Injury incidence according to athlete impairment type during the 2012 and 2016 Summer Paralympic Games: A combined analysis of 101 108 athlete days

Authors: Faatima Adam [1], Wayne Derman [1,2], Martin Schwellnus [2,3], Pieter Boer [4], Esme Jordaan [5], Phoebe Runciman [1]

[1] Institute of Sport and Exercise Medicine (ISEM), Department of Exercise, Sport and Lifestyle Medicine, Faculty of Medicine and Health Sciences, Stellenbosch University (Cape Town, South Africa)
[2] International Olympic Committee (IOC) Research Centre (South Africa)
[3] Sport, Exercise Medicine, and Lifestyle Institute (SEMLI), Faculty of Health Sciences, University of Pretoria (Pretoria, South Africa)
[4] Department of Human Movement Science, Cape Peninsula University of Technology (Cape Town, South Africa)
[5] Biostatistics unit, Medical Research Council, Cape Town, South Africa

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Address for correspondence:
Dr Phoebe Runciman
Institute of Sport and Exercise Medicine (ISEM), Department of Exercise, Sport, and Lifestyle Medicine
Faculty of Medicine and Health Sciences
Stellenbosch University
Email: para@sun.ac.za

ABSTRACT

Objectives: The relationship between sport-related injuries and Para athlete impairment type has not yet been comprehensively studied. This study aimed to describe injury incidence according to athlete impairment type during the London 2012 and Rio 2016 Summer Paralympic Games (S-PGs), by sex, age, Games period, chronicity, and anatomical area.

Methods: Combined analysis of 7222 athletes were conducted comprising 101 108 athlete days, using pooled data. Internet sources were used to identify impairments of registered athletes. Impairment types: brain disorders (BD), limb deficiency (LD), neuromuscular disorders (NMD), spinal cord-related disorders (SCRD), visual impairment (VI), and 'all others' (OTH: impaired passive range of movement (IPROM), intellectual impairment (II), leg length difference (LLD), short stature (SS), and unknown impairments). Results by impairment type are reported as univariate unadjusted incidences (injuries/1000 athlete days; 95%CIs). Statistical significance between impairment types was determined when 95%CIs did not overlap.

Results: The overall crude unadjusted incidence of injury was 11.1 (95%CI 10.4-11.9), significantly higher in VI (13.7 (11.0-15.7)) and NMD (13.3 (11.1-16.1)) compared with BD (9.1 (7.7-10.8)). Acute (sudden onset) (8.6 (7.3-10.1)) and lower limb (6.6 (5.4-8.1)) injuries were higher amongst athletes with VI, while athletes with NMD had a higher incidence of repetitive (gradual onset) (5.9 (4.3-8.0)) and upper limb (6.9 (5.2-9.0)) injuries compared to other impairments.

Conclusions: Incidence and type of injuries differed between Para athlete impairment types. Athletes with VI or NMD sustained the highest incidence of injury, and athletes with BD the lowest. Findings of this study can inform the management of competition-related injuries in Para athletes.

What is already known on the topic?

- The profiles of sport-related injuries have been studied in the Para sport population, in and out of competition. However, impairment-related injury risk factors remain understudied.
- During the Summer Paralympic Games, high incidence rates have been reported during precompetition periods, for acute (sudden onset) injuries and during sports such as football-5-a-side, and judo, which are contested mainly by athletes with VI.

What this study adds?

- The incidence of injury in Para athletes participating at the 2012 and 2016 Summer Paralympic Games differs by Para athlete impairment type.
- Para athletes with VI or NMD had the highest injury incidence, and athletes with BD the lowest incidence, of all impairment types.

- This study informs clinicians of the differences in injury incidence by impairment types for better medical management of competition-related injuries in Para athletes.

How this study might affect research, practice or policy?

- This study has implications for injury management practices as it provides knowledge of the susceptibility to injury, type, and area of injury for Para athletes with different impairment types.
- This study informs the next steps in injury surveillance and prevention programs in Para sport. Future studies should investigate the impact of sport characteristics on injury incidence by impairment type.

INTRODUCTION

Injury and illness surveillance in Para sport has become an increasingly important part of Para athlete medical management and informs important injury prevention strategies in this population.[1–3] Whilst the incidence of sport-related injuries have been studied, impairment-related injury risk factors remain understudied and are needed, given the impact impairment may have on injury susceptibility.[2,4–8]

The ongoing Paralympic Injury & Illness Surveillance Studies have reported incidence and proportion of injury by age, sex, Games period, sport, chronicity, and anatomical area during the Paralympic Games.[4–6] During the Summer Paralympic Games (S-PGs), these studies reported overall incidence/1000 athlete days of 12.7 (95%CI 11.7-13.7) during the London 2012 S-PGs and 10.0 (95%CI 9.1-10.9) during the Rio 2016 S-PGs.[4–6] The incidence of injury was higher during the precompetition periods, in older athletes (26-35+), for acute (sudden onset) and in the shoulder joint.[4–6] However, the incidence of injury by impairment type could not be calculated as the impairment of uninjured Para athletes competing at the same Games (denominator) was not available. Thus, the effect of a Para athlete's impairment type on each injury factor, and associated incidence of injury, has not yet been reported in these large-scale studies.[4–6,9]

