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Characteristics of Falls in Wheelchair Athletes: A Video Analysis of the Rio 2016 Summer Paralympic Games

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Complete List of Authors:	Sasadai, Junpei; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Maeda, Noriaki; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Shimizu, Reia; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Kobayashi, Takumi; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Sakai, Shogo; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Komiya, Makoto; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Urabe, Yukio; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation
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Characteristics of Falls in Wheelchair Athletes: A Video Analysis of the Rio 2016 Summer Paralympic Games

Junpei Sasadai, RPT, PhD; Noriaki Maeda, RPT, PhD; Reia Shimizu, RPT; Takumi Kobayashi, RPT; MSc; Shogo Sakai, RPT, MSc; Makoto Komiya, RPT, MSc; Yukio Urabe, RPT, PhD

Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan

Corresponding author:

Junpei Sasadai, RPT, PhD

Institution: Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University

Address: 1-2-3 Kasumi, Minami-ku, Hiroshima, Hiroshima 734-8553, Japan

Telephone: +8182-257-5406

Fax: +8182-257-5344

E-mail: j-sasadai@hiroshima-u.ac.jp

ORCID

https://orcid.org/0000-0001-6134-4577

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Strengths and limitations of this study

- This is the first study to reveal the characteristics of falls in popular wheelchair team sports at the Paralympic Games.
- These characteristics are due to various factors, and it is important for players to take measures to preventing falls during games.
- In the present study, falls not included in the video were not analysed.
- This study could not be clarified whether injury actually occurred due to these falls, because it has not been able to confirm the occurrence of injury during the Games

ABSTRACT

OBJECTIVES: To clarify the different fall characteristics of wheelchair rugby (WR) and wheelchair basketball (WB) using official videos from the Rio Paralympic Games.

METHODS: A total of 18 game videos of WR and 10 game videos each of men's WB (MWB) and women's WB (WWB), including 8 teams per sport, were obtained from among the official International Paralympic Committee videos of the Rio 2016 Paralympic Games. The videos were screened for the number of falls, playing quarter when fall occurred, playing phase, contact with other athletes, direction of the fall, body part making first contact with the floor, and suspected cases of serious injuries.

RESULTS: A total of 359 falls occurred (96 WR, 172 MWB, and 91 WWB), with a frequency of 5.3, 17.2, and 9.1 falls per game, respectively. Significant differences among the three sports were detected in playing quarter ($p = 0.011$), contact or non-contact ($p = 0.037$), direction of fall ($p<0.001$), and body part making first contact with the floor ($p<0.001$).

CONCLUSION: The data from this study indicate that falls occurring in WR were primarily in the second half of games, included some cases of falling without contact with other athletes, and were primarily lateral falls with first floor contact by body parts other than hands. WB falls tended to be in the first quarter for female athletes and in the fourth quarter for male athletes. Most falls were caused by contact with others, and were in a forward direction with the hands making first floor contact.

KEYWORDS: Paralympic sports, fall injuries, para athletes, wheelchair

INTRODUCTION

Wheelchair sports are adapted to athletes with impairment in their lower limbs and trunk. These competitions are diverse, including non-contact sports such as tennis and intense contact sports like rugby and basketball. Recently, over 10 wheelchair sports have been adopted as official competitions of the Paralympic Games.[1] Wheelchair athletes who play these sports account for a large proportion of the Paralympic competitors. The Paralympic Games are the third-largest sporting event in the world and continue to be fast growing. The Tokyo 2020 Paralympic Games will feature 22 sports in total, and 4,400 athletes will compete in 540 medal events.[2] As the competition levels increase, prevention of sports injuries becomes even more important.

Previous surveys about sports injuries among impaired athletes have reported that injuries to the upper limb were most prevalent, with an incidence of 3.4 injuries/1000 athlete days. The anatomical areas most affected by injury included the shoulder, wrist, hand and finger complex.[3] It is inferred that the characteristics of wheelchair sports strongly influence this. However, there are no studies investigating the relationship of sports injuries and the characteristics of wheelchair sports. Moreover, in recent years, it has been pointed out that measures to prevent severe sports injuries and disorders such as concussion are lacking.[4] In order to deepen understanding of wheelchair sports injuries, it is extremely important to analyse the occurrence of these injuries in competition footage.

Research on sports injuries in impaired athletes is a growing area of interest. Epidemiological studies of sports injuries and disorders during the Paralympic Games have been conducted by the International Paralympic Committee (IPC) in recent years.[3,5] However, these studies have not included detailed analyses of the causes of sports injury, and prevention plans have not been developed. Video analysis is one of the useful methods to understand the characteristic of injury and injury incidence situation. Application of video

analysis to clarify the situations leading to sports injuries has been done for many able-bodied athletes.[6,7] For example, many analyses have been carried out on anterior cruciate ligament injury, leading to an understanding of the dynamic alignment risks and aiding in planning prevention methods.[6]

Wheelchair rugby (WR) and wheelchair basketball (WB) are two of the more popular Paralympic sports.[8] WR and WB have been adapted for quadriplegic and paraplegic athletes, amputees and so on. WR athletes are classified based on function in their hands, arms, shoulders, and trunk, and there are seven player classifications ranging from 0.5 to 3.5, with the lower classes having severe impairment.[9] In WB, players must have a permanent physical disability which reduces the function of the lower limbs, and they are assigned a classification from 1.0 (being the player with least physical function) through to 4.5 (being the player with most physical function).[10] It is known that there are many collisions among wheelchairs, and players frequently fall during the games. Acute sports injuries accounted for 70% of the total injuries in WB and WR.[11] Falling in wheelchair athletes can cause various sports injuries including contusions, fractures, and concussions. Therefore, it is very important for players to take measures to preventing falls during games. However, there is no research about the differences in fall situations between WR and WB during competitions.

This study was to clarify the differences in fall characteristics between WR and WB using official videos from the Rio Paralympic Games.

MATERIALS AND METHODS

A total of 18 game videos of WR and 10 game videos each of men's WB (MWB) and women's WB (WWB), including 8 teams per sport, were obtained from among the official IPC videos of the Rio 2016 Paralympic Games. Three physical therapists familiar

with para sports independently and systematically analysed the videos to describe the falling mechanisms and playing situations. Standardized forms were used to record the number of falls, playing quarter when falls occurred, playing phase (offense or defence), contact with other athletes, direction of the fall, body part making first contact with the floor, and suspected cases of serious injuries (Table 1). A fall was defined as the body coming into contact with the floor.

Table 1.
Variables and categories used in the video analysis for the 3 physical therapists.

Variable	Category
1. Playing Quarter	First; Second; Third; Fourth; Over Time (OT)
2. Playing phase	Offence: a team is in possession; Defense: the opposing team is in possession
3. Contact with another player	Contact: contact to the body or their wheelchair with other players before the falling; Non-contact: no contact with other players before the falling; Unidentified: insufficient footage to judge
4. Direction of the fall	Forward; Backward; Right; Left; Unidentified: insufficient footage to judge Definition: Direction of wheelchair when the part of body touching the floor or other player by the fall
5. Body part where contact with floor	Hand (including the stump amputated distal to the elbow); Elbow (including the stump amputated between the shoulder and elbow); Shoulder; Back; Unidentified: insufficient footage to judge or combined contact (ex. hand and elbow) Definition: The part of the body that touched the floor or other player by the fall firstly
6. Serious injuries	Yes: Cases which need the emergency transportation; No: Cases which don't need the emergency transportation

Athlete information (sport, age, sex, and impairment classification) was obtained from a publicly available IPC database. There were each 96 athletes in total and the breakdown of sports classification is in Table 2.

Table 2.
Demographic characteristics of athletes who participated the matches.

	Wheelchair Rugby (n=96)	Men's Wheelchair Basketball (n=96)	Wemen'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)

Statistical analysis

For categorical variables, we reported the results in which at least 2 of the 3 observers agreed in their assessments. Data analysis for significant differences was carried out using JMP® Pro 14.0.0 (SAS Institute Inc, Cary, NC USA). Pearson's Chi-square test or Fisher's exact test were used for comparison of categorical variables. Fisher's Exact Test was used as an alternative to a Chi-square test when expected counts were below 5. The alpha level used for all analyses was set at $p < 0.05$.

