

BMJ Paediatrics Open

BMJ Paediatrics Open is committed to open peer review. As part of this commitment we make the peer review history of every article we publish publicly available.

When an article is published we post the peer reviewers' comments and the authors' responses online. We also post the versions of the paper that were used during peer review. These are the versions that the peer review comments apply to.

The versions of the paper that follow are the versions that were submitted during the peer review process. They are not the versions of record or the final published versions. They should not be cited or distributed as the published version of this manuscript.

BMJ Paediatrics Open is an open access journal and the full, final, typeset and author-corrected version of record of the manuscript is available on our site with no access controls, subscription charges or pay-per-view fees (<http://bmjpaedsopen.bmj.com>).

If you have any questions on BMJ Paediatrics Open's open peer review process please email info.bmjpo@bmj.com

BMJ Paediatrics Open

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Journal:	<i>BMJ Paediatrics Open</i>
Manuscript ID	bmjpo-2022-001723
Article Type:	Original research
Date Submitted by the Author:	21-Oct-2022
Complete List of Authors:	<p>Singh, Sonia; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Hoch, Jeffrey; University of California Davis Health System, Center for Healthcare Policy and Research, ; University of California Davis, Department of Public Health Sciences</p> <p>Hearps, Stephen; Murdoch Children's Research Institute, Child Neuropsychology</p> <p>Dalziel, Kim ; The University of Melbourne School of Population and Global Health, Centre for Health Policy</p> <p>Cheek, John; Royal Children's Hospital Melbourne, Emergency Department</p> <p>Holmes, James; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Anderson, Vicki; Murdoch Children's Research Institute</p> <p>Babl, Franz; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; The Royal Children's Hospital Melbourne, Emergency Department</p> <p>Kuppermann, Nathan; University of California Davis School of Medicine, Department of Emergency Medicine; University of California Davis School of Medicine, Department of Pediatrics</p>
Keywords:	Health Economics, Health services research

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Sonia Singh,^{1,2,3} Jeffrey S. Hoch,^{4,5} Stephen J.C. Hearps,² Kim Dalziel,^{2,6} John A. Cheek,^{1,2,7}

James F. Holmes,^{3,5} Vicki Anderson,^{1,2,8} Franz E. Babl,^{1,2,7} and Nathan Kuppermann,^{3,9}

1. Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne, Melbourne, VIC, Australia
2. Murdoch Children's Research Institute, Melbourne, VIC, Australia
3. Department of Emergency Medicine, University of California Davis School of Medicine, Sacramento, CA, USA
4. Division of Health Policy and Management, Department of Public Health Sciences, University of California at Davis, Davis, California, USA
5. Center for Healthcare Policy and Research, University of California at Davis, Sacramento, California, USA
6. Centre for Health Policy, The University of Melbourne School of Population and Global Health, Melbourne, VIC, Australia
7. Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia
8. Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia
9. Department of Pediatrics, University of California Davis School of Medicine, Sacramento, CA, USA

Corresponding Author: Dr Sonia Singh

Department of Paediatrics, The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Melbourne, Victoria, Australia

Email: singhsd@student.unimelb.edu.au

Author Affiliations

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1. Sonia Singh, MBBS, MPH, MBA, MSc

Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of

Melbourne, Melbourne, VIC, Australia

Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

Department of Emergency Medicine

University of California Davis School of Medicine, Sacramento, CA, USA

2. Jeffrey S. Hoch, PhD

Division of Health Policy and Management, Department of Public Health Sciences,

University of California at Davis, Davis, California, USA

Center for Healthcare Policy and Research,

University of California at Davis, Sacramento, California, USA

3. Stephen J.C. Hearps, MBIostat

Child Neuropsychology, Murdoch Children's Research Institute, Melbourne, VIC, Australia

4. Kim Dalziel, PhD

Centre for Health Policy, The University of Melbourne School of Population and Global

Health, Melbourne, VIC, 3010, Australia

Health Services, Centre for Community Child Health, Murdoch Children's Research Institute,

Melbourne, VIC, Australia

5. John A. Cheek, MBBS

1
2
3 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
4 Melbourne, Melbourne, VIC, Australia

5
6
7 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

8
9
10 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia

11
12
13
14
15 6. James F. Holmes, MD, MPH

16
17 Department of Emergency Medicine

18
19 University of California Davis School of Medicine, Sacramento, CA, USA

20
21 Center for Healthcare Policy and Research,

22
23
24 University of California at Davis, Sacramento, California, USA

25
26
27
28 7. Vicki Anderson, PhD

29
30 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
31 Melbourne, Melbourne, VIC, Australia

32
33
34 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

35
36
37 Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia

38
39
40
41
42 8. Franz E. Babl, MD, MPH, DMedSc

43
44 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
45 Melbourne, Melbourne, VIC, Australia

46
47
48 Emergency Research, Clinical Sciences, Murdoch Children's Research Institute, Melbourne,
49 VIC, Australia

50
51
52
53
54 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia

1
2
3 9. Nathan Kuppermann MD, MPH
4

5 Department of Emergency Medicine
6

7 University of California Davis School of Medicine, Sacramento, CA, USA
8

9
10 Department of Pediatrics
11

12 University of California Davis School of Medicine, Sacramento, CA, USA
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Confidential: For Review Only

ABSTRACT

Objective: To estimate traumatic brain injuries (TBIs) and acute care costs due to sports activities.

Methods: A planned secondary analysis of 7,799 children 5 to <18 years old with head injuries enrolled in a prospective multicentre study between 2011 and 2014. Sports-related TBIs were identified by the epidemiology codes for activity, place and injury mechanism. The sports cohort was stratified into two age groups (younger: 5–11 and older: 12–17 years). Acute care costs from the publicly funded Australian health system perspective are presented in 2018 pounds sterling (£).