The few published studies that have reported injuries by impairment type show high injury incidence for Para athletes with visual impairment (VI) and limb deficiency (LD) and lower injury incidence for Para athletes with cerebral palsy (CP) and intellectual impairment (II).[10–17] However, these studies were limited by the inclusion of Para athletes from single nationality cohorts or sporting codes. The recent International Olympic Committee (IOC) consensus statements on injury and illness reporting in Para sport have provided guidelines to overcome previous methodological limitations, including recommendations on categorising impairment types.[2,3]

The aim of this study was to describe the injuries sustained by Para athletes during the London 2012 and Rio 2016 S-PGs per athlete impairment type by sex, age, Games period, chronicity, and anatomical area. The underlying impairment type of each Para athlete requires an impairment-specific approach in order to successfully manage injuries, therefore findings of this study can be used to inform injury management for specific athlete groups.[9,18]

METHODS

The current study was a secondary analysis of the ongoing Paralympic Injury and Illness Surveillance Studies conducted during the 3-day precompetition and 11-day competition period of the London 2012 and Rio 2016 S-PGs. The methodologies were consistent for both S-PGs, making a combined data analysis possible. Detailed procedures of the methodology used for these prospective studies can be found in previous literature.[5,6] For the merged analysis, 96.7% of injury data were extracted from the web-based injury and illness surveillance system (WEB-IISS), while 3.3% were extracted from the electronic medical data capture system (EMDCS) used by the local polyclinic during the London 2012 S-PGS. No data entries from the EMDCS were received from Rio 2016 S-PGS for analysis. Datasheets were extracted for the 2012 and 2016 S-PGs and each Games' datasheet underwent cleaning before being merged, accounting for athletes who participated at both Games.

Definition of Games period and injury

Games Period: In this study, Games period comprised a 3-day precompetition period when athletes are at the event venue prior to competing, as well as an 11-day competition period, in which athletes actively compete.[5,6]

This study adhered to the operational definitions recommended by Derman *et al.,* (2021) and Bahr *et al.,* (2020): (1) *Injuries:* "Damage to tissue or the derangement of natural physical function resultant of sports involvement and the rapid and repetitive transfer of kinetic energy." (2) *Acute (sudden onset)*: "An injury caused by a sudden event." (3) *Repetitive (gradual onset): "*An injury that develops over days or weeks without an acute precipitating mechanism." (4) *Repetitive (sudden onset) :* "An acute injury (sudden onset) that occurs in athletes presenting with symptoms of a previous repetitive injury (gradual onset) in the same anatomical site".[2,3]

Impairment categories

During the London 2012 and Rio 2016 S-PGs, impairment data of all the athletes participating at the Games were not available. In order to conduct this impairment-specific study, authors collected information of all competing Para athletes' impairment types via open-source internet sites (IPC website (approximately 80% of information sourced), Wikipedia, social media). These sources were searched for the primary medical pathology (impairment type) of all athletes. Impairment types sourced were given a referenced hyperlink, reviewed, and validated by three of the six authors (FA, PR, WD) of this study.

The IOC epidemiology consensus statement for Para sport suggested reporting injuries and illnesses by nine impairment types.[2,3] In this study, statistical power was reduced for certain impairment types with low numbers, and Para athletes were grouped according to six impairment types. These included: brain disorders (BD), limb deficiency (LD), neuromuscular disorders (NMD), spinal cord-related disorders (SCRD), visual impairment (VI)), and all other (OTH). The OTH category included impaired passive range of movement (IPROM), intellectual impairment (II), leg length difference (LLD), short stature (SS), and unknown impairments which included athletes whose impairment could not be sourced (Table 1). Data for OTH category

have been shown for descriptive purposes in table 1, results for these individual impairment types have not been reported individually for other outcome tables due to low statistical power.

Table 1: Impairment type and definitions as presented in IOC consensus statement on reporting injury and illness in sport [2,3]

Impairment type	Definition	Example of medical conditions associated with the impairment group
Brain Disorders (BD)	Congenital and acquired brain injuries and cerebrovascular accidents that cause decreased muscle power, ataxia, hypertonia and athetosis.[2]	Perinatal and infant cerebral palsy (CP), Traumatic brain injury (TBI), Multiple sclerosis (MS) or Stroke.
Limb Deficiency (LD)	Total or partial absence of bones or joints as a result of an amputation, illness or congenital dysmelia.[24]	Lower limb (LL) or upper limb (UL) amputations.
Neuromuscular Disorders (NMD)	Stable and progressive neuromuscular disorders that cause impaired muscle power.[2]	Post-polio syndrome (PPS), peripheral nerve injury (Brachial plexus injury, ERB palsy), motor neuron disease, myopathy, muscular dystrophy (MD).
Spinal cord-related disorders (SCRD)	Complete or incomplete lesions that result in Tetraplegia or Paraplegia.[24]	Paraparesis, spinal bifida, para-tetraplegia.[2]
Visual Impairment (VI)	Reduced, or no vision caused by damage to the eye, visual pathways, or cortex of the brain.[24]	Retinopathy or Retinitis related conditions.
ALL OTHER (OTH)		
Impaired Passive Range of Movement (IPROM)	Restriction or lack of passive joint movement in one or more joint.[24]	Talipes equinovarus (Club foot), Ehlers–Danlos syndromes, Arthrogryposis.
Intellectual Impairment (II)	Restriction in intellectual and adaptive behaviour-present before the age of 18.[24]	Autism, Asperger syndrome, Fragile X and Down syndromes.
Leg Length Difference (LLD)	Difference in the length of an individual's legs as a result of a disturbance of limb growth, or trauma.[24]	Congenital deformities, post-polio deformities, joint dysplasia, fractures.