For variables with significant differences, correspondence analysis was used to analyse two-way and multiway category data that were transformed into cross tables.[12] In this analysis, the relationship and correspondence between categories of the same or different variables can be revealed. The results are demonstrated graphically in a biplot as points, and the interpretation is based upon proximities between points. If the category points are in close proximity, they are associated with each other. Closer proximity indicates a stronger association.

Patient and public involvement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

RESULTS

Of the 359 falls, 96 (26.7%) occurred in WR, 172 (47.9%) in MWB, and 91 (25.3%) in WWB, with a frequency of 5.3, 17.2, and 9.1 falls per game, respectively. Table 3 shows the fall characteristics of the three sports groups. Significant differences among the three groups were detected in playing quarter ($p = 0.011$), contact or non-contact ($p = 0.037$), direction of fall ($p<0.001$), and body part making first contact with the floor ($p<0.001$).

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 Quarter (%)				
First	20 (20.8)	24 (14.0)	28 (30.8)	0.011
Second	17 (17.7)	36 (20.9)	21 (23.1)	
Third	27 (28.1)	49 (28.5)	24 (26.4)	
Fourth	27 (28.1)	60 (34.9)	18 (19.8)	
Over time	5 (5.2)	3 (1.7)	0 (0.0)	
Playing Phase (%)				
Offence	53 (55.2)	114 (66.3)	58 (63.7)	0.117
Defense	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 where contact with 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	9 (9.4)	10 (5.8)	4 (4.4)	
Serious injuries (%)				
Yes	0 (0.0)	0 (0.0)	0 (0.0)	

Figures 1 to 4 show the results of correspondence analysis in biplot graphs. Because dimension 1 had a much higher proportion of inertia (71.55 to 99.88%) than dimension 2

(0.12 to 28.45%) for all graphs, we can only see the results on dimension 1 (horizontal axis). Figure 1 shows the analysis of the three sports and five playing quarters. WR was close to the third playing quarter, MWB was close to the fourth quarter, and WWB was close to the first quarter. Figure 2 shows the correspondence analysis biplot of the three sports and contact with other athletes. MWB was correlated with contact and indeterminate contact, and WWB also showed a similar tendency. However, WR was not closely linked to any contact category. While MWB and WWB were correlated with forward direction falls, WR showed a lesser association with left and right direction falls (Figure 3). Finally, Figure 4 shows that MWB and WWB were associated with falls where the hand made the first contact with the floor, while WR was more closely associated with cases where the part making first contact with the floor was unidentified.

DISCUSSION

The present study reveals the characteristics of falls in two popular wheelchair sports based on video analysis of the Rio 2016 Summer Paralympic Games. In daily life, falling in a wheelchair is a serious problem that should be prevented, as it can cause various injuries ranging from minor abrasions and contusions to more serious fractures and concussions.[13] There has been some epidemiological research concerning injury characteristics in summer and winter Paralympic Games,[3,5, 14,15] but it has not included video analysis as is widely performed in able-bodied sports to elucidate the pathogenesis of sports-related injuries.[6,7] In addition, correspondence analysis is often used in qualitative research, but in recent years it has also been applied in the field of medical sciences and is a useful method for analysing the relationships between multiple categorical variables.[12,16] In this study, we used correspondence analysis to visually represent the relationship between sports and each variable. Based on our results, there were 5.3 to 17.2 falls per game in the three sports

categories, and it was found that the playing quarter, contact with another player, direction of the fall, and the body part making first contact with the floor were characteristic for each sport. To the best of our knowledge, this is the first study to reveal the characteristics of falls in WR and men's and women's WB, which are two of the more popular wheelchair team sports at the Paralympic Games.

According to our results, there was high probability of falling in WB, especially MWB, compared with WR. In general, WB athletes have only lower limb impairments, and many participants have fully functioning upper limbs and trunks, while WR athletes, including the high pointers, have a higher incidence of impairment in the upper limbs. Therefore, it seems that WR participants have more severe impairment overall. In previous research, the average speed and distance of basketball players and rugby players has been calculated using miniaturized data loggers. WB players were reported to have a slightly higher average speed than WR players (1.48 vs 1.33 m/s).[17] Furthermore, considering gender differences, it is speculated that male athletes are faster than female athletes. Such differences in speed may also affect the difference in the frequency of falls.

Unexpectedly, there were no severe injuries that required emergency transportation in this research. This might be related to lower risk of emergency situation in these Paralympic sports as compared with other able-bodied sports. Athletes in sports such as WR and WB are subject to severe falls and collisions between wheelchairs, so some athletes may not participate due to fear of injuries. However, the actual injury occurrence is not particularly large compared to that of corresponding other able-bodied sports, which is good news for WR and WB athletes. On the other hand, a survey to estimate the incidence of concussions in WB revealed that 6.1% of athletes experienced a concussion in just one season.[18] Webborn et al. note that our understanding and guidelines regarding assessment, management and prevention of concussion in Para athletes is lacking.[4] However, in the Rio

2016 Paralympic survey no concussions were reported and some incidences may have been overlooked.[3] Medical staff should provide appropriate support and management to athletes who have fallen, including assessing the possibility of concussion.

The results of the correspondence analysis showed that WWB athletes tended to fall in the first quarter (30.8%), in contrast to WR (third quarter, 28.1%), and MWB (fourth quarter, 34.9%). This may be due to the difference in performance degradation due to the accumulation of fatigue. Physical and mental fatigue definitely have various adverse effects on sports performance.[19] Although there is a possibility that gender differences may appear in fatigue during competition, there is a paucity of data that quantifies the physiological functions of male and female WB athletes.[20] On the other hand, it is reported that the wheelchair velocity does not change in the first half and the second half of WR matches.[21] 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. It is inferred that similar principles apply to falls in the second half of MWB games. In the case of WWB, fatigue may have reduced the velocity and intensity of the wheelchair propulsion and reduced falls. In addition, MWB and WWB athletes' falls were frequently due to contact with other players. Contact between wheelchairs is officially permitted in WR, however, it is prohibited in the WB rules against charging and holding. Although most of the falls were due to other athlete contact in WR, 14.5% were non-contact falls. It is possible that the difference between these game rules influenced the presence of other athlete contact at the time of fall.

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 made first floor contact with the hand, while first contact in WR falls was not only hand, but also the elbow or other body part. To be eligible for Paralympics, WR players must have an impairment that affects both the arms and the legs, such as spinal cord injury (C5-7), or bilateral upper- and

lower-extremity limb loss.[9] Their impairment is asymmetrical, and thus they often fall to the high-level paralyzed side or defect side or fall over using residual function. On the other hand, WB players have milder impairment than WR players, and in most cases, there is no impairment of the upper limbs. Therefore, it is considered that MWB and WWB athletes more frequently use their hands to catch themselves when falling. When considering falls of wheelchair athletes, it is necessary to focus on the differences in impairment level, wheelchair structure, wheelchair sprint and agility, and classification category for each player.

In summary, WR athletes experienced more falls in the second half of games, with some falls without other athlete contact, and more lateral falls with body parts other than the hand making first contact with the floor. In WB, female athletes had more falls in the first quarter and male athletes in the fourth quarter. Both male and female athletes had many falls caused by contact with others, and tended to fall forward and make first ground contact with their hands. It is suggested that these characteristics are due to various factors such as sports characteristics and disability levels, gender differences in physical function, and wheelchair configuration.[22, 23]

This study has some limitations. Firstly, it was not possible to analyse falls that were not in the official video, because this study analysed information which is available from the official IPC videos and report. Even so, most of the falls, including the ones for which would interrupt the play, could be analyzed from these official videos. Secondly, we have not been able to confirm the occurrence of injury during the Games. Thus, it could not be clarified whether injury actually occurred due to these falls. However, we expect this study to increase attention and research on para sports injuries. Further investigation is needed to clarify the differences in fall-related injuries in WR and WB athletes.

