared them according to each sport.

This study aimed to characterise falls of team-sports wheelchair athletes during the Rio 2016 Summer Paralympic Games and compare key fall characteristics between three main wheelchair team-sport events (WR, men's WB and women's WB).

METHODS

For the video-based cross-sectional analysis, we acquired the official game videos of the selected wheelchair team sports—WR and WB from the official website of the IPC. We analysed the match videos of all eight teams participating in WR, and the eight MWB and WWB teams that entered the quarterfinals of the [4] Rio 2016 Paralympic Games. A total of 18 WR and 10 WB game videos for men's (MWB) and women's (WWB) including eight teams per sport, were obtained from the official IPC website of the [4] Rio 2016 Paralympic Games (figure 1). WR is played in four periods of 8 min, whereas, in WB, the game consists of four quarters of 10 min each. Three physical therapists familiar with parasports systematically analysed the videos to describe the falling mechanisms and playing situations independently. They watched the videos repeatedly to view the sequences as necessary—at the normal speed, at a slow speed or as still pictures. Standardised forms similar to those used in previous video analyses[9] were modified to record the number of falls, playing time when the falls occurred, playing phase (offence or defence), contact with other athletes, the direction of the fall and body part making first in contact with the floor (table 1). Floor contact was deemed necessary for recording every fall.

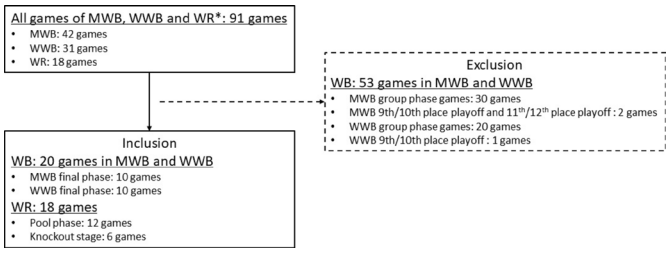

Figure 1 Inclusion and exclusion criteria of match videos. *Because WR is a mixed sport, there were no women and men categories. MWB,WB game videos for men; WB, wheelchair basketball; WR, wheelchair rugby; WWB, WB game videos for women.

Data on the athletes' information (sport played, age, sex and impairment classification) were obtained from the publicly available IPC website. In the videos analysed, there were 96 athletes participating in the wheelchair team sport competitions (table 2).

Statistical analysis

For all categorical variables, we reported the results for which two of the three observers agreed in their assessments and were consistent. Because two or more agreements were consistent for all categorisations and the kappa coefficients were greater than 0.8, good to very good agreement between the three observers for all variables was concluded. Data were analysed for significant differences using the JMP Pro 14.0.0 (SAS Institute Inc, Cary, North Carolina, USA). A one-way analysis of variance was used for comparing the mean incidence rate of falls per match among the three wheelchair sports. When appropriate, follow-up analyses were performed using Bonferroni post hoc tests. Pearson's X^2 test or Fisher's exact test was used for comparing categorical variables. Fisher's exact test was used as an alternative to a X^2 test when expected counts were below 5. The alpha level used for all analyses was set at $p<0.05$.

Patient and public involvement

This research was done without patient involvement. Patients were not invited to comment on the study design or consulted to develop patient-relevant outcomes or interpret the results. Neither were they invited to contribute to the writing or editing of this document for readability or accuracy.

RESULTS

In total, 359 falls were recorded, of which 96 (26.7%) occurred in WR, 172 (47.9%) in MWB and 91 (25.3%) in WWB, with a mean of 5.3, 17.2 and 9.1 falls per match, respectively. There were significant differences in the characteristics of all three sports ($p<0.05$), and table 3 shows the fall characteristics of the three sports groups. Significant differences among the three sports were detected in the playing time ($p=0.011$), contact or non-contact ($p=0.037$), direction of fall ($p<0.001$) and body part first impacted ($p<0.001$). Significant differences among the direction of the fall were also detected in the body part first impacted with the floor ($p<0.001$, table 4).