Short Stature (SS)	Reduced length in the bones of the upper limbs (UL), lower limbs (LL) and/or mid-thoracic area.[24]	Osteogenesis imperfecta, Achondroplasia, Growth hormone dysfunction.
Unknown Impairment	Medical conditions of athletes that could not be clearly grouped.	Congenital limb deformities, bone tumours, Garre's sclerosing, osteomyelitis.

Calculation of athlete days

The total athlete days were calculated as follows: total team days (Pre and competition period) × daily team size. Athlete days of each Games period were summed to get the total (101 108) athlete days. These data were used as denominator data for the calculation of injury incidence, expressed as the number of injuries per 1000 athlete days.

Calculation of injury incidence and proportion

Injury incidence was calculated as injuries per 1000 athlete days. The proportion of athletes with an injury was calculated as: number of athletes with an injury/the total number of athletes in the relevant subgroup multiplied by 100.[5,6]

Statistical analysis of the data

Upon completion of impairment data integration, data were delinked from personal information. Data were analysed according to (1) age (12–25 years, 26–34 years and 35+ years), (2) sex (male or female), (3) Games period (pre- vs. competition), (4) chronicity (acute, repetitive, or gradual), and (5) anatomical area (head, face and neck (HFN), upper limb (UL), mid-thoracic or lower limb (LL)). Standard descriptive analyses were reported for all established data outcomes per impairment type as: number of reported injuries, and proportion of athletes with an injury. Results by impairment type are reported as incidences per 1000 athlete days including 95% confidence intervals (CIs) for all outcomes. The number of athletes by sport and impairment type participating at the 2012 and 2016 S-PGs are shown in supplement 1. Results by sport and impairment type have only been reported for athlete impairment types with the highest incidence per sport due to low statistical power when modelling for some sports and all impairment types (supplement 2). If athletes sustained multiple injuries during the Games period, each injury was counted as a distinct injury encounter. Additionally, for athletes who participated in both Games, we included a repeated statement to account for the correlated nature of the data, using an exchangeable correlation structure. All athletes' data were analysed using SAS statistical software (version 9.4, Cary NC). The Poisson distribution with the procedure generalised linear model statement and an associated log link option were used for analysis. Univariate unadjusted incidence (% and 95% confidence interval (CIs)) were reported for all mentioned outcomes. Type 3 Generalised Estimating Equation (GEE) analysis were reported for comparisons between impairment types for each risk factor, and estimates were reported for the univariate unadjusted incidence (95% CIs) for impairment types, and impairment types by sex, age groups, Games period, chronicity, and anatomical area. The statistical analysis

and presentation are consistent with the Checklist for statistical Assessment of Medical Papers (CHAMP statement).[19]

RESULTS

Participants

This study is a merged analysis of injury data collected from 3565 Para athletes during the London 2012 S-PGs and 3657 Para athletes from the Rio 2016 S-PGs, totalling 7222 Para athletes and representing 84.3% of the total number of Para athletes over both Games (8565 athletes). The combined study population comprised 63.9% male and 36.1% female athletes, with most athletes between the ages of 26-34 years (36.6%; median 30 years).

Overall incidence of injury by impairment type

Table 2 shows the injuries sustained by Para athletes of all impairment types competing during the London 2012 and Rio 2016 S-PGs. A total of 1143 injuries were recorded in 980 athletes, representing 13.6% of all Para athletes (incidence 11.1 (95%CI 10.4-11.9/1000 athlete days)). The incidence of injury was significantly higher in athletes with VI (13.7 (95%CI 11.0-15.7)) and NMD (13.3 (95%CI 11.1-16.1)) compared with BD (9.1 (95%CI 7.7-10.8)). In the OTH category, athletes with SS had the highest incidence of 13.3 (95%CI 8.1-21.8), followed by athletes with IPROM (11.2 (95%CI 8.4-14.3)) and athletes with LLD (10 (95%CI 5.7-17.4)).

Table 2: Injuries sustained by athletes during the London 2012 and Rio 2016 Summer Paralympic Games by impairment type

Impairment type	Total number of injuries (percentage of total number of injuries)	Number of athletes with an injury	Total number of athletes competing	Total number of athlete days	Proportion of athletes with an injury	Injury incidence: number of injuries/1000 athlete days (95% CI)
All	1143 (100%)	980	7222	101108	13.6	11.1 (10.4-11.9)
VI	258 (22.6%)	205	1347	18858	15.2	13.7 (11.0-15.7) *
NMD	113 (9.9%)	102	604	8456	16.9	13.3 (11.1-16.1) *
SCRD	251 (22.0%)	211	1607	22498	13.1	11.1 (9.7-12.8)
LD	190 (16.6%)	171	1243	17402	13.8	10.9 (9.3-12.7)
OTH **	182 (15.9%)	160	1256	17584	12.7	10.3 (8.8-12.0)
BD	149 (13.0%)	131	1165	16310	11.2	9.1 (7.7-10.8)
OTH CATERGORY **						
Due to low numbers, the following impairment categories were combined for analysis						
SS	25 (2.2%)	20	132	1848	15.1	13.3 (8.1-21.8)
IPROM	57 (5.0%)	53	367	5138	14.4	11.2 (8.4-14.3)
LLD	11 (1.0%)	10	76	1064	13.2	10.0 (5.7-17.4)
II	30 (2.6%)	22	226	3164	9.7	9.4 (5.9-14.9)
UNKNOWN	59 (5.2%)	55	455	6370	12.1	9.7 (7.5-12.7)
SUBTOTAL	182 (15.9%)	160	1256	17584	12.7	10.3 (8.8-12.0)

*Significantly higher than athletes with BD.