Results: There were 2,903 children (37%) with sports-related TBIs. Mean age was 12.0 years (95% CI: 11.9–12.1 years); 78% were male. Bicycle riding was associated with the most TBIs (14%), with mean per-patient costs of £802 (95% CI: £644–£960) and 17% of acute costs. The highest acute costs (21%) were from motorcycle-related TBIs (3.8% of injuries), with mean per-patient costs of £3,795 (95% CI: £1,850–£5,739). For younger boys and girls, bicycle riding was associated with the highest TBIs and total costs; however, the mean per-patient costs were highest for motorcycle and horse riding, respectively. For older boys, rugby was associated with the most TBIs. However, motorcycle riding had the highest total and mean per-patient acute costs. For older girls, horse riding was associated with the most TBIs and highest total acute costs, and motorcycle riding with the highest mean per-patient costs.

Conclusion: Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.

Clinical Trial Registration: Australian New Zealand Clinical Trials Registry (ANZCTR)

ACTRN12614000463673

INTRODUCTION

Injuries from sports activities are a global health concern, with children 5–14 years requiring more medical care than other ages.¹ The need for comprehensive surveillance and injury prevention initiatives has been recognised internationally.^{2–4} Sports activities are frequently associated with traumatic brain injuries (TBIs) in children.^{5–7} In Australia, head trauma occurred with 5.8%–44% of sports-related injuries in children with ED presentations between 1989–1993.⁵ Additionally, an increasing trend in hospitalisations for all sports injuries was reported between 2004 and 2010.⁸ In 2012, the age-standardised incidence rate of hospitalisations for all sports-related injuries in children ≤ 16 years was 281 per 100,000 population with annual costs of the Australian dollar (AUD) \$40 million.⁹

There are no population-based estimates of ED presentations for paediatric sports-related TBIs in Australia. In a prior study, we reported sports activities were the second most frequent injury mechanism after falls for head injuries in Australian children.⁷ In the US, the incidence of nonfatal sports-related TBIs in children in 2018 was 299 per 100,000.¹⁰ An increasing trend in ED visits for sports-related TBIs was reported between 2001 and 2012, followed by a subsequent decline of 27% by 2018.^{10 11} Contact sports accounted for approximately 45% of injuries, with American football and bicycle riding accounting for the most TBIs.⁴ While playground-related TBIs were the most common mechanism for children younger than 10 years, American football in boys and soccer in girls accounted for the most TBIs for older children.⁴ In the UK, the annual incidence of head injuries in 2013 was 400 per 100,000 for children younger than 15 years. Sports activities were the second most frequent injury mechanism after falls, with Rugby, football, and horse riding being the most prevalent.⁶

1
2
3 The aim of this study was to estimate the ED and acute hospital costs for children with TBIs
4 due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and
5
6 age of the child.
7
8
9

10 11 12 **METHODS**

13
14 This was a secondary analysis of the prospective multicentre Australasian Paediatric Head
15 Injury Study (APHIRST), in which 17,841 Australian children <18 years were enrolled
16
17 between April 2011 and November 2014. There were two mixed and six free-standing
18
19 children's hospital emergency departments (EDs), all members of the Paediatric Research in
20
21 Emergency Departments International Collaborative (PREDICT) network. The Human
22
23 Research Ethics Committee of the Royal Children's Hospital (RCH), Melbourne (reference,
24
25 31008A) and the institutional ethics committees at the participating sites approved the study.
26
27 The detailed methodology of the APHIRST study has been previously published.¹²
28
29
30
31
32
33
34

35 Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the
36
37 activity codes noted on the case report form of the APHIRST study.¹³ Helmet use was noted
38
39 for TBIs from bicycle riding. We considered injuries sports-related if they occurred from
40
41 organised or recreational sports and not falls from playground equipment or casual play. The
42
43 research assistants assigned the activity codes at each site based on information recorded by
44
45 the clinician at the time of the ED visit, obtained from medical record review and during the
46
47 follow-up call.¹³ Epidemiology codes for activity, place and injury mechanism of injury
48
49 employed by the Victorian Injury Surveillance Unit in Australia were used across all study
50
51 sites in APHIRST.^{8 14 15} These were mapped to the International Classification of Diseases
52
53 *10th revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71).^{9 16} The
54
55
56
57
58
59
60

1
2
3 combined football codes (U 50.01-50.05) included rugby, Australian rules football, touch
4
5 football, soccer and football-not otherwise specified.^{9 16}
6
7
8
9

10 The sports cohort was stratified into two age groups (younger: 5 to 11 and older: 12 to 17
11 years). TBI was defined as any injury to the brain caused by an external force.¹⁷ TBI severity
12 was defined as mild, moderate, and severe. Mild TBI was defined as Glasgow Coma Scale
13 (GCS) scores of 13–15 on ED presentation, no neurological deficits, with no evidence of TBI
14 on cranial computed tomography (CT) or magnetic resonance imaging (MRI) if performed.¹⁸
15 Moderate TBI included either GCS scores 9–13, or GCS scores 13–15 with neurological
16 deficits or evidence of TBI on CT or MRI. Severe TBI was defined as GCS scores ≤ 8 .¹⁸
17
18
19
20
21
22
23
24
25
26
27
28

29 The costing analysis was conducted from a publicly funded health system perspective,
30 applying direct and indirect costs from the RCH to patient-level data in the Australian cohort
31 (Appendix 1).^{7 19} The details of the costing methods and data inputs have been published.⁷
32
33
34

35 Acute care included ED presentations with either discharge or acute admissions until hospital
36 discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals
37 (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All
38 costs were inflated to 2018 Australian dollars (\$) using the Reserve Bank of Australia general
39 consumer price index rates from 13 September 2019 and presented as pounds sterling with
40 the average exchange rate of UK £0.60 from 30 June 2018.^{20 21} Data analysis was performed
41 with Stata (version 15; StataCorp, College Station, TX).
42
43
44
45
46
47
48
49
50
51
52
53

54 **RESULTS**

55 **Sports cohort: Patient characteristics**

56
57
58
59
60

Of the 7,799 Australian children between 5 and 18 years with head injuries enrolled in APHIRST, 2,903 (37%) had TBIs from sports activities (Figure 1, Table 1). The mean age for the sports cohort was 12.0 years (95% CI: 11.9–12.1 years), and 78% were male. The acute care costs for sports-related TBIs were £1.9 million, with mean per-patient costs of £669 (95% CI: £566–£772). The acute admission rate was 34%, with mean per-patient costs of £1,559 (95% CI: £1,265–£1,853), which accounted for 80% of acute care costs. Paediatric intensive care unit admissions for 43 children (1.5% of the sports cohort) accounted for 29% of acute care costs, with mean per-patient costs of £13,199 (95% CI: £8,217–£18,180). There were no deaths reported from sports activities.