DISCUSSION

According to our results, there was a high probability of falling in WB, especially MWB, than that in WR. There were 5.3 to 17.2 falls per match in the three sports categories, and the characteristics such as the playing time, intensity of contact with another player during the fall, the direction of the fall and the body part first impacted with the floor were distinct for each sport. To the best of our knowledge, this is the first study to characterise falls of wheelchair athletes playing team sports at the Paralympic Games and compare the three popular sports events.

The results showed that WWB athletes tended to fall in the first quarter (30.8%), in contrast to the WR players (third and fourth quarter, 28.1%, respectively), and MWB (fourth quarter, 34.9%). Comparing the falls of the first half versus those of the second half, WWB had a slightly higher fall frequency in the first half (54%), while WR and MWB players had higher fall frequencies in the second half (56% and 63%, respectively).

Table 1 Variables and categories used in the video analysis for the three physical therapists

Variable	Category
1. Playing time	First quarter; second quarter; third quarter; fourth quarter; overtime
2. Playing phase	Offence: a team is in possession; defence: the opposing team is in possession
3. Contact with another player	Contact: contact to the body or their wheelchairs with other players before falling; non-contact: no contact with other players and their wheelchairs before falling; unidentified: insufficient video record to judge
4. Direction of the fall	Forward; backward; right; left; unidentified: insufficient video record to judge Definition: direction of the wheelchair when the part of the body touching the floor or another player by the fall
5. Body part first in contact with the floor	Hand (including the stump amputated distal to the elbow); elbow (including the stump amputated between the shoulder and elbow); shoulder; back; unidentified/combined: insufficient footage to judge or combined contact (example hand and elbow) Definition: the part of the body that first touched the floor or another player by the fall

Table 2 Demographic characteristics of athletes who participated the matches

	Wheelchair rugby (n=96)	Men's wheelchair basketball (n=96)	Women's wheelchair basketball (n=96)
Age (years±SD)	32.9±7.1	30.2±6.7	28.6±7.0
Gender			
Male	94	96	–
Female	2	–	96
Classification (%)			
0.5	14 (15)	–	–
1	15 (16)	16 (17)	17 (18)
1.5	8 (8)	9 (9)	6 (6)
2	23 (24)	8 (8)	7 (7)
2.5	14 (15)	12 (13)	10 (10)
3	15 (16)	10 (10)	21 (22)
3.5	7 (7)	9 (9)	4 (4)
4	–	10 (10)	18 (19)
4.5	–	22 (23)	13 (14)

First, gender differences must be considered while analysing the differences in the playing time between MWB and WWB. The differences in physical activity during a WB game between men and women have not been reported yet. However, one study comparing the sports performance levels of male and female soccer players reported that female soccer players lost their energies at a medium intensity of 12 to 18 km/hour in the second half, in contrast to that of men who had no changes between two halves.[17] Hence, gender differences can affect fatigue levels during sports competitions. Considering that there is a decrease in activity in WWB players, we ascertained that this might have reduced the number of falls in the second half. Nevertheless, the tendencies of falling during WR and MWB were the same for each of the playing times, possibly because WR included only two female players and therefore the gender difference was almost negligible. Furthermore, in a study considering gender differences, male athletes were faster than female athletes. Although not a wheelchair sport, male soccer players covered more distance than female soccer players during a match and at higher thresholds.[17] Reports suggest that the wheelchair velocity does not change in the first half and the second half of WR.[18] Moreover, physical and mental fatigue affects sports performance.[19] If athletes are moving at the same speed in a state of fatigue, more frequent falls might occur in the second half due to less effective wheelchair operation. We considered this as the cause for a greater number of falls in the second half for WR and MWB.

In general, WB athletes have only lower limb impairments, and many participants had fully functioning upper limbs, while WR athletes, including the high pointers, had upper limb impairments. Therefore, we observed that WR participants had more severe impairments overall. A previous study recorded the average speed and distance of WB and WR players using miniaturised data loggers. The study showed that WB players had a slightly higher average speed than the WR players (1.48 vs 1.33 m/s).[12] Faster wheelchair speeds are assumed to be associated with greater impact while making contact with another player or the floor, and a possibly greater number of falls. Falls due to contact are specific to these team wheelchair sports, and the data suggest that participants in team wheelchair sports fall more frequently than those in other wheelchair sports. In addition, contact associated falls of MWB and WWB athletes were more in number. Although in WR, most falls were contact falls, 14.5% were non-contact falls. Possibly, the different game rules may have influenced the occurrence of contact with another athlete during the fall. Differences in speed may also affect the different mean fall incidence rates.