** OTH is a combined category of athletes with SS, IMPROM, LLD, II and unknown impairment types.

Abbreviations: CI=confidence intervals, VI=visual impairment, NMD=neuromuscular disorders, SCRD=spinal cord-related disorders, LD=limb deficiency, OTH=all others, BD=brain disorders, SS=short stature, IMPROM=impaired passive range of movement, LLD=leg length difference, II=intellectual impairment.

Incidence of injury in impairment types by sex, and age group

Incidence of injury in impairment types by sex and age group (12–25, 26–34, 35+ years) are presented in table 3. Overall, female, and male athletes had similar rates of injury, while athletes 26 years+ showed slightly higher rates than athletes below 26 years. The incidence of injury in females was significantly lower in athletes with BD (7.6 (95%CI 5.5-10.5)) compared with NMD (14.7 (95%CI 10.8-19.9)). For males, the incidence of injury was significantly lower for athletes with BD (9.9 (95%CI 8.09-12.1)) and OTH (9.2 (95%CI 7.4-11.3)) compared with VI (14.8 (95%CI 12.5-17.5)). The incidence of injury by impairment types within age groups showed no significant difference.

Table 3: Injuries sustained by athletes during the London 2012 and Rio 2016 Summer Paralympic Games by impairment type, sex, and age group

Sex/age	Impairment type	Total number of injuries (percentage of total number of injuries)	Number of athletes with an injury	Total number of athletes competing	Total number of athlete days	Proportion of athletes with an injury	Injury incidence: number of injuries/1000 athlete days (95%CI)
	ALL	1143 (100%)	980	7222	101 108	13.6	11.1 (10.4-11.9)
FEMALE	**NMD**	47 (4.1%)	42	226	3164	18.6	14.7 (10.8-19.9)
	OTH	87 (7.6%)	74	518	7252	14.3	11.9 (9.3-15.0)
	VI	83 (7.3%)	67	503	7042	13.3	11.7 (9.1-15.0)
	SCRD	84 (7.3%)	71	557	7798	12.8	10.9 (8.6-13.7)
	LD	63 (5.5%)	57	427	5978	13.3	10.5 (8.1-13.6)
	BD	40 (3.5%)	36	376	5264	9.6	7.6 (5.5-10.5) *
	TOTAL	404 (35.3%)	347	2607	36 498	13.3	11.03 (9.9-12.3)
MALE	**VI**	175 (15.3%)	138	844	11816	16.4	14.8 (12.5-17.5))
	NMD	66 (5.8%)	60	378	5292	15.9	12.5 (9.7-16.0)
	SCRD	167 (14.6%)	140	1050	14700	13.3	11.3 (9.5-13.5)
	LD	127 (11.1%)	114	816	11424	14.0	11.1 (9.2-13.4)
	BD	109 (9.5%)	95	789	11046	12.0	9.9 (8.09-12.1) ǂ
	OTH	95 (8.3%)	86	738	10332	11.7	9.2 (7.4-11.3) ǂ
	TOTAL	739 (64.7%)	633	4615	64 610	13.7	11.4 (10.5-12.3)
AGE 12-25	**NMD**	23 (2.0%)	21	124	1736	16.9	13.3 (8.7-20.2)
	VI	90 (7.9%)	69	510	7140	13.5	12.6 (9.9-16.1)
	OTH	62 (5.4%)	50	451	6314	11.1	9.7 (7.3-13.0)
	SCRD	22 (1.9%)	17	182	2548	9.3	8.8 (5.3-14.4)
	BD	56 (4.9%)	52	459	6426	11.3	8.7 (6.7-11.4)
	LD	47 (4.1%)	46	412	5782	11.2	8.1 (6.2-10.7)
	TOTAL	300 (26.2%)	255	2138	29 932	11.9	10.3 (8.9-11.4)

AGE 26-34	**VI**	111 (9.7%)	92	528	7392	17.4	14.9 (12.2-18.2)
	NMD	40 (3.5%)	34	208	2912	16.4	13.6 (9.8-18.9)
	SCRD	94 (8.2%)	81	560	7840	14.5	11.8 (9.4-14.9)
	OTH	68 (5.95%)	61	410	5740	14.9	11.8 (9.2-15.1)
	LD	69 (6.0%)	63	425	5950	14.8	11.4 (8.9-14.5)
	BD	64 (5.6%)	54	438	6132	12.3	10.4 (8.0-13.6)
	TOTAL	446 (39.0%)	385	2569	35 966	15.0	12.3 (11.1-13.6)
AGE 35+	**VI**	57 (5.0%)	44	309	4326	14.2	13.3 (9.9-17.9)
	LD	74 (6.5%)	62	406	5684	15.3	13.2 (10.3-16.8)
	NMD	50 (4.4%)	47	272	3808	17.3	13.1 (9.9-17.2)
	SCRD	135 (11.8%)	113	865	12110	13.1	11.2 (9.3-13.5)
	OTH	52 (4.5%)	49	395	5530	12.4	9.3 (7.0-12.3)
	BD	29 (2.5%)	25	268	3752	9.3	7.7 (5.2-11.3)
	TOTAL	397 (34.7%)	340	2515	35 210	13.5	11.3 (10.2-12.6)

*Significantly lower than females with NMD.