Table 1 Sports cohort: Demographics and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Ages 5–17 years	7,799 (100)	£749 (£650–£849)	£5,843,060 (100)
Sports cohort	2,903 (37)	£669 (£566–£772)	£1,942,345 (33)
Age group			
Younger (5–11 years)	1,286 (44)	£501 (£438–£564)	£644,045 (33)
Older (12–17 years)	1,617 (56)	£803 (£624–£982)	£1,298,300 (67)
Sex			
Male	2,272 (78)	£682 (£554–£810)	£1,549,252 (80)
Female	628 (22)	£625 (£513–£738)	£392,447 (20)
TBI severity[§]			
Mild	2,727 (93.9)	£443 (£389–£497)	£1,209,200 (62)
Moderate	146 (5.0)	£2,269 (£1,622–£2,916)	£331,272 (17)
Severe	30 (1.0)	£13,395 (£6,400–£20,392)	£401,873 (21)
Disposition			
Discharge from ED	1,902 (66)	£205 (£203–£206)	£389,483 (20)
Admission	995 (34)	£1,559 (£1,265–£1,853)	£1,551,083 (80)
Paediatric ward	267 (9.2)	£4,184 (£3,173–£5,194)	£1,117,009 (59)

PICU	43 (1.5)	£13,199 (£8,217–£18,180)	£567,538 (29)
Death	0 (0)	£0.00	£0.00

TBI, traumatic brain injury; CI, confidence interval; PICU, paediatric intensive care unit; ED, emergency department; NOS, not otherwise specified; GCS, Glasgow Coma Scale

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits, negative neuroimaging; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or positive neuroimaging; Severe TBI, GCS scores \leq 8.

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: TBI severity

Most head injuries from sports activities resulted in mild TBIs (94%), which were associated with 62% of the sports-related acute care costs with mean per-patient costs of £443 (95% CI: £389–£497) (Table 1). Moderate TBIs occurred with 5% of injuries, accounting for 17% of sports-related acute costs, with mean per-patient costs of £2,269 (95% CI: £1,622–£2,916). Severe TBIs in 1.0% of the sports cohort accounted for 21% of acute care costs, with mean per-patient costs of £13,395 (95% CI: £6,400–£20,392).

Sports cohort: Mechanisms of injury

The top ten individual sports in decreasing frequency (Figure 2, Table 2) cumulatively accounted for 76% of sports-related TBIs and 87% of acute care costs. Bicycle riding was associated with the most TBIs (14%) and 17% of sports-related acute care costs, with mean per-patient costs of £802 (95% CI: £644–£960). Children with bicycle-related TBIs who were not wearing helmets (48%) with mean per-patient costs of £1,047 (95% CI: £626–£1,468) accounted for 63% of bicycle-related costs. Motorcycle riding was associated with the largest proportion of moderate (9.1%) and severe TBIs (8.2%) for any sport. Further, with 3.8% of TBIs, motorcycle riding was associated with the highest mean per-patient costs of £3,795 (95% CI: £1,850–£5,739) and acute costs (21%) from individual sports.

Team ball sports were associated with the most sports-related TBIs (45%), which accounted for 25% of acute care costs (Appendix 2). Specifically, the combined football codes (U50.01–50.05) were associated with 39% of sports-related TBIs and accounted for 21% of acute care costs. On the other hand, wheeled non-motored sports, with 26% of TBIs, were associated with the highest acute costs (35%) and wheeled motorsports, with 3.9% of TBIs, were associated with the highest mean per-patient cost.

Table 2 Sports-related TBIs and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Sports cohort	2903 (100)	£669 (£566–£773)	£1,942,345 (100)
<i>Sports activities</i>			
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
No helmet (% bicycle riding)	197 (48)	£1,047 (£626–£1,468)	£206,223 (63)
Australian rules football	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football-NOS	289 (10.0)	£370 (£298–£443)	£107,007 (5.5)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Motorecycle riding	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)
Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)

1				
2				
3				
4	Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
5	Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
6				
7	Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
8				
9	Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
10				
11	Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
12				
13	Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
14				
15	Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
16				
17	Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
18				
19	Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
20				
21	Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
22				
23	High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
24				
25	Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
26				
27	Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
28				
29	Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
30				
31	Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
32				
33	Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
34				
35	Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
36				
37	Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
38				
39	All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
40				
41	Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
42				
43	Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
44				
45	Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

TBI, traumatic brain injury; NOS, not otherwise specified

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: Mechanisms of injury and TBI severity

By TBI severity, mild TBIs from bicycle riding (93% of bicycle riding injuries and 13% of the sports cohort) and severe TBIs from motorcycle riding (8% of motorcycle riding injuries and 0.31% of the sports cohort) accounted for the highest acute care costs (11%) for the

1
2
3 sports cohort (Figure 2). In contrast, the combined football sports were associated with
4
5 primarily mild TBIs and the lowest acute costs.
6
7
8
9

10 **Sports cohort: Age groups**

11
12 In Figure 2, the top ten mechanisms of injury in decreasing frequency are shown for the
13
14 younger and older age groups, which accounted for 70% and 86% of sports-related TBIs,
15
16 respectively and 79% and 91% of associated acute care costs. Of the 1,286 children (44%) in
17
18 the younger age group, 73% were male. Similarly, 82% of the 1,617 children in the older age
19
20 group were male.
21
22
23
24
25

26 In the younger age group, bicycle riding was associated with the highest proportion of TBIs
27
28 (17%) and age group-related costs (26%). Although rugby was the most frequent injury
29
30 mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related
31
32 TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger
33
34 age group, mild TBIs from bicycle riding were associated with the highest group-related
35
36 acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest
37
38 group-related acute costs (15%) in the older age group.
39
40
41
42
43
44