CONCLUSION

The results of this study identified the characteristics of fall in representative wheelchair sports. Team physicians, physical therapists, athletic trainers, coaches, and athletes should be aware of the situational risk of falling in order to prevent injuries. An understanding of the difference in WR and WB fall characteristics will further enable medical staff to provide appropriate support and management for fall injured athletes.

Contributors

JS designed the study, and drafted the paper and all authors provided edits and comments for its revision. NM contributed to analysis and interpretation of data, and assisted in the preparation of the manuscript. RS and TK and SS performed video analysis. MK 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.

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Competing interests

None declared.

Ethics approval

This study protocol was approved by Hiroshima University's Institutional Review Board

(Study protocol ID number: E-1459).

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Data sharing statement

No additional data are available.

Patient consent for publication

Not required.

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FIGURE LEGENDS

Fig. 1

Correspondence analysis biplot of three sports and five playing quarters. 1: first quarter, 2: second quarter, 3: third quarter, 4: fourth quarter, OT: over time; WR: wheelchair rugby,

MWB: men's wheelchair basketball, WWB: women's wheelchair basketball.

Fig. 2

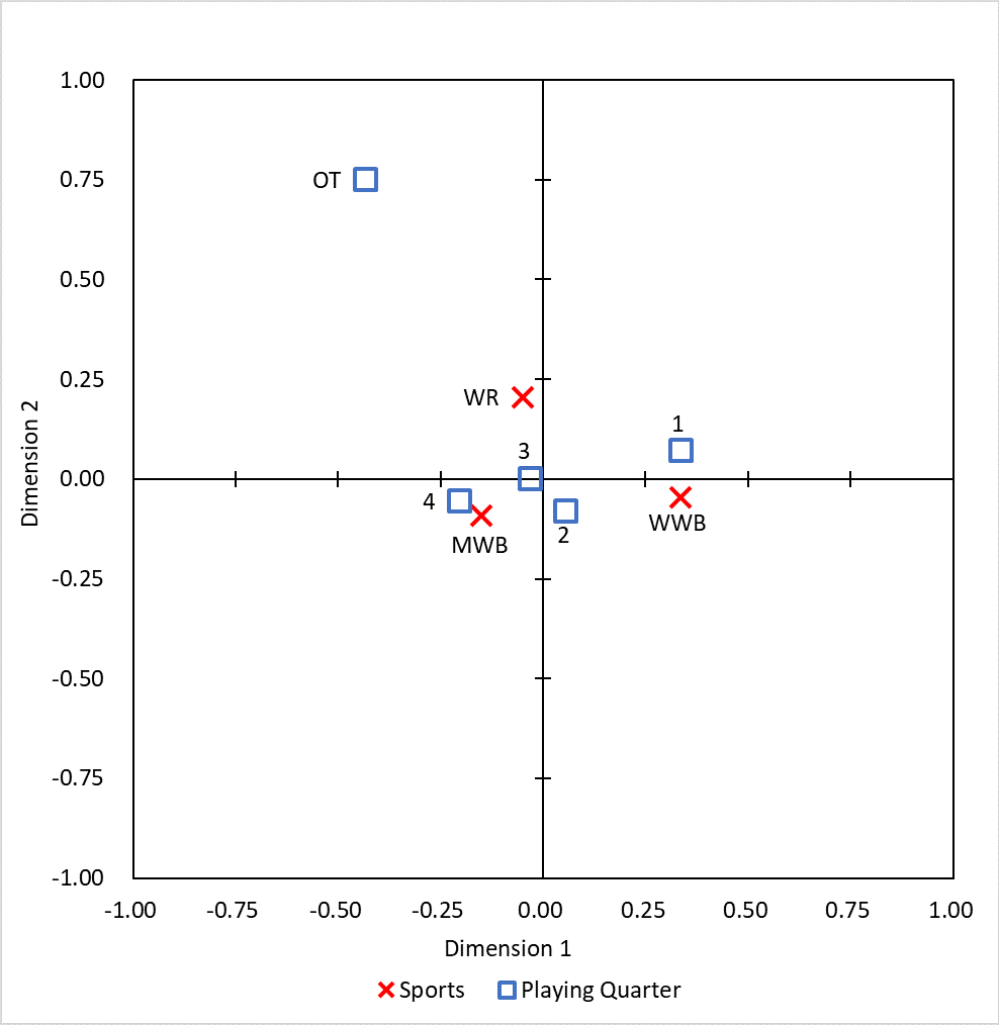
Correspondence analysis biplot of three sports and contact with other athletes.