ǂ Significantly lower than males with VI.

Abbreviations: CI=confidence interval, NMD=neuromuscular disorders, OTH=all others, VI=visual impairment, SCRD=spinal cord-related disorders, LD=limb deficiency, BD=brain disorder.

Incidence of injury in impairment types by Games period

The precompetition period had a significantly higher total incidence of injury (13.8 (95%CI 12.2-15.5)) compared to the competition (10.6 (95%CI 9.9-11.4)) period (Table 4). There were no significant differences in the incidence of injury in impairment types during the precompetition period. In the competition period, there was a significantly lower overall incidence of injury in athletes with BD (9.1 (95%CI 7.5-11.0)) and OTH (8.8 (95%CI 7.3-10.7)) impairment types compared to VI (12.9 (95%CI 11.0-15.1)).

Table 4: Injuries sustained by athletes during the London 2012 and Rio 2016 Summer Paralympic Games by impairment type and Games period

Period	Impairment type	Total number of injuries (percentage of total number of injuries)	Number of athletes with an injury	Total number of athletes competing	Total number of athlete days	Proportion of athletes with an injury	Injury incidence: number of injuries/1000 athlete days (95%CI)
	ALL	**1143 (100%)**	**980**	**7222**	**101 108**	13.6	**11.1 (10.4-11.9)**
PRECOMPETITION PERIOD	**NMD**	32 (10.7%)	31	604	1812	5.1	17.6 (12.4-25.0)
	VI	67 (22.4%)	63	1347	4041	4.7	16.6 (12.8-21.3)
	OTH	59 (19.7%)	55	1256	3768	4.4	15.6 (12.0-20.3)
	LD	48 (16.0%)	47	1243	3729	3.8	12.9 (9.7-17.2)
	SCRD	60 (20.1%)	57	1607	4 821	3.5	12.4 (9.5-16.1)
	BD	33 (11.0%)	33	1165	3495	2.8	9.3 (6.6-13.2)
	TOTAL	**299 (26.2%)**	**286**	**7222**	**21 666**	4.0	**13.8 (12.2-15.5) ***
COMPETITION PERIOD	**VI**	191 (22.6%)	158	1347	14817	11.7	12.9 (11.0-15.1)
	NMD	81 (9.6%)	77	604	6644	12.7	12.2 (9.7-15.2)
	SCRD	191 (22.6%)	164	1607	17677	10.2	10.8 (9.2-12.7)
	LD	142 (16.8%)	132	1243	13673	10.6	10.4 (8.7-12.3)
	BD	116 (13.7%)	103	1165	12815	8.8	9.1 (7.5-11.0) ǂ
	OTH	123 (14.6%)	113	1256	13816	9.0	8.8 (7.3-10.7) ǂ
	TOTAL	**844 (73.8%)**	**747**	**7222**	**79 442**	10.3	**10.6 (9.9-11.4)**

* Significantly higher than competition period.

ǂ Significantly lower than athletes with VI during the competition period.

Abbreviations: CI=confidence interval, NMD=neuromuscular disorders, VI=visual impairment, OTH=all others, LD=limb deficiency, SCRD=spinal cord-related disorders, BD=brain disorders.

Incidence of injury in impairment types by chronicity

The overall incidence of acute (sudden onset) (5.8 (95%CI 5.4-6.4)) injuries were significantly higher, compared to repetitive (gradual onset) (3.7 (95%CI 3.3-4.1)) and repetitive (sudden onset) (1.7 (95%CI 1.5-2.0)) injuries, except for athletes with NMD, where repetitive (gradual onset) injuries had the highest incidence

(5.9 (95%CI 4.3-8.0)) compared to acute (sudden onset) injuries (4.8 (95%CI 3.5-6.6)). Athletes with VI had a significantly higher incidence of acute (sudden onset) injuries (8.6 (95%CI 7.3-10.1)) compared to all other impairment categories (Table 5).

Table 5: Injuries sustained by athletes during the London 2012 and Rio 2016 Summer Paralympic Games by impairment type and chronicity