45 **Sports cohort: Sex**

46
47 Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care
48
49 costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and
50
51 the highest acute costs (27%) for the age group (Figure 3, Appendix 3). For boys in the older
52
53 age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)
54
55
56
57
58
59
60

1
2
3 accounted for the highest acute costs (28%) for the age group. Motorcycle riding was
4
5 associated with the highest mean per-patient costs for boys in both age groups (Appendix 3).
6
7
8
9

10 For young girls, bicycle riding was associated with the most TBIs (19%) and the highest
11
12 acute costs (25%) for the age group (Figure 3, Appendix 4). For girls in the older age group,
13
14 horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%)
15
16 for the age group. The highest mean per-patient costs were associated with horse riding and
17
18 motorcycle riding for younger and older girls, respectively (Appendix 4).
19
20
21
22
23

24 **DISCUSSION**

25
26 This cost of illness study estimates the frequency and economic burden of TBIs from sports
27
28 activities in children between 5 and 18 years in Australia. While bicycle riding was
29
30 associated with the most TBIs, motorcycle-related TBIs, with 4% of injuries, were associated
31
32 with the highest total and mean per-patient acute care costs. When the combined effect of
33
34 TBI severity and sports activities on the acute care costs were explored, bicycle riding
35
36 injuries with mild TBIs and motorcycle riding with severe TBIs accounted for similar acute
37
38 care costs for the sports cohort. Therefore, while motorcycle-related injuries had the most
39
40 severe TBIs and the highest patient-level costs, the combined effect of injury frequency and
41
42 TBI severity from bicycle and motorcycle riding contributed to the high economic burden on
43
44 the health system.
45
46
47
48
49
50

51 In a recent population-based report, the total acute care costs for *all* sports-related injuries in
52
53 Australia were AUD \$764 million for FY 2019.²² ED visits for *all* sports injuries accounted
54
55 for 22% of the total acute care costs (AUD \$164 million), and 37% of the ED costs were for
56
57
58
59
60

1
2
3 children <20 years, who accounted for 25% of the Australian population.^{22 23} The acute care
4 costs for sports-related TBIs were AUD \$32 million (4% of total costs for all sports injuries),
5 and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-
6 related TBIs accounted for 80% of the acute care costs.²²
7
8
9
10
11
12
13
14

15 There are few published reports of paediatric sports-related head injuries in Australia.^{13 15 18}
16 While one study excluded bicycle, motorcycle and playground injuries,¹⁸ another did not
17 report motorcycle-related head injuries.¹³ Australian rules football was associated with the
18 highest proportion of head injuries in the retrospective study,¹⁸ baseball and softball were
19 associated with the most clinically important TBIs in the prospective study.¹³ In the current
20 study, we excluded playground injuries. We reported bicycle riding in younger children,
21 rugby in older boys and horse riding in older girls were associated with the most sports-
22 related TBIs.
23
24
25
26
27
28
29
30
31
32
33
34

35 To our knowledge, no prior studies have compared the acute costs of TBIs from sports
36 activities in children. In this study, bicycle riding was the most frequent injury mechanism for
37 the sports cohort and was associated with the highest costs for younger boys and girls.
38 Additionally, the highest mean per-patient costs were associated with motorcycle riding for
39 younger boys and horse riding for younger girls. While rugby was the most frequent injury
40 mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For
41 older girls, horse riding was associated with the most head injuries and the highest total acute
42 costs, and motorcycle riding with the highest mean per-patient costs. Education programmes
43 on safe riding practices and protective gear are needed to reduce sports-related TBIs.²⁴
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 Prior research has shown that helmet laws and the proper use of helmets reduce head injuries
4 and fatalities from bicycle riding.²⁵⁻³⁰ For the sports cohort, 52% of children with TBIs from
5 bicycle riding were reported to be wearing helmets, accounting for 37% of bicycle-related
6 acute care costs. Although we only obtained information regarding helmet use with bicycle
7 riding, the effect of helmet use on reducing TBIs with other wheeled sports is strongly
8 supported by research.^{31 32} The impact of helmet legislation on reducing fatalities from
9 motorcycle and bicycle riding has been shown globally.³³ In Australia, helmets are required
10 for motorcycle and bicycle riding for all ages.³⁴ In the UK, helmet use is required for
11 motorcycle riding for all ages.³⁵ Helmets are only recommended for riding bicycles, all-
12 terrain vehicles, scooters or skateboards. In the US, state and local laws are responsible for
13 helmet legislation, and there are no helmet laws for bicycle riding in 29 states and motorcycle
14 riding in 3 states.^{28 36} While helmet laws are necessary for reducing mortality from sports
15 activities, our results indicate that additional strategies are required to reduce injury severity.

16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35 This study is not without some limitations. First, we focused on acute care costs of sports-
36 related TBIs from the Australian publicly funded health system perspective. We did not
37 consider the costs associated with long-term follow-up and rehabilitation, which would
38 increase the total costs of these injuries. Second, the proportion of TBIs due to sports
39 activities is underestimated because not all patients present to EDs after head injuries. Third,
40 we did not collect information regarding helmet use during non-bicycle activities. Fourth, the
41 high acute costs of severe TBIs could be associated with multi-organ injuries. However, since
42 individual cost inputs were applied (Appendix 1), this would only be reflected in the length
43 of hospital stay.⁷ Finally, while this was a multicentre study, our results do not reflect
44 children with sports injuries who present for care outside of EDs or never seek medical care.

CONCLUSION

Sports activities are common mechanisms of TBIs in children and have a significant economic impact on patients and the health system. Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children. We highlight the effect of TBI severity on the associated acute costs of head injuries from wheeled sports in children. This has implications for resource allocations for population-based injury surveillance and targeted injury prevention programmes.