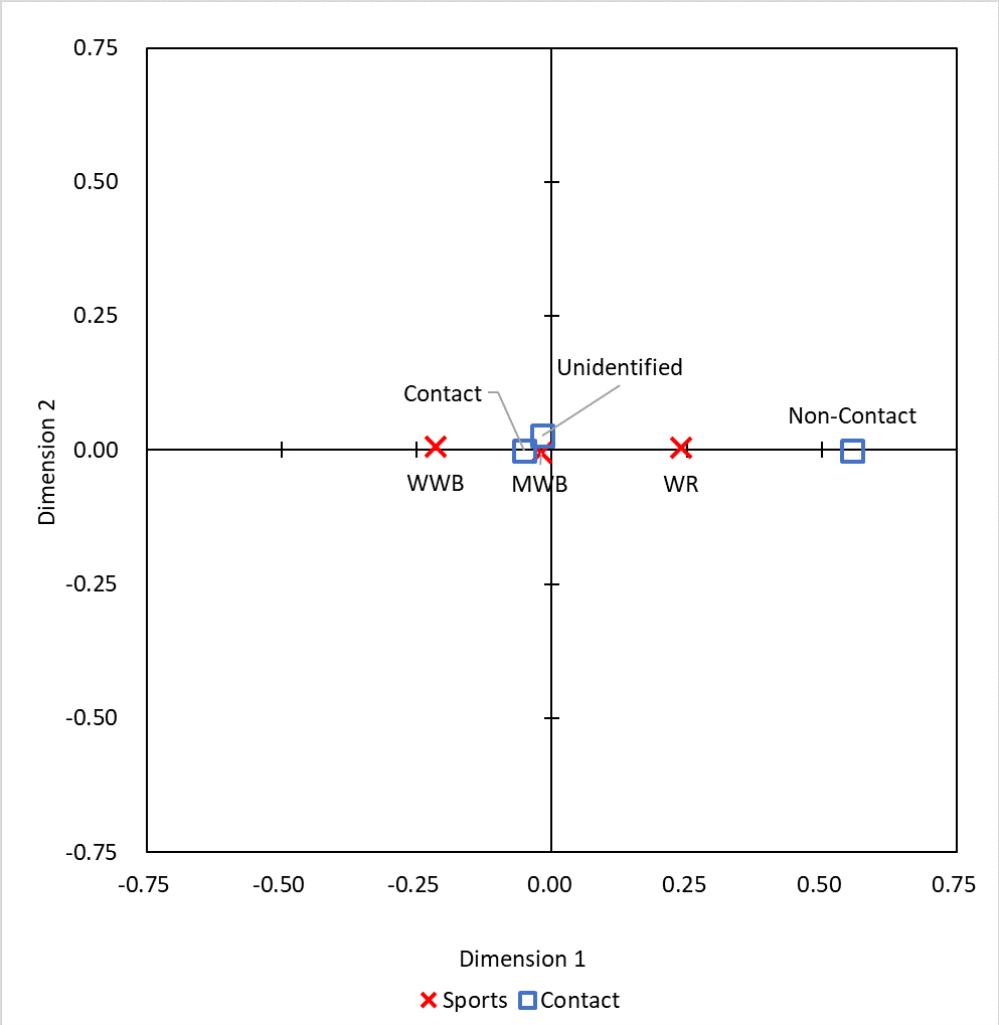
Fig. 3

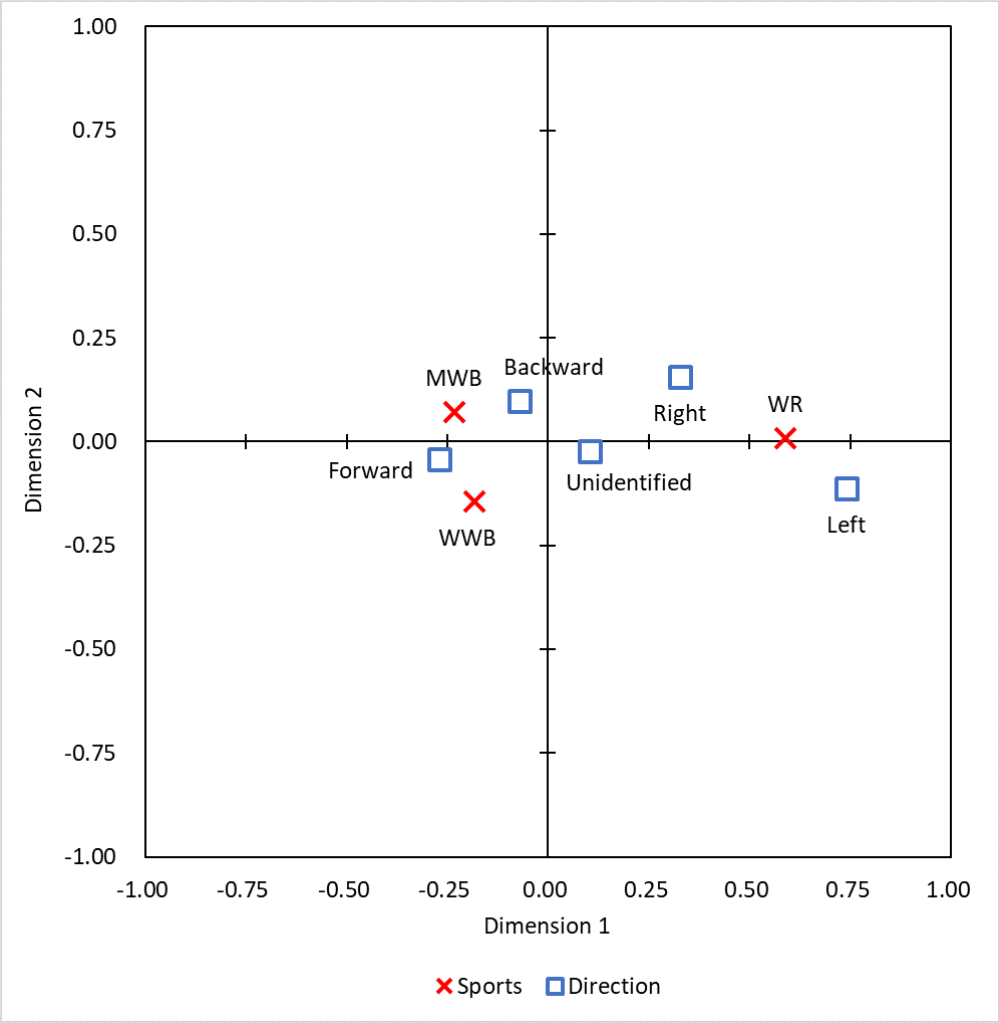
Correspondence analysis biplot of three sports and direction of falling.

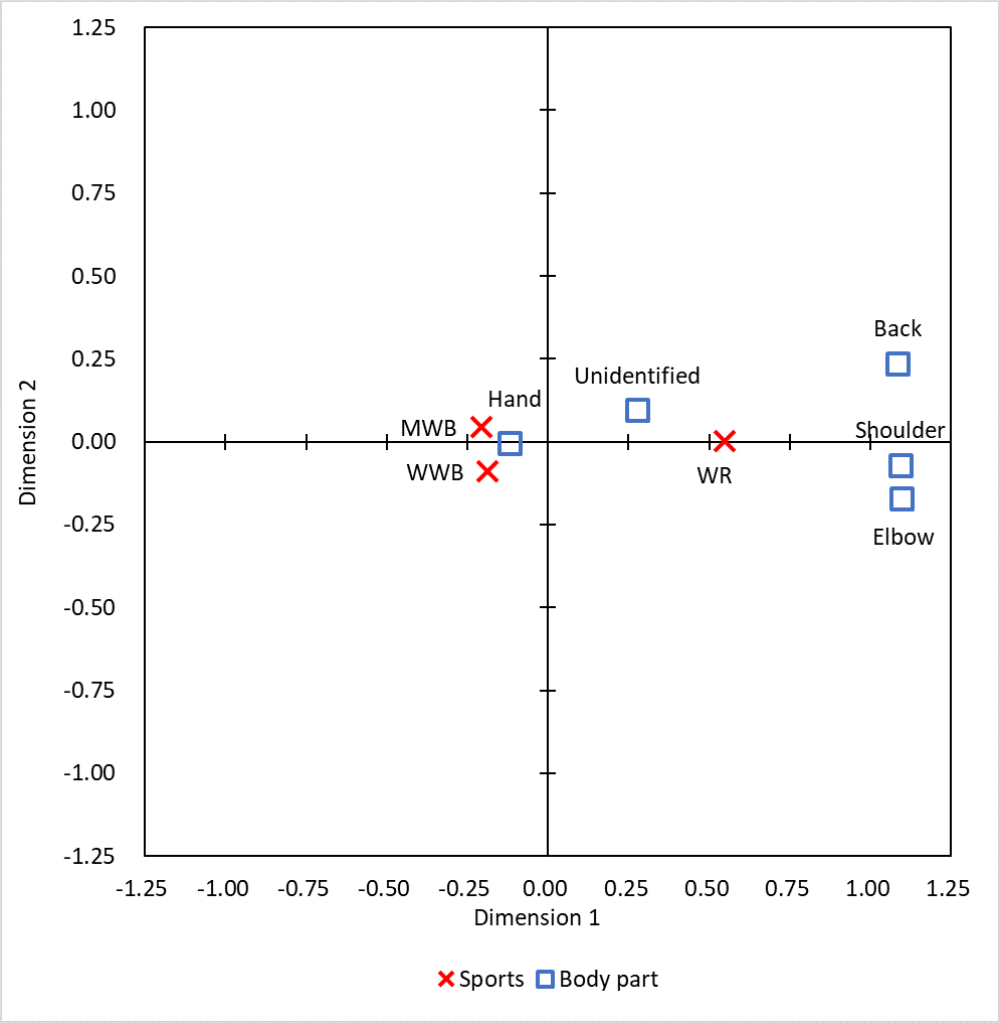
Fig. 4

Correspondence analysis biplot of three sports and body part making first contact with the floor.









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

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Complete List of Authors:	Sasadai, Junpei; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Maeda, Noriaki; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Shimizu, Reia; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Kobayashi, Takumi; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Sakai, Shogo; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Komiya, Makoto; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation Urabe, Yukio; Hiroshima University Faculty of Medicine Graduate School of Biomedical and Health Sciences, Department of Sports Rehabilitation
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Analysis of team-sport wheelchair falls during the Rio 2016 Summer Paralympic Games: a video-based cross-sectional observation study

Junpei Sasadai, RPT, PhD; Noriaki Maeda, RPT, PhD; Reia Shimizu, RPT; Takumi Kobayashi, RPT; Shogo Sakai, RPT, MSc; Makoto Komiya, RPT, MSc; Yukio Urabe, RPT, PhD

Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan

Correspondence to: Junpei Sasadai, RPT, PhD

Institution: Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University

Address: 1-2-3 Kasumi, Minami-ku, Hiroshima, Hiroshima 734-8553, Japan

Telephone: +8182-257-5406

Fax: +8182-257-5344

E-mail: j-sasadai@hiroshima-u.ac.jp

ORCID

https://orcid.org/0000-0001-6134-4577

ABSTRACT

OBJECTIVES: To present the fall characteristics of wheelchair rugby (WR) and wheelchair basketball (WB) using official videos from the Rio Paralympic Games.