Falling from a wheelchair should be prevented, as it can cause minor abrasions, contusions or more serious injuries such as fractures and concussions.[20] When considering falls of wheelchair athletes, it is necessary to focus on the differences in impairment level, wheelchair structure, wheelchair sprint and agility and the classification category of each player.[21 22] In addition, based on our results of the relationship between the fall direction and body part in first contact with the floor, wheelchair athletes tended to resist falling using their hands when they fall forward. However, the data indicated more attempts involving the use of elbows and shoulders to resist falling laterally, or the back when falling backward. These lateral and backward falls are less frequent but may be of more injury risks. Lateral falls were more frequent in WR and forward falls were more frequent in MWB and WWB. In addition, the majority of falls in MWB and WWB involved floor contact with the hand to resist falling, while in WR

Table 3 Fall characteristics of the three groups

	Wheelchair rugby (n=96)	Men's wheelchair basketball (n=172)	Women's wheelchair basketball (n=91)	P value
Playing time (%)				
First quarter	20 (20.8)	24 (14.0)	28 (30.8)	0.011
Second quarter	17 (17.7)	36 (20.9)	21 (23.1)	
Third quarter	27 (28.1)	49 (28.5)	24 (26.4)	
Fourth quarter	27 (28.1)	60 (34.9)	18 (19.8)	
Overtime	5 (5.2)	3 (1.7)	0 (0.0)	
Playing phase (%)				
Offence	53 (55.2)	114 (66.3)	58 (63.7)	0.117
Defence	41 (42.7)	58 (33.7)	33 (36.3)	
Unidentified	2 (2.1)	0 (0.0)	0 (0.0)	
Contact with another player (%)				
Contact	78 (81.3)	152 (88.4)	85 (93.4)	0.037
Non-contact	14 (14.6)	13 (7.6)	2 (2.2)	
Unidentified	4 (4.2)	7 (4.1)	4 (4.4)	
Direction of the fall (%)				
Left	29 (30.2)	10 (5.8)	10 (11.0)	<0.001
Right	20 (20.8)	21 (12.2)	7 (7.7)	
Forward	27 (28.1)	100 (58.1)	56 (61.5)	
Backward	15 (15.6)	34 (19.8)	14 (15.4)	
Unidentified	5 (5.2)	7 (4.1)	4 (4.4)	
Body part first in contact with the floor (%)				
Hand	66 (68.8)	158 (91.9)	84 (92.3)	<0.001
Elbow	9 (9.4)	1 (0.6)	2 (2.2)	
Shoulder	6 (6.3)	1 (0.6)	1 (1.1)	
Back	6 (6.3)	2 (1.2)	0 (0.0)	
Unidentified/combined	9 (9.4)	10 (5.8)	4 (4.4)	

falls, the first body parts in contact with the floor were the hand, elbow or other body parts.

A few web-based large epidemiological studies concerning injury characteristics in summer and winter Paralympic Games were conducted twice each year.[4–6 23] The first large prospective epidemiological study on injuries in impaired athletes that expressed injury rates and injury proportions per 1000 athlete days was reported following the London 2012 Summer Paralympic Games.[6]

In this study, 633 injuries were incurred by 539 athletes during the 14-day event at an incidence rate of 12.7 injuries/1000 athlete days. In addition, more detailed studies on sports report high mean injury incidence rates such as in football 5-a-side (22.4 injuries/1000 athlete days), powerlifting (19.3 injuries/1000 athlete days) and athletics (15.8 injuries/1000 athlete days).[24–26] These investigations coupled with the understanding of the current situation of injuries in sports for impaired

Table 4 Fall characteristics of the five directions and body part first in contact with the floor