ACKNOWLEDGMENTS

We thank the participating families and emergency department staff at participating sites. We thank Meredith L. Borland (Perth Children's Hospital, Perth, WA); Stuart R. Dalziel (Starship Children's Health, Auckland, New Zealand and Departments of Surgery and Paediatrics: Child and Youth Health, University of Auckland, Auckland, New Zealand); Ed Oakley (Royal Children's Hospital, Melbourne, VIC); Amit Kochar (Women's & Children's Hospital, Adelaide, SA); Natalie Phillips and Yuri Gilhotra (Queensland Children's Hospital, Brisbane, QLD); Sarah Dalton and Mary McCaskill (The Children's Hospital at Westmead, Sydney, NSW); Jeremy Furyk (The Townsville Hospital, Townsville, QLD); Jocelyn Neutze (Kidzfirst Middlemore Hospital, Auckland, New Zealand); Mark Lyttle (Bristol Royal Hospital for Children, Bristol, UK and Academic Department of Emergency Care, University of the West of England, Bristol, UK); Silvia Bressan (Department of Women's and Children's Health, University of Padova, Padova, Italy); and Louise Crowe (Murdoch Children's Research Institute, Melbourne, VIC) for their involvement with obtaining the data and prior data analysis.

FUNDING SOURCES/DISCLOSURES

Funding and support: The study was funded by grants from the National Health and Medical Research Council (project grant GNT1046727, Centre of Research Excellence for Pediatric Emergency Medicine GNT1058560), Canberra, Australia; the Murdoch Children's Research Institute, Melbourne, Australia; the Emergency Medicine Foundation (EMPJ-11162), Brisbane, Australia; Perpetual Philanthropic Services (2012/1140), Australia; Auckland Medical Research Foundation (No. 3112011) and the A + Trust (Auckland District Health Board), Auckland, New Zealand; WA Health Targeted Research Funds 2013, Perth,

1
2
3 Australia; the Townsville Hospital and Health Service Private Practice Research and
4
5 Education Trust Fund, Townsville, Australia; and supported by the Victorian Government's
6
7 Infrastructure Support Program, Melbourne, Australia. The funding organisations were not
8
9 involved in the collection of the data, their analysis and interpretation, or in the approval or
10
11 rejection of the publication of the completed manuscript.
12
13
14
15
16

17 **Clinical Trial Registration:** Australian New Zealand Clinical Trials Registry (ANZCTR)
18
19 ACTRN12614000463673
20
21
22
23

24 **Competing interests:** No relevant disclosures.
25
26
27

28 **Financial Disclosure:** The authors have no financial relationships relevant to this article to
29
30 disclose.
31
32
33

34
35 **Patient and public involvement:** Patients and the public were not involved in
36
37 the design, or conduct, or reporting, or dissemination plans of this research.
38
39
40
41

42 **Patient consent for publication:** Not required.
43
44
45

46
47 **Provenance and peer review:** Not commissioned; externally peer reviewed
48
49
50

51 **Data availability statement:** All data relevant to the study are included in the article or
52
53 uploaded as supplementary information.
54
55
56
57
58
59
60

AUTHOR CONTRIBUTIONS

SS conceptualised the study, conducted the analysis, wrote the first draft of the manuscript, and reviewed and revised the manuscript. FEB conceptualised and designed, coordinated and supervised data collection of APHIRST, contributed to data interpretation, and critically reviewed and revised the manuscript. SS, JAC, and KD acquired the cost data and conducted the analysis. SJCH had full access to the data, analysed the data, contributed to data interpretation, and critically reviewed and revised the manuscript. JSH, KD, JAC, JFH, VA, and NK contributed to the interpretation of the data and reviewed and revised the article critically. All authors revised the paper critically and approved the final manuscript as submitted.

ORCID iDs

Sonia Singh [0000-0003-2430-0262](https://orcid.org/0000-0003-2430-0262)

Jeffrey S. Hoch [0000-0002-4880-4281](https://orcid.org/0000-0002-4880-4281)

Stephen J.C. Hearps [0000-0003-2984-1172](https://orcid.org/0000-0003-2984-1172)

Kim Dalziel [0000-0003-4972-8871](https://orcid.org/0000-0003-4972-8871)

John A. Cheek [0000-0002-3615-3821](https://orcid.org/0000-0002-3615-3821)

James F Holmes [0000-0003-3270-2720](https://orcid.org/0000-0003-3270-2720)

Vicki Anderson [0000-0001-5233-3147](https://orcid.org/0000-0001-5233-3147)

Franz E Babl [0000-0002-1107-2187](https://orcid.org/0000-0002-1107-2187)

Nathan Kuppermann [0000-0002-7854-4943](https://orcid.org/0000-0002-7854-4943)

FIGURE LEGENDS

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort TBI, traumatic brain injury

Figure 2. Sports-related TBI severity[§] and acute care costs[†] by age groups

Top ten sports activities in decreasing order of injury frequency

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

[§]TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤ 8

TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

(Please use colour for Figure 2)

Figure 3. Acute care costs[†] of sports-related TBIs stratified by age and sex

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

1
2
3 *What is already known on this topic*
4

- 5 • Sports activities are frequently associated with traumatic brain injuries in children.
6
7

8
9 *What this study adds*
10

- 11 • Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were
12 associated with the highest mean per-patient and total acute care costs.
13
14 • Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated
15 with the highest total acute care costs for the sports cohort.
16
17 • The highest mean per-patient costs were from horse riding in younger girls and
18 motorcycle riding for older girls and boys in both age groups.
19
20
21

22 *How this study might affect research, practice or policy*
23

- 24 • Injury prevention strategies should focus on age and sex-related sports activities to reduce
25 the burden of TBIs in children.
26
27 • While contact sports are common mechanisms of injury, they are not associated with
28 severe TBIs or high acute care costs.
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