METHODS: In total, 18 WR and 10 WB game videos each of men's (MWB) and women's (WWB), including 8 teams per sport, were obtained from the official International Paralympic Committee of the Rio 2016 Paralympic Games. The videos were analysed for the number of falls, time of fall, playing phase, contact with other athletes, direction of the fall, body part first contact with the floor.

RESULTS: A total of 359 falls (96 WR, 172 MWB, and 91 WWB) occurred with a frequency of 5.3, 17.2, and 9.1 falls per game, respectively ($p<0.05$). Significant differences among the 3 sports were detected in playing time ($p = 0.011$), contact or non-contact ($p = 0.037$), direction ($p<0.001$), and body part first contact with the floor ($p<0.001$). During WR, the falls were primarily lateral and occurred in the second half, including few non-contact falls. WB falls tended to be in the first half for WWB and in the second half for MWB. Most falls were contact falls in a forward direction.

CONCLUSION: The difference in fall frequency due to sports was interpreted to reflect differences in movement speed, gender and rules, such as the permission of contact. From the results of the playing time when the fall occurred, we ascertained that the decrease in intensity due to fatigue reduced the fall in the second half in WWB. The direction of the fall and the characteristics of the affected body part indicate differences in the impairments depending on the sport, and a fall to the side or back may be a risk of injury.

KEYWORDS: Paralympic sports, fall injuries, para athletes, wheelchair

Strengths and limitations of this study

- This is the first study to reveal the characteristics of falls in popular wheelchair team sports at the Paralympic Games.
- This study is based on an analysis of the Paralympic official videos which are publicly available on the Internet, focusing on the fall 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 injuries were sustained from the wheelchair falls captured.
- In order 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 are the third-largest sporting event in the world behind the Olympic Games and FIFA World Cup.[1] The Tokyo 2020 Paralympic Games will feature 22 sports in total, and 4,400 athletes will compete in 540 medal events.[2] The number of wheelchair athletes playing wheelchair sports constitute a majority of the Paralympic competitors. Wheelchair sports are adapted 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 even include combat sports like wheelchair fencing. Recently, over 10 wheelchair sports were newly adopted as official competitions of the Paralympic Games.[3]

As the competition levels increase, prevention of sports injuries becomes even more important. Previous surveys on sports injuries among impaired athletes reported that 510 injuries were incurred by 441 athletes during the 14-day Games, reflecting an injury rate of 10.0 injuries per 1000 athlete days. Of these injuries, 61 were of athletes participating in WR (14.9 per 1000 athlete days) and WB (12.8 per 1000 athlete days) at the Rio Paralympic Games.[4] Additionally, a survey on the winter competitions reports of 142 injuries at an incidence rate of 20.9 per 1000 athlete days [5] Furthermore, contact team sports such as WR and WB have a higher incidence of acute injuries than fencing and tennis (61%, 65%, 42%, 37%, respectively).[6] However, no study has investigated the relationship of sports injuries and the characteristics of wheelchair team sports yet. Moreover, it was mentioned recently that measures to prevent sports injuries and disorders such as concussion were lacking for wheelchair athletes.[7] In the case of wheelchair sports, a shock on the head is possible during a fall, but this requires more attention. Analysing the occurrence of wheelchair sports injuries using competition footage may provide a medium to better understand them.

As sports for disabled persons and the Paralympic Games become popular, research

on sports injuries in impaired athletes gain prominence as well. The International Paralympic Committee (IPC) has conducted epidemiological studies on sports injuries and disorders during the Paralympic Games in the recent years,[4,8] which report that acute injuries by the Para Alpine ski were decreased to less than half in the PyeongChang 2018 Paralympic Winter Games compared to that in the Sochi 2014 Paralympic Winter Games.[9] However, these studies did not describe the causes of sports injuries or their prevention methods.

Video analysis of Games videos –an effective method to characterise sports injuries– was applied to interpret the incidence of injuries for able-bodied athletes.[10,11] Even anterior cruciate ligament injuries were analysed to provide an understanding of the dynamic alignment risks and aiding in planning prevention methods.[10]

WR and WB, two popular competitive team wheelchair sports, are included in the Paralympic Games.[12] Both these indoor wheelchair team sports require intense movements and are performed on wooden floor surfaces. Since contact between wheelchairs is officially permitted in WR, they are designed to be robust and heavy. On the other hand, WB rules prohibit charging and holding. Therefore, wheelchairs for WB are light and highly mobile.

WR and WB athletes comprise quadriplegic and paraplegic persons, as well as amputees. Overall, WR atletes have more severe dysfunction than WB athletes. WR athletes are classified based on their functionality of hands, arms, shoulders, and trunk, with 7 player classifications from 0.5 to 3.5 according to decreasing impairment levels.[13] WB players must have a permanent physical disability with reduced lower limb functionality and are assigned classifications from 1.0 (least physical function) to 4.5 (most physical function).[14]

Wheelchair collisions and falls are frequent during the Games, while acute sports injuries accounted for 70% of the total injuries in WB and WR.[6] Wheelchair users with traumatic spinal cord injuries are most prone to falls during wheelchair sports, with injuries occurring once every four times.[15] Hollander et al. reported that 9 out of 100 injuries that

occurred during the WB World Championships 2018 were trauma due to falls.[16] This study compared gender differences, and reported that 8 out of 42 injuries in women were caused by falls. Therefore, the characteristics of falls between men and women in the same sport are different. Falling in wheelchair athletes can cause contusions, fractures, and concussions. Therefore, players need to prevent falls during the Games. Falls can be caused by contact with others, losing one's own balance, shock-relieving, or completely unexpected. Not all may cause injuries, and their characteristics may differ with the sports characteristics. However, no study has analysed the characteristics of wheelchair falls and compares them for each sport yet.

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

MATERIALS AND METHODS

A total of 18 WR and 10 WB game videos for men's (MWB) and women's (WWB) including 8 teams per sport, were obtained from the official IPC website of the Rio 2016 Paralympic Games (Figure 1). WR video analysis included all 8 participating teams of the Rio 2018 Paralympic Games, and WB analysis included 8 MWB and WWB teams that entered the quarterfinals. WR is played in 4 periods of 8 minutes, whereas, in WB, the game consists of 4 quarters of 10 minutes each. Three physical therapists familiar with para sports independently and systematically analysed the videos to describe the falling mechanisms and playing situations. They watched the videos independently on a web browser, repeatedly viewing the sequences as needed—at normal speed, at slow speed, or as still pictures. Standardized forms similar to those used in previous video analyses[9] were modified before to record the number of falls, playing time when falls occurred, playing phase (offense or

defence), contact with other athletes, direction of the fall, body part making first contact with the floor (Table 1). Floor contact was deemed necessary for recording every fall.

Table 1.

Variables and categories used in the video analysis for the 3 physical therapists.

Variable	Category
1. Playing time	First quarter; Second quarter; Third quarter; Fourth quarter; Over Time (OT)
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 wheelchair with other players before the falling; Non-contact: no contact with other players before the falling; Unidentified: insufficient footage to judge
4. Direction of the fall	Forward; Backward; Right; Left; Unidentified: insufficient footage to judge Definition: Direction of wheelchair when the part of body touching the floor or other player by the fall
5. Body part first in contact with 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 (ex. hand and elbow) Definition: The part of the body that touched the floor or other player by the fall firstly

Athlete information (sport, age, sex, and impairment classification) was obtained from a publicly available IPC database on the Internet. There were 96 athletes participating in each of the team wheelchair sports analysed (Table 2). These 96 athletes belonged to the 8 teams. WR, and Top 8 teams MWB and WWB that participated in the Rio 2016 Paralympic Games.