Chronicity	Impairment type	Total number of injuries (percentage of total number of injuries)	Number of athletes with an injury	Total number of athletes competing	Total number of athlete days	Proportion of athletes with an injury	Injury incidence: number of injuries/1000 athlete days (95% CI)
	ALL	**1143 (100%)**	**980**	**7222**	**101 108**	13.6	**11.1 (10.4-11.9)**
ACUTE (SUDDEN ONSET)	**VI**	162 (14.2%)	141	1347	18858	10.5	8.6 (7.3-10.1) *
	SCRD	131 (11.5%)	118	1607	22498	7.3	5.8 (4.8-7.1)
	BD	85 (7.4%)	77	1165	16310	6.6	5.2 (4.2-6.6)
	LD	90 (7.8%)	87	1243	17402	7.0	5.2 (4.2-6.4)
	NMD	41 (3.6%)	39	604	8456	6.5	4.8 (3.5-6.6)
	OTH	81 (7.09%)	74	1256	17584	5.9	4.6 (3.6-5.8)
	TOTAL	**590 (51.6%)**	**536**	**7222**	**101 108**	7.4	**5.8 (5.4-6.4)** **
REPETITIVE (SUDDEN ONSET)	**NMD**	22 (1.9%)	19	604	8456	3.1	2.6 (1.6-4.1)
	VI	42 (3.7%)	37	1347	18858	2.7	2.2 (1.6-3.1)
	SCRD	41 (3.6%)	39	1607	22498	2.4	1.8 (1.3-2.5)
	LD	27 (2.4%)	26	1243	17402	2.1	1.6 (1.1-2.8)
	OTH	23 (2.01%)	23	1256	17584	1.8	1.3 (0.8-2.0)
	BD	21 (1.8%)	21	1165	16310	1.8	1.3 (0.8-2.0)
	TOTAL	**176 (15.4%)**	**165**	**7222**	**101 108**	2.3	**1.7 (1.5-2.0)**
REPETITIVE (GRADUAL ONSET)	**NMD**	50 (4.4%)	48	604	8456	7.9	5.9 (4.3-8.0)
	OTH	78 (6.8%)	73	1256	17584	5.8	4.4 (3.5-5.5)
	LD	73 (6.4%)	68	1243	17402	5.5	4.2 (3.3-5.3)
	SCRD	79 (6.9%)	74	1607	22498	4.6	3.5 (2.8-4.4)
	VI	54 (4.7%)	49	1347	18858	3.6	2.9 (2.3-3.9)
	BD	43 (3.8%)	42	1165	16310	3.6	2.6 (1.9-3.5)

TOTAL	**377 (33.0%)**	**354**	**7222**	**101 108**	4.9	**3.7 (3.3-4.1)**

***** Significantly higher than other impairment types for acute (sudden onset) injuries.

**** S**ignificantly higher than repetitive (gradual onset) and repetitive (sudden onset) injuries.

Abbreviations: CI=confidence interval, VI=visual impairment, SCRD=spinal cord-related disorders, BD=brain disorders, LD=limb deficiency, NMD=neuromuscular disorders, OTH=all others.

Incidence of injury in impairment types by anatomical area

The anatomical area with the highest incidence was the UL (4.3 (95%CI 3.8-4.7)) (Table 6). The highest incidence of UL injuries was seen in athletes with NMD (6.9 (95%CI 5.2-9.0)) and athletes with SCRD (6.2 (95%CI 5.1-7.4)) which were significantly higher compared to athletes with LD, VI and BD. LL injuries were significantly higher in athletes with VI (6.6 (95%CI 5.4-8.1)) compared to athletes of all other impairment types. Following athletes with VI, athletes with BD ranked second for incidence of injuries to the LL (3.8 (95%CI 3.0-4.9)). Athletes with SCRD had significantly lower incidence of LL injuries (1.2 (95%CI 0.8-1.8)) compared to athletes of all other impairment types, except athletes with NMD. There were no significant differences in impairment types for HFN and mid-thoracic injuries.

Table 6: Injuries sustained by athletes during the London 2012 and Rio 2016 Summer Paralympic Games by impairment type and anatomical area

Anatomical area	Impairment type	Total number of injuries (percentage of total number of injuries)	Number of athletes with an injury	Total number of athletes competing	Total number of athlete days	Proportion of athletes with an injury	Injury incidence: number of injuries/1000 athlete days (95% CI)
	ALL	**1042 (91.2%)**	**968**	**7222**	**101 108**	**13.4**	**9.6 (10.2-9.0)**
HEAD, FACE & NECK	NMD	13 (1.7%)	13	604	8456	2.2	1.6 (0.1-2.7)
	VI	23 (2.01%)	23	1347	18858	1.7	1.2 (0.8-1.8)
	OTH	20 (1.7%)	20	1256	17584	1.6	1.1 (0.7-1.8)
	SCRD	20 (1.7%)	20	1607	22498	1.2	0.9 (0.6-1.4)
	BD	9 (0.8%)	9	1165	16310	0.8	0.6 (0.3-1.1)
	LD	9 (0.8%)	8	1243	17402	0.6	0.5 (0.3-1.1)
	TOTAL	**94 (8.2%)**	**93**	**7222**	**101 108**	**1.3**	**0.1 (0.8-1.2)**
UPPER LIMB	NMD	59 (5.2%)	54	604	8456	8.9	6.9 (5.2-9.0) *
	SCRD	140 (12.2%)	121	1607	22498	7.5	6.2 (5.1-7.4) *
	OTH	74 (6.4%)	72	1256	17584	5.7	4.2 (3.3-5.5)
	LD	67 (5.7%)	63	1243	17402	5.77	3.8 (3.0-4.3)
	VI	50 (4.4%)	45	1347	18858	3.3	2.7 (2.0-3.6)
	BD	44 (3.8%)	41	1165	16310	3.5	2.7 (1.9-3.7)
	TOTAL	**434 (38%)**	**396**	**7222**	**101 108**	**5.5**	**4.3 (3.8-4.7)**
MID THORACIC AREA	VI	44 (3.8%)	39	1347	18858	2.9	2.3 (1.7-3.2)
	LD	36 (3.1%)	34	1243	17402	2.7	2.1 (1.5-2.9)
	OTH	29 (2.5%)	28	1256	17584	2.2	1.6 (1.1-2.4)
	NMD	13 (1.1%)	12	604	8456	2.0	1.5 (0.9-2.7)
	SCRD	30 (2.6%)	28	1607	22498	1.7	1.3 (0.9-1.9)
	BD	20 (1.7%)	20	1165	16310	1.7	1.2 (0.8-1.9)
	TOTAL	**172 (15.05%)**	**161**	**7222**	**101 108**	**2.2**	**1.7 (1.5-2.0)**