REFERENCES

1. Finch C, Cassell E. The public health impact of injury during sport and active recreation. *J Sci Med Sport* 2006;9(6):490-7. doi:10.1016/j.jsams.2006.03.002
2. Australian Institute of Health and Welfare. National sports injury data strategy: draft consultation report. Cat. no. INJCAT 222. Canberra: Australian Institute of Health and Welfare, 2022.
3. Timpka T, Finch CF, Goulet C, et al. Meeting the global demand of sports safety. The intersection of science and policy in sports safety. *Sports Med* 2008;38(10):795-805. doi:10.2165/00007256-200838100-00001
4. Sarmiento K, Thomas KE, Daugherty J, et al. Emergency department visits for sports- and recreation-related traumatic brain injuries among children — United States, 2010–2016. *MMWR Morb Mortal Wkly Rep* 2019;68:237-42. doi:10.15585/mmwr.mm6810a2
5. Finch C, Valuri G, Ozanne-Smith J. Sport and active recreation injuries in Australia: evidence from emergency department presentations. *Br J Sports Med* 1998;32:220–25. doi:10.1136/bjism.32.3.220
6. Trefan L, Houston R, Pearson G, et al. Epidemiology of children with head injury: a national overview. *Arch Dis Child* 2016;101(6):527–32. doi:10.1136/archdischild-2015-308424
7. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274–80. doi:10.1111/jpc.15699
8. Finch CF, Wong Shee A, Clapperton A. Time to add a new priority target for child injury prevention? The case for an excess burden associated with sport and exercise injury: population-based study. *BMJ Open* 2014;4(7):e005043. doi:10.1136/bmjopen-2014-005043

- 1
2
3 9. Lystad RP, Curtis K, Browne GJ, et al. Incidence, costs, and temporal trends of sports
4
5 injury-related hospitalisations in Australian children over a 10-year period: A nationwide
6
7 population-based cohort study. *J Sci Med Sport* 2019;22(2):175–80.
8
9 doi:10.1016/j.jsams.2018.07.010
10
11
- 12 10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in Sports- and Recreation-Related
13
14 Traumatic Brain Injuries Treated in US Emergency Departments: The National Electronic
15
16 Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma*
17
18 *Rehabil* 2015;30(3):185-97. doi:10.1097/HTR.000000000000156
19
20
- 21 11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for
22
23 contact sports-related traumatic brain injuries among children — United States, 2001–
24
25 2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870-74. doi:10.15585/mmwr.mm6927a4
26
27
- 28 12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE
29
30 head injury decision rules in children: a prospective cohort study. *Lancet*
31
32 2017;389(10087):2393–402. doi:10.1016/s0140-6736(17)30555-x
33
34
- 35 13. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain
36
37 injuries in children. *Med J Aust* 2019;211(8):365–66. doi:10.5694/mja2.50311
38
39
- 40 14. Australian Institute of Health and Welfare. Injury surveillance National Minimum Data
41
42 Set. National Health Data Dictionary. Version 12. AIHW Cat. No. HWI 57. Canberra:
43
44 Australian Institute of Health and Welfare, 2003.
45
46
- 47 15. Fernando DT, Berecki-Gisolf J, Finch CF. Sports injuries in Victoria, 2012–13 to 2014–
48
49 15: evidence from emergency department records. *Med J Aust* 2018;208(6):255–60.
50
51 doi:10.5694/mja17.00872
52
53
54
55
56
57
58
59
60

16. AIHW: Kreisfeld R, Harrison JE. Hospitalised sports injury in Australia, 2016–17. Injury Research and Statistics Series no.131. Cat. No. INJCAT 211. Canberra: Australian Institute of Health and Welfare, 2020.
17. Centers for Disease Control and Prevention. *Traumatic brain injury and concussion* Atlanta, GA: National Center for Injury Prevention and Control; [updated 07 March 2022]. Available: <https://www.cdc.gov/traumaticbraininjury/concussion/symptoms.html> [Accessed 09 Apr 2022].
18. Crowe LM, Anderson V, Catroppa C, et al. Head injuries related to sports and recreation activities in school-age children and adolescents: data from a referral centre in Victoria, Australia. *Emerg Med Australas* 2010;22(1):56–61. doi:10.1111/j.1742-6723.2009.01249.x
19. Singh S, Babl FE, Huang L, et al. Paediatric traumatic brain injury severity and acute care costs. *Arch Dis Child* 2022;107:497–99. doi:10.1136/archdischild-2021-322966
20. The Reserve Bank of Australia inflation calculator: Reserve Bank of Australia. Available: <https://www.rba.gov.au/calculator/> [Accessed 19 Sep 2018].
21. Australian Taxation Office. Foreign currency exchange rates for financial year ending 2018. Available: <https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-June-2018/> [Accessed 31 Aug 2020].
22. Australian Institute of Health and Welfare. Economics of sports injury and participation – Preliminary results. Cat. no. INJCAT 224. Canberra: Australian Institute of Health and Welfare, 2022.
23. Australian Demographic Statistics (June 2019). Table 7: Population by age and sex tables [data cubes] Canberra: Australian Bureau of Statistics. Available:

- 1
2
3 [https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDo](https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument)
4 [cument](https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument) [Accessed 18 Jul 2020].
5
6
7
8 24. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged
9 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance
10 Unit, Monash University Accident Research Centre, 2016.
11
12
13
14 25. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a*
15 *formal review. June 2020.* ACT: Australian Transport Safety Bureau, 2000.
16
17
18
19 26. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid*
20 *Anal Prev* 2001;33:345–52.
21
22
23
24 27. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta,
25 GA: National Center for Injury Prevention and Control. Available:
26 <https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html> [Accessed
27 09 Apr 2022].
28
29
30
31
32
33 28. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and*
34 *countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National
35 Transportation Safety Board, 2019.
36
37
38
39
40 29. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to
41 increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76-82.
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
30. Olivier J, Creighton P. Bicycle injuries and helmet use: a systematic review and meta-analysis. *Int J Epidemiol* 2017;46(1):278-92. doi:10.1093/ije/dyw153
31. Institute of Medicine (IOM) and National Research Council (NRC). *Sports-related concussions in youth: Improving the science, changing the culture.* Washington, DC: The National Academies Press, 2014.