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)

Statistical analysis

For all categorical variables, we reported the results in which 2 of the 3 observers agreed in their assessments and were consistent. Because 2 or more agreements are consistent for all categorizations and the kappa coefficients were greater than 0.8, which together indicated good to very good agreement between the 3 observers for all variables. Data analysis for significant differences was carried out using the JMP® Pro 14.0.0 (SAS Institute Inc, Cary, NC USA). A one-way ANOVA was used for comparisons of frequency of falls per game among the 3 wheelchair sports. When appropriate, follow-up analyses were performed using Bonferroni post-hoc tests. Pearson's Chi-square test or Fisher's exact test was used for comparison of categorical variables. Fisher's Exact Test was used as an alternative to a Chi-square 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.

Ethics approval

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

RESULTS

Of the 359 falls, 96 (26.7%) occurred in WR, 172 (47.9%) in MWB, and 91 (25.3%) in WWB, with a frequency of 5.3, 17.2, and 9.1 falls per game, respectively. There were significant differences between all sports ($p<0.05$). Table 3 shows the fall characteristics of the 3 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 floor ($p < 0.001$, Table 4).

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)	
Over time	5 (5.2)	3 (1.7)	0 (0.0)	
Playing Phase (%)				
Offence	53 (55.2)	114 (66.3)	58 (63.7)	0.117
Defense	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 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)	

Table 4.

Fall characteristics of the five direction and body part first contact with 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)	

DISCUSSION

The study presents the characteristics of falls in 3 wheelchair sports based on video analysis of the Rio 2016 Summer Paralympic Games. Falling from a wheelchair should be prevented, as it can cause minor abrasions, contusions, or more serious injuries such as fractures and concussions.[17] Few web-based large epidemiological studies concerning injury characteristics in summer and winter Paralympic Games were conducted twice each year.[4, 5, 6, 18] The first large prospective injury epidemiological study in athletes with impairment was reported following the London 2012 Summer Paralympic Games that expressed injury rates and injury proportions per 1000 athlete days. [6] In this study, 633 injuries were incurred by 539 athletes during 14 days at the incidence rate of 12.7 injuries per 1000 athlete days. In addition, more detailed studies on sports report high incidence rate such as 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).[19,20,21] These investigations coupled with the understanding of the current situation of injuries in disabled sports led to a slightly decreased incidence rate in the Rio Paralympics (10.0 injuries/1000 athlete days),[4] and improved the the Alpine skiing at the PyeongChang winter Paralympics.[9] However, the

incidence of injuries in WR and WB, which are team sports games of the Paralympic Games, has not improved in London and Rio, and detailed analyses of trauma and elucidation of injury mechanism have not progressed. From our results, there were 5.3 to 17.2 falls per game in the three sports categories, and the playing time, contact with another player, direction of the fall, and the body part first impacted were distinct for each sport. To the best of our knowledge, this is the first study to characterise falls of team-sport wheelchair athletes at the Paralympic Games.

According to our results, there was high probability of falling in WB, especially MWB, compared with WR. In general, WB athletes have only lower limb impairments, and many participants have fully functioning upper limbs, while WR athletes, including the high pointers, often have impairments in the upper limbs. Therefore, it seems that WR participants have more severe impairments overall. A previous study recorded the average speed and distance of WB and WR players using miniaturized data loggers. WB players were reported to have a slightly higher average speed than WR players (1.48 vs 1.33 m/s).[22] Furthermore, considering gender differences, it is speculated that male athletes are faster than female athletes. Although not a wheelchair sport, in soccer, male players covered more distance than female players during a match and at higher thresholds, at speeds of more than 15 km/h.[23] Faster wheelchair speeds are assumed to be associated with greater impacts at contact and a possibly more falls. In addition, contacted falls of MWB and WWB athletes were more. Although most falls were contacted falls in WR, 14.5% were non-contact falls. It is possible that the difference between these game rules influenced the contact with another athlete at the time of fall. Differences in speed may also affect the different fall frequencies.

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 second half, WWB had a slightly

higher fall frequency in the first half (54%), while WR and MWB players had higher fall frequency in the second half (56% and 63%, respectively). Firstly, the gender differences have to be considered while analysing the differences in playing time between MWB and WWB. No study has compared the physical activity during a wheelchair basketball game between men and women. However, female soccer players lost their energies at a medium intensity of 12-18 km/h in the second half, in contrast to that of men who had no changes between two halves.[23] Hence, gender differences can possibly affect the level of fatigue during a competition. Considering that the decrease of activity in WWB players, we ascertained that this may be have reduced the falls in the second half. Nevertheless, WR and MWB showed the same tendency of falling frequency for each playing time, and this was because WR had only two female players. Reports suggest that the wheelchair velocity does not change in the first half and the second half of WR.[24] Physical and mental fatigue definitely affect sports performance.[25] 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. It was considered to be the cause of many falls in the second half of WR and MWB.

When considering falls of wheelchair athletes, it is necessary to focus on the differences in impairment level, wheelchair structure, wheelchair sprint and agility, and classification category for each player.[26, 27] In addition, based on our results of the relationship between the fall direction and body part first impacted with floor, wheelchair athletes are mostly grounded from their hands when they fall forward. On the other hand, there was a lot of grounding from the elbows and shoulders when falling to the side, and from the back when falling backwards. These lateral and backward falls are less frequent but may be more at risk of injuries. 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

made first floor contact with the hand, while first contact in WR falls was not only on the hand but also the elbow or other body parts. To be eligible for Paralympics, WR players must have an impairment that affects both the arms and the legs, such as spinal cord injury (C5-7), or bilateral upper- and lower-extremity limb loss.[13] Their impairment is asymmetrical, which results in falling to the high-level paralyzed side or defect side or fall over using residual function. On the other hand, WB players have milder impairment than WR players, and in most cases, there is no impairment of the upper limbs. Therefore, it is considered that MWB and WWB athletes more frequently use their hands to catch themselves when falling.

From the result of body part first impacted with floor, there were no cases of contact from the head and no head injuries. On the other hand, a survey to estimate the incidence of concussions in WB revealed that 6.1% of athletes experienced a concussion in just one season.[28] Therefore, head injuries cannot be identified with video. 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 Rio 2016 Paralympic Games.[4] Webborn et al. noted that the understanding and guidelines regarding assessment, management and prevention of concussion in Para athletes is lacking.[7] Analysis of immediate head injuries during team sports competitions, such as rugby on able-bodied persons may provide conclusive evidence for injury prevention..[29] Using these as examples, it is necessary to work on maintaining athlete health in disabled sports.

This study has some limitations. Firstly, it was not possible to analyse falls not officially recorded, because we analysed only the official IPC videos and report on the Internet. Even then, most of the falls, including the ones for which would interrupt the videos, could be analysed from these official videos. Secondly, we analysed the games of the Top 8 teams of MWB and WWB in order to unify the number of teams, players, and competition level with WR. The analysis of the 30 qualifying games excluded this time may be able to

present the characteristics of WB falls. Thirdly, we have not been able to confirm the occurrence of injury during the Games. Thus, whether injury actually occurred due to these falls was unclear. However, we expect this study to increase attention and research on Paralympic sports injuries. Further investigation is needed to clarify the differences in fall-related injuries in WR and WB athletes.

CONCLUSION

This study characterized falls of team wheelchair sports athletes participating in the Rio 2016 Summer Paralympic Games and compared these characteristics between the three main wheelchair team-sport with video analysis. The characteristics of wheelchair team sports were revealed, and the differences between sports in terms of playing time, contact or not, direction, and body part contact with floor also clarified. To understand the mechanisms of injury caused by wheelchair athletes falling, further research is needed to 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 analysis and interpretation of data, and assisted in the preparation of the manuscript. RS and 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.

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Competing interests

None declared.

Ethics approval

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

Provenance and peer review

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Data availability statement

All data generated or analysed during this study are included in this published article.

Patient consent for publication

Not required.