LOWER LIMB	VI	125 (10.9%)	109	1347	18858	8.1	6.6 (5.4-8.1) **
	BD	62 (5.4%)	60	1165	16310	5.2	3.8 (3.0-4.9)
	LD	59 (5.2%)	58	1243	17402	4.7	3.4 (2.6-4.4)
	OTH	50 (4.4%)	46	1256	17584	3.7	2.8 (2.1-3.8)
	NMD	18 (1.6%)	18	604	8456	3.0	2.1 (1.3-3.4)
	SCRD	28 (2.4%)	27	1607	22498	1.7	1.2 (0.8-1.8) ǂ
	TOTAL	**342 (29.9%)**	**318**	**7222**	**101 108**	**4.4**	**3.4 (3.0-3.8)**

The table above shows 1042 sport-related injuries during the combined Games period. There were 101 non-sport-related injuries sustained during the Games period.

* Significantly higher than athletes with LD, VI and BD.

** Significantly higher than other impairment types for lower limb injuries.

ǂ Significantly lower than athletes with VI, BD, LD and OTH for lower limb injuries.

Abbreviations: CI=confidence interval, NMD=neuromuscular disorders, SCRD=spinal cord-related disorders, OTH=all others, LD=limb deficiency, VI=visual impairment, BD=brain disorder.

Incidence of injury in impairment types by sport

Supplement 2 displays the overall incidence of injury per sport, ranked by incidence, and identifies the athlete impairment type with the highest incidence within each sport. The sports with the highest incidences were football-5-a-side (FB5) (25.9 (95%CI 18.1-36.9)), wheelchair fencing (WF) (17.06 (95 %CI 11.8-24.6)) and judo (15.5 (95%CI 11.3-21.3)). Judo (100%) and FB5 (80%) are contested almost exclusively by athletes with VI, while WF (n=167) is contested mainly by athletes with SCI (45.5%; incidence 20.5 (95%CI 12.0-35.0)). Due to low statistical power when analysing all 22 sports by impairment types, further results, and comparisons between impairment types per sport could not be reported.

DISCUSSION

Para athletes are distinguished from non-disabled athletes by their underlying medical impairment and related functional limitations, which have significant implications for injury. [2,9,20] This study represents the largest investigation of Para athletes to date, describing the incidence of injury across the different Para athlete impairment types. It provides a novel contribution towards informing medical practitioners caring for Para athletes. The findings of this study were that the overall crude unadjusted incidence of injury per 1000 athlete days differed between Para athlete impairment types. Most importantly, there was a significantly higher incidence of injury in Para athletes with VI (13.7 (95%CI 11.0-15.7)) and NMD (13.3 (95%CI 11.1-16.1)) compared with BD (9.1 (97%CI 7.7-10.8)).

High incidence of acute injury amongst athletes with VI, low incidence in athletes with BD

Injury rates for Para athletes with VI was characterised by a high incidence of acute (sudden onset) (8.6 (95%CI 7.3-10.1)) and LL injuries (6.6 (95%CI 5.4-8.1)). When assessing injury incidence across impairment types and anatomical areas, athletes with VI ranked first in incidence for injuries at the LL and mid-thoracic areas (2.3 (97% CI 1.7-3.2)) and second last in incidence for injuries in the UL (2.7 (95% CI 2.0-3.6)). This is in agreement with previous studies that showed that injuries to the LL are common in Para athletes with VI during athletics and FB5 [13,14,16].

During both the London 2012 and Rio 2016 S-PGs, FB5 had the highest incidence of injury, while Goalball ranked third during the London 2012 S-PGs and Judo third during the Rio 2016 S-PGs. All three sports are exclusively contested by athletes with VI.[5,6] The impact of VI on parameters such as joint stability, visual perception, agility, and postural control are particularly relevant during Para sport participation, potentially contributing to the high incidence of injuries in Para athletes with VI.[13,14,17,21,22] It is also important to understand the sport-specific demands placed on athletes during competition. For example, injury profiles may differ depending on whether they were sustained during contact sports with protective gear (e.g.: FB5), high-velocity weight bearing sports (e.g.: athletics), or non-weight-bearing sports which require less postural and dynamic stability (e.g.: swimming).[13,15–17] The high incidence of injury in athletes with VI needs to be investigated in light of the interaction with specific demands of different sports. Particularly, future research

should investigate whether the observed high incidence and type of injuries are inherent to the type of sport or the severity of the underlying impairment.