	Hand	Elbow	Shoulder	Back	Unidentified/ combined	P value
Direction of the fall (%)						
Right	42 (13.6)	2 (16.7)	2 (25.0)	0 (0.0)	2 (8.7)	<0.001
Left	39 (12.7)	4 (33.3)	5 (62.5)	0 (0.0)	1 (4.3)	
Forward	176 (57.1)	3 (25.0)	1 (12.5)	0 (0.0)	3 (13.0)	
Backward	51 (16.6)	3 (25.0)	0 (0.0)	8 (100.0)	1 (4.3)	
Unidentified	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	16 (69.6)	

athletes led to a slightly decreased injury incidence rate in the [4]Rio 2016 Paralympics (10.0 injuries/1000 athlete days),[4] and improved the injury rates during the Alpine skiing at the [5]PyeongChang 2018 Winter Paralympics.[9] However, the incidence of injuries in WR and WB, which are team sports events of the Paralympic Games, had not improved for the Paralympics in London and Rio (2012 and 2016, respectively). In addition, detailed analyses of trauma and injury mechanisms have not been reported.

To be eligible for Paralympics, WR players must have an impairment that affects both the arms and the legs, such as spinal cord injury (C5-C7), or bilateral upper-extremity and lower-extremity limb loss.[13] Their impairment is asymmetrical, which results in falling to the high-level paralysed side or defect side or falling overusing the residual function. On the other hand, WB players have milder impairment than WR players, and most impaired WB athletes, do not have upper limb impairments. Therefore, we considered this to be the reason why MWB and WWB athletes use their hands more frequently to resist falling compared with WR players.

From the data on body parts first in contact with the floor, there were no cases of contact from the head and no head injuries. Interestingly, a survey was conducted earlier to estimate the incidence of concussions in WB, and the results revealed that 6.1% of WB athletes experienced a concussion in just one season.[27] However, head injuries could not be identified from the studied videos. Moreover, Derman *et al* stated that despite several incidents where athletes were observed to suffer a blow to the head followed by unsteady gait, no concussions were reported among participants of the [4]Rio 2016 Paralympic Games.[4] Webborn *et al* noted that there are very little understanding and no guidelines regarding the assessment, management and prevention of concussions in impaired athletes.[7] Therefore, we believe that the analysis of immediate head injuries during team sports competitions, such as rugby on able-bodied persons, may provide conclusive evidence for injury prevention.[28] Using these as examples, we suggest that it would be necessary to work on maintaining athletes' health for sports events of impaired athletes.

Limitations

This study has some limitations. First, it was not possible to analyse falls not officially recorded, because we analysed only the official IPC videos and the IPC report on the Internet. Even then, most of the falls, including the ones for which would interrupt the videos, could be analysed. Second, we analysed the games of the top eight teams of MWB and WWB to unify the number of teams, players and competition level with WR. The analysis of the 53 qualifying games, which were excluded in our study could be used to present the characteristics of WB falls in the future. Furthermore, we have not been able to confirm the occurrence of injury during the games. Thus, whether the injury occurred due to these falls was unclear. However, we expect this study to increase the attention and research focus on Paralympic sports injuries occurring among Paralympic competitors. Further investigation is needed to clarify the differences in fall-related injuries in WR and WB athletes.

CONCLUSION

This study determined the characteristics of falls experienced by wheelchair athletes who participated in team sports competitions during the [4]Rio 2016 Summer Paralympic Games. A large number of falls occurred during these team sports, with MWB, WWB and WR accounting for the most falls (in order). The data suggested that many falls were associated with contact, a unique characteristic of team sports. In addition, each sport had characteristics attributable to differences in gender, the degree of impairment and rules. Furthermore, the direction of the fall and characteristics of the affected body part indicate differences in impairments depending on the sport, and suggest that a fall to the side or back may indicate a risk of injury. Further research is needed to understand the mechanisms of injury caused by falls among wheelchair athletes and link these results to injury investigations.

Contributors JS designed the study, and drafted the paper and all authors provided edits and comments for its revision. NM contributed to the analysis and interpretation of data, and assisted in the preparation of the manuscript. RS, TK and SS performed video analysis. MK advised and assisted in the development of statistical analysis. YU was the chief investigator. All authors approved the final version of the manuscript, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study protocol was approved by Hiroshima University's Institutional Review Board (Study protocol ID number: E-1459).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. All data generated or analysed during this study are included in this published article.

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