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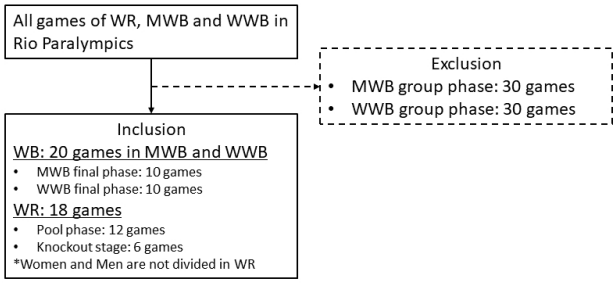
FIGURE LEGENDS

Fig. 1

Inclusion and exclusion criteria of match videos



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

	Item No	Recommendation
Title and abstract	✓ 1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	✓ 2	Explain the scientific background and rationale for the investigation being reported
Objectives	✓ 3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	✓ 4	Present key elements of study design early in the paper
Setting	✓ 5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	✓ 6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	✓ 7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
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
Bias	✓ 9	Describe any efforts to address potential sources of bias
Study size	✓ 10	Explain how the study size was arrived at
Quantitative variables	✓ 11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	✓ 12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
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
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	✓ 14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	✓ 15*	Report numbers of outcome events or summary measures
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
		(*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

Discussion		
Key results	✓ 18	Summarise key results with reference to study objectives
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
Interpretation	✓ 20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	✓ 21	Discuss the generalisability (external validity) of the study results
Other information		
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

*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.

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Sasadai Junpei

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

Junpei Sasadai, RPT, PhD; Noriaki Maeda, RPT, PhD; Reia Shimizu, RPT; Takumi Kobayashi, RPT; Shogo Sakai, RPT, MSc; Makoto Komiya, RPT, MSc; Yukio Urabe, RPT, PhD

Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan

Correspondence to: Junpei Sasadai, RPT, PhD

Institution: Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University

Address: 1-2-3 Kasumi, Minami-ku, Hiroshima, Hiroshima 734-8553, Japan

Telephone: +8182-257-5406

Fax: +8182-257-5344

E-mail: j-sasadai@hiroshima-u.ac.jp

ORCID

https://orcid.org/0000-0001-6134-4577

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, direction of the fall, and the body part first in contact with the floor during the fall.

RESULTS: A total of 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 3 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 ($p<0.001$). During WR, the falls were primarily lateral and caused by contact, and occurred in the second half of the match. WB falls tended to be in the first half for women and in 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.

KEYWORDS: Paralympic Games, sports injuries, falls, impaired athletes, wheelchair, traumatic injuries.

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, focusing 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 4,400 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 even include 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]

Although, wits increasing competition levels, preventing sports injuries should be prioritised. 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 of 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 are a 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 characterized 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 sports injuries including of 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 another

medical emergency. Therefore, careful attention would be needed to understand the cause 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 PyeongChang 2018 Paralympic Winter Games compared to that in the Sochi 2014 Paralympic Winter Games.[9] However, these studies did not describe the causes of sports injuries or their prevention methods.

Games Videos is an effective method to characterise the 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] Both these indoor wheelchair team sports 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.[13]

WR athletes are classified based on their functionality of hands, arms, shoulders, and trunk, with 7 player classifications from 0.5 to 3.5 according to decreasing impairment levels.[14] WB players must have a permanent physical disability associated with reduced lower limb functionality, including paraplegia, musculoskeletal conditions, spina bifida, amputation and poliomyelitis.[13] These athletes and are assigned classifications from 1.0 (least physical function) to 4.5 (most physical function).[15]

Since WR and WB are team sports, collisions between wheelchairs and falls from wheelchairs occur frequently during the Games. Moreover, these two sports together have high incidence rate of acute injuries, which accounted for 70% of the total injuries in WB and WR.[6] Wheelchair users with traumatic spinal cord injuries are most prone to falls while playing wheelchair sports, with injuries occurring once every four times.[16] Hollander et al. reported that 9 out of 100 injuries, which occurred during the WB World Championships 2018 were traumatic injuries due to falls.[17] In this study, gender differences were compared, and the 8 out of 42 injuries report in women were caused by falls. 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 own 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, by 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 the 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 8 teams participating in WR, and the 8 MWB and WWB teams that entered the quarterfinals of the Rio 2016 Paralympic Games. A total of 18 WR and 10 WB game videos for men's (MWB) and women's (WWB) including 8 teams per sport, were obtained from the official IPC website of the Rio 2016 Paralympic Games (Figure 1). WR is played in 4 periods of 8 minutes, whereas, in WB, the game consists of 4 quarters of 10 minutes each. Three physical therapists familiar with para-sports 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. Standardized 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, body part making first in contact with the floor (Table 1). Floor contact was deemed necessary for recording every fall.

Table 1.

Variables and categories used in the video analysis for the 3 physical therapists.

Variable	Category
1. Playing time	First quarter; Second quarter; Third quarter; Fourth quarter; Over Time (OT)
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 (ex. hand and elbow) Definition: The part of the body that first touched the floor or another player by the fall

Data of 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).

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)

Statistical analysis

For all categorical variables, we reported the results for which 2 of the 3 observers agreed in their assessments and were consistent. Because 2 or more agreements were consistent for all categorizations and the kappa coefficients were greater than 0.8, it was concluded as good to very good agreement between the 3 observers for all variables. Data were analysed for significant differences using the JMP® Pro 14.0.0 (SAS Institute Inc, Cary, NC USA). A one-way ANOVA was used for comparing the mean incidence rate of falls per match among the 3 wheelchair sports. When appropriate, follow-up analyses were performed using Bonferroni post-hoc tests. Pearson's Chi-square test or Fisher's exact test was used for comparing categorical variables. Fisher's Exact Test was used as an alternative to a Chi-square 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.

Ethics approval

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

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 3 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).

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)	
Over time	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)	

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)	

DISCUSSION

According to our results, there was a high probability of falling in WB, especially MWB, compared to 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, 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 sport 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 second half, WWB had a slightly higher fall frequency in the first half (54%), while WR and MWB players had higher fall frequency in the second half (56% and 63%, respectively).

Firstly, the gender differences have to be considered while analysing the differences in the playing time between MWB and WWB. The differences in the 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 12-18 km/h in the second half, in contrast to that of men who had no changes between two halves.[18] Hence, gender differences can possibly affect the fatigue levels during sports competitions. Considering that there is a decrease of activity in WWB players, we ascertained that this may be 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 the 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.[18] Reports suggest that the wheelchair velocity does not change in the first half and the second half of WR.[19] Moreover, physical and mental fatigue definitely affects sports performance.[20] 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 of 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 miniaturized 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).[21] Faster wheelchair speeds are assumed to be associated with greater impact while contacting with another player or when contacted with 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,

contacted falls of MWB and WWB athletes were more in number. Although, in WR, most falls were contacted 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.[22] 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.[23, 24] In addition, based on our results of the relationship between the fall direction and body part first impacted with the floor, wheelchair athletes may attempt 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 backwards. These lateral and backward falls are less frequent but may be more at risk of injuries. 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 from falling, while in WR falls the first contacted body parts with the floor were the hand or the elbow, or other body parts.

Few web-based large epidemiological studies concerning injury characteristics in summer and winter Paralympic Games were conducted twice each year.[4, 5, 6, 25] The first large prospective epidemiological study on injuries in impaired athletes was reported following the London 2012 Summer Paralympic Games that expressed injury rates and injury proportions per 1000 athlete days. [6] In this study, 633 injuries were incurred by 539 athletes during the 14-day event at the incidence rate of 12.7 injuries/1000 athlete days. In addition, more detailed studies on sports report high mean injury incidence rates such as 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).[26,27,28] These investigations coupled with the understanding of the current situation of injuries in sports for impaired athletes led to a slightly decreased injury incidence rate in the Rio 2016 Paralympics (10.0 injuries/1000 athlete days),[4] and improved the injury rates during the Alpine skiing at the 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 at 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 (C5-7), or bilateral upper- and lower-extremity limb loss.[14] Their impairment is asymmetrical, which results in falling to the high-level paralyzed side or defect side or falling over using 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 that MWB and WWB athletes use their hands more frequently to resist falling.