- 1
2
3 32. Weiss H, Agimi Y, Steiner C. Youth motorcycle-related brain injury by state helmet law
4 type: United States, 2005–2007. *Pediatrics* 2010;126(6):1149–55.
5
6 doi:10.1542/peds.2010-0902
7
8
9
10 33. Cassidy JD, Carroll LJ, Peloso PM, et al. Incidence, risk factors and prevention of mild
11 traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild
12 Traumatic Brain Injury. *J Rehabil Med* 2004(Suppl. 43):28-60.
13
14 doi:10.1080/16501960410023732
15
16
17
18 34. Kaddis M, Stockton K, Kimble R. Trauma in children due to wheeled recreational
19 devices. *J Paediatr Child Health* 2016;52(1):30-3. doi:10.1111/jpc.12986
20
21
22
23 35. The highway code: Department of Transport. UK Government; 2015, updated 2021.
24 Available: <https://www.highwaycodeuk.co.uk> [Accessed 04 Jun 2021].
25
26
27
28 36. Centers for Disease Control and Prevention. Universal motorcycle helmet laws Atlanta,
29 GA: National Center for Injury Prevention and Control. Available:
30
31 <https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/mchelmet.html> [Accessed
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

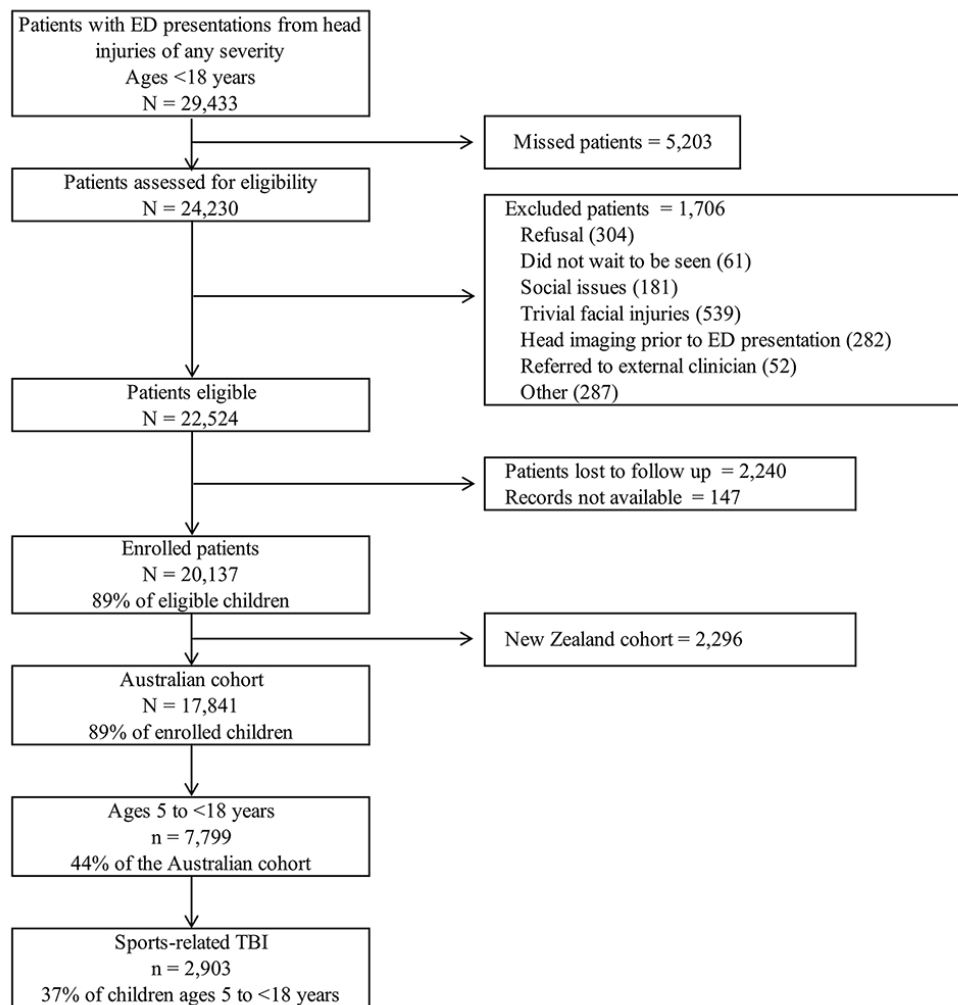


Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort TBI, traumatic brain injury