Athletes with BD showed a similar injury incidence to athletes with VI, although with significantly lower injury rates. Despite comprising approximately 80% of the population at the S-PGs, athletes with BD reported the lowest incidence of injury compared to all other impairment types. Most injuries occurred at the LL (3.8 (95%CI 3.0-4.9)) and typically were acute (sudden onset) (5.2 (95%CI 4.2-6.6)). Athletes with BD (CP) have been found to have decreased activation of the spinal stabilising muscles on the affected side leading to movement instability, as well as equinus and valgus deformities, which may contribute to the LL injuries in this population.[12,23] Previous studies showed that athletes with BD are responsive to training regimens and thus clinicians should consider the use of proprioceptive training for injury prevention in this Para athlete group.[24,25]

High incidence of repetitive (gradual onset) injury in athletes with NMD

In contrast to athletes with VI or BD, athletes with NMD in this study sustained more repetitive (gradual onset) injuries (5.9 (95%CI 4.3-8.0)) than acute (sudden onset) injuries (4.8 (95%CI 3.5-6.6)). Athletes with NMD had a high incidence of UL injuries (6.9 (95%CI 5.2-9.0)), which was also observed in athletes with SCRD (6.2 (95%CI 5.1-7.4)). There is limited information available regarding injuries in athletes with NMDs.[26,27] This could be attributed to the relatively recent consensus of categorising athletes based on medical pathophysiology rather than functional limitation when reporting on injury/illness risk factors.[2] Therefore, previous reports may have categorised neuromuscular-related medical conditions -causing impaired muscle power- as SCRD by clustering them broadly into “wheelchair users”.[2,5,9,28] A study investigating wheelchair basketball injuries, found that shoulder pain was less associated with players with SCRD, compared to those with LD or lower limb NMD.[29] This was linked to players' roles within the team, as those with LD or NMD often had more overhead shoulder straining positions due to full trunk control.[30] Additionally, athletes with stable NMD, like post-polio syndrome, may not use UL-demanding equipment like wheelchairs during activities of daily living.[29] These athletes might encounter additional strain when using a wheelchair during sport, due to high load in the upper extremity during sport and perhaps sustain more injuries at the UL.[29,30] Consequently, clinicians should consider equipment adaptation and kinetic chain compensations when managing UL injuries in athletes with NMD.

Injury by impairment and sport: insights

Understanding the intricate relationship between medical impairment, sport discipline, equipment utilisation and impairment class is important.[2,9] Our study represents a pioneering effort as a large-scale investigation to report injury incidence by medical impairment type, comprising initial strides toward impairment-specific injury management. However, the description of injuries by impairment type raises intriguing questions about the interplay between specific impairments in the context of sports, athlete classification, sports demands, and the effect of equipment usage. This is particularly important for sports designed exclusively for certain impairments, such as FB5 for athletes with VI, which is consistently ranked highest in injury incidence

(supplement 2) among all Paralympic sports.[5,6] While our study could not provide conclusive insights into these complex relationships, we anticipate that our current findings will serve as a foundation for advancing injury surveillance and prevention efforts within Para sport.

STRENGTHS AND LIMITATIONS OF THE STUDY

This study is the largest investigation of Para athlete injuries by impairment type to date. Impairment-specific results contribute towards improving the quality of Para sport research and injury prevention. A limitation of this study was the low statistical power for impairment type, which hindered our ability to report on all nine impairment types separately. Consequently, we reported overall injury incidences and combined less populated impairment types into the OTH category. Within this combined category, athletes with SS showed a notably high overall injury incidence, followed by athletes with IPROM. Future studies should consider analysing these impairment types individually. Power was also limited for the 22 summer sports. Thus, we did not report results by all impairment type and sports. Results have only been reported for impairment types with the highest incidence per sport, which does not allow for conclusive findings. However, these results may offer descriptive insights, and we have included sport-specific outcomes as supplementary material which could serve as a motivation for further analysis. Future studies using a larger 3-Game combined dataset are planned for further sub-analyses of impairment and sport including the use of multivariate models. Finally, due to obtaining impairment information via open-source sites, only 93.7% of Para athletes' impairment information was available.

CONCLUSION

This study reported impairment-specific injury incidence from a combined analysis of two S-PGs (101 108 athlete days). The incidence of injury differed between Para athlete impairment types. Specifically, athletes with VI had a high incidence of injury, particularly of the LL. Athletes with NMD also had a greater susceptibility to sustaining injuries, particularly repetitive (gradual onset) injuries, while athletes with BD sustained the lowest incidence of injuries. The results of this study broaden the understanding of the relationships between medical impairment and injury in elite Para athletes. Findings of this study can contribute towards improved health and safe participation in sport for all Para athletes.

COMPETING INTERESTS

All authors have declared no competing interests.

CONTRIBUTORS

All authors have contributed to the development, application and write up of the current study. Each author has completed a Conflicts of Interest form.

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ETHICS APPROVAL

Ethical approval for the larger study was obtained from Stellenbosch University (N16/05/067) and University of Brighton (FREGS/ES/12/11) Health Research Ethics Committees. Ethical approval for the current study was obtained from Stellenbosch University (S20/11/324).

EQUITY, DIVERSITY, AND INCLUSION STATEMENT

This study was conducted exclusively in athletes with disability, who are classified as a marginalised group, and was inclusive of all athletes participating at the London 2012 and Rio 2016 Paralympic Games. The author team is balanced and represent different genders from a developing socio-economic status country. Furthermore, the research group includes individuals from marginalised groups, as well as perspectives from multiple disciplines.

DATA SHARING STATEMENT

No data are available.

PATIENT AND PUBLIC INVOLVEMENT

None

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