From the data of the body part first impacted with the floor, there were no cases of contact from the head and no head injuries. On the other hand, a survey was conducted earlier to estimate the incidence of concussions in WB, which revealed that 6.1% of WB athletes experienced a concussion in just one season.[29] However, head injuries cannot be identified in the 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 Rio 2016 Paralympic Games.[4] Webborn et al. noted that there is 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..[30] 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. Firstly, 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. Secondly, we analysed the games of the Top 8 teams of MWB and WWB in order 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 future. Thirdly, we have not been able to confirm the occurrence of injury during the Games. Thus, whether injury actually occurred due to these falls was unclear. However, we expect this study to increase the attention and research 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 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 attributable to 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 falling among wheelchair athletes and to 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 analysis and interpretation of data, and assisted in the preparation of the manuscript. RS and 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.

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Competing interests

None declared.

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 generated or analysed during this study are included in this published article.

Patient consent for publication

Not required.

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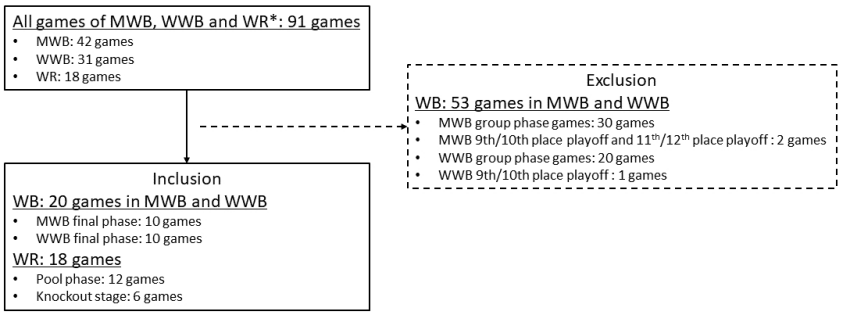
FIGURE LEGENDS

Fig. 1

Inclusion and exclusion criteria of match videos

*Because WR is a mixed sport, Women and Men are not divided



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

	Item No	Recommendation
Title and abstract	✓ 1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	✓ 2	Explain the scientific background and rationale for the investigation being reported
Objectives	✓ 3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	✓ 4	Present key elements of study design early in the paper
Setting	✓ 5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	✓ 6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	✓ 7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
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
Bias	✓ 9	Describe any efforts to address potential sources of bias
Study size	✓ 10	Explain how the study size was arrived at
Quantitative variables	✓ 11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	✓ 12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
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
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	✓ 14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	✓ 15*	Report numbers of outcome events or summary measures
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
		(*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

Discussion		
Key results	✓ 18	Summarise key results with reference to study objectives
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
Interpretation	✓ 20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	✓ 21	Discuss the generalisability (external validity) of the study results
Other information		
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

*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.

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Sasadai Junpei

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

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

Junpei Sasadai, RPT, PhD; Noriaki Maeda, RPT, PhD; Reia Shimizu, RPT; Takumi Kobayashi, RPT; Shogo Sakai, RPT, MSc; Makoto Komiya, RPT, MSc; Yukio Urabe, RPT, PhD

Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan

Correspondence to: Junpei Sasadai, RPT, PhD

Institution: Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University

Address: 1-2-3 Kasumi, Minami-ku, Hiroshima, Hiroshima 734-8553, Japan

Telephone: +8182-257-5406

Fax: +8182-257-5344

E-mail: j-sasadai@hiroshima-u.ac.jp

ORCID

https://orcid.org/0000-0001-6134-4577

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 3 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.

KEYWORDS: Paralympic Games, sports injuries, falls, impaired athletes, wheelchair, traumatic injuries.

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, focusing 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 4,400 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 characterized 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 PyeongChang 2018 Paralympic Winter Games compared to that in the Sochi 2014 Paralympic Winter Games.[9] However, these studies did not describe the causes of sports injuries or available their prevention methods.

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 7 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 and 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 8 teams participating in WR, and the 8 MWB and WWB teams that entered the quarterfinals of the Rio 2016 Paralympic Games. A total of 18 WR and 10 WB game videos for men's (MWB) and women's (WWB) including 8 teams per sport, were obtained from the official IPC website of the Rio 2016 Paralympic Games (Figure 1). WR is played in 4 periods of 8 minutes, whereas, in WB, the game consists of 4 quarters of 10 minutes each. Three physical therapists familiar with para-sports 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. Standardized 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.

Table 1.

Variables and categories used in the video analysis for the 3 physical therapists.

Variable	Category
1. Playing time	First quarter; Second quarter; Third quarter; Fourth quarter; Over Time (OT)
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 (ex. hand and elbow) Definition: The part of the body that first touched the floor or another player by the fall

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).

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)

Statistical analysis

For all categorical variables, we reported the results for which 2 of the 3 observers agreed in their assessments and were consistent. Because 2 or more agreements were consistent for all categorizations and the kappa coefficients were greater than 0.8, good to very good agreement between the 3 observers for all variables was concluded. Data were analysed for significant differences using the JMP® Pro 14.0.0 (SAS Institute Inc, Cary, NC USA). A one-way ANOVA was used for comparing the mean incidence rate of falls per match among the 3 wheelchair sports. When appropriate, follow-up analyses were performed using Bonferroni post-hoc tests. Pearson's Chi-square test or Fisher's exact test was used for comparing categorical variables. Fisher's Exact Test was used as an alternative to a Chi-square 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.

Ethics approval

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

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 3 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).

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)	
Over time	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)	

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)	

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).

Firstly, 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 12-18 km/h 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 miniaturized 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).[20] 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.[21] 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.[22, 23] 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 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, 24] 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).[25-27] These investigations coupled with the understanding of the current situation of injuries in sports for impaired athletes led to a slightly decreased injury incidence rate in the Rio 2016 Paralympics (10.0 injuries/1000 athlete days),[4] and improved the injury rates during the Alpine skiing at the 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 (C5-7), or bilateral upper- and lower-extremity limb loss.[13] Their impairment is asymmetrical, which results in falling to the high-level paralyzed 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 to 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.[28] 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 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.[29] 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 8 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 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.

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Competing interests

None declared.

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 generated or analysed during this study are included in this published article.

Patient consent for publication

Not required.

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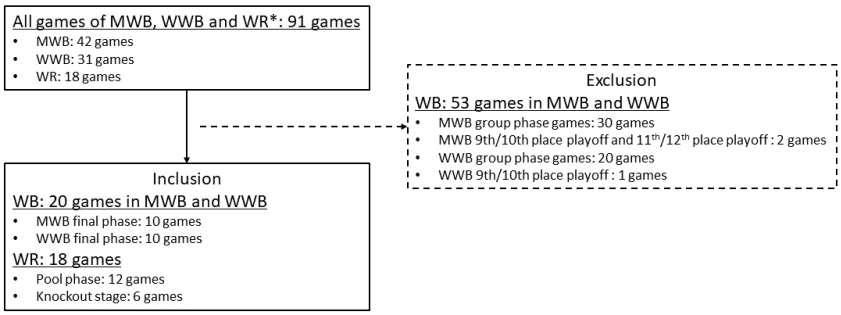
FIGURE LEGENDS

Figure. 1

Inclusion and exclusion criteria of match videos

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



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

	Item No	Recommendation	page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	7 & Fig1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
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	7-9
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	n/a
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9
		(*b*) Describe any methods used to examine subgroups and interactions	n/a
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	n/a
Results			
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	7-9 & Fig1
		(b) Give reasons for non-participation at each stage	Fig1
		(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	9
		(b) Indicate number of participants with missing data for each variable of interest	10 & Tab1,2
Outcome data	15*	Report numbers of outcome events or summary measures	10
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	n/a

		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10 & Tab2
Discussion			
Key results	18	Summarise key results with reference to study objectives	12-16
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	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	3, 16-17
Other information			
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	17

*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.