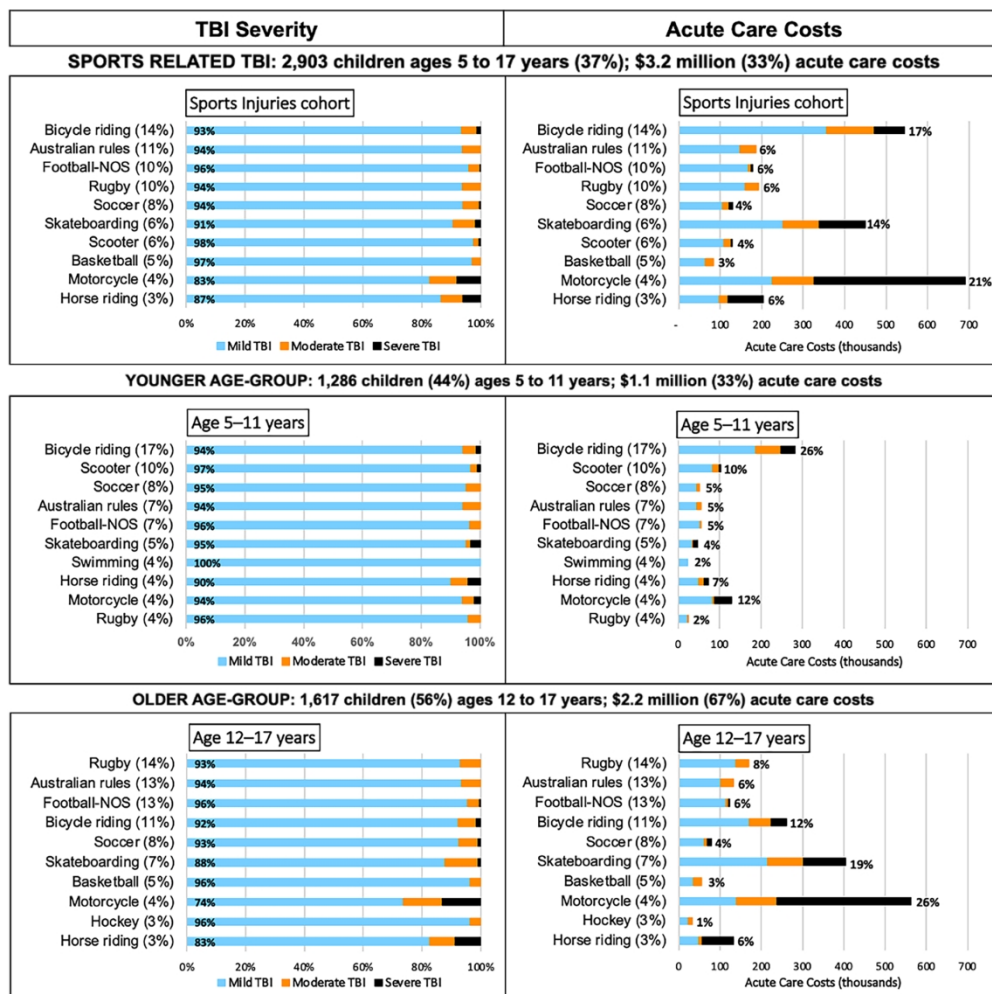


Figure 2. Sports-related TBI severity§ and acute care costs† by age groups

Top ten sports activities in decreasing order of injury frequency

†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤8

TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

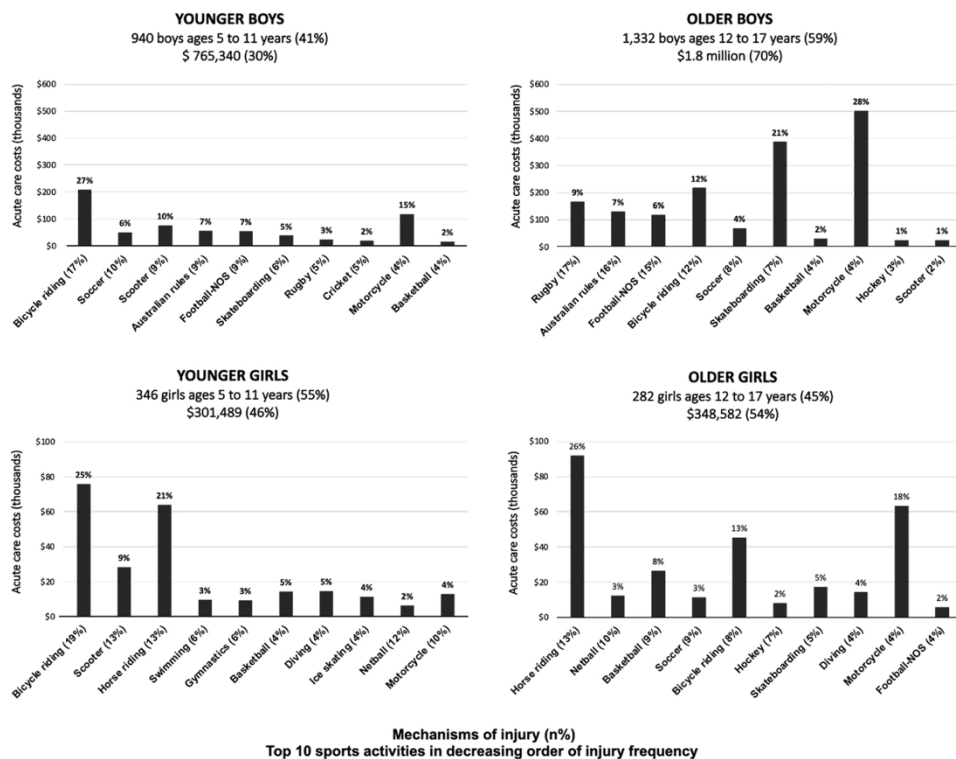


Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
 †Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Appendix 1 Source: the author: Acute care cost[†] inputs¹

	Mean cost	95% CI	Source
ED visit	£188	£183–£194	RCH data
Admission			
SSU/day	£245	£223–£267	RCH data
Ward/day	£969	£944–£994	RCH data
ICU/day	£2,456	£2,287–£2,624	RCH data
Intervention			
Intubation	£177	£4–£351	Dalziel et al. ²
Neurosurgery	£1,442	£1,300–£1,584	RCH data
Radiology			
Cranial CT	£118	£2–£233	MBS schedule (2018) ³
Brain MRI	£243	£5–£482	MBS schedule (2018)
Skull X-ray	£39	£1–£78	MBS schedule (2018)
Cranial Ultrasound	£66	£1–£130	MBS schedule (2018)
Follow up			
GP visit	£40	£1–£80	MBS schedule (2018)

[†]Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; RCH, Royal Children's Hospital; ED, emergency department; SSU, short stay unit; ICU, intensive care unit; CT, computed tomography; MRI, magnetic resonance imaging; GP, general practitioner; MBS, Medicare Benefits Schedule

REFERENCES

1. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274–80. doi:10.1111/jpc.15699
2. Dalziel K, Cheek JA, Fanning L, et al. A cost-effectiveness analysis comparing clinical decision rules PECARN, CATCH, and CHALICE with usual care for the management of pediatric head injury. *Ann Emerg Med* 2019;73(5):429–39. doi:10.1016/j.annemergmed.2018.09.030
3. Australian Government. MBS online: Medicare benefits schedule, 2018. Available: <http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/Home> [Accessed 18 Sep 2019].

Appendix 2 Acute care costs[†] for sports-related TBIs using the ICD-10-AM external cause codes

Sports Cohort	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs	2,903 (100)	£669 (£566–£773)	£1,942,345 (100)
<i>U50: Team ball sports</i>	1,315 (45)	£366 (£334–£398)	£481,241 (25)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
<i>U50.01-05: Football</i>	1,120 (39)	£369 (£336–£403)	£413,952 (21)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
AFL	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football - not specified	289 (10)	£370 (£298–£443)	£107,007 (5.5)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
<i>U50.1-50.3: Basketball and Netball</i>	179 (6.2)	£354 (£245–£462)	£63,301 (3.3)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
<i>U51: Team bat sports</i>	193 (6.6)	£396 (£244–£548)	£76,476 (3.9)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
<i>U53: Boating sports</i>			
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)

U54: Individual water sports	198 (6.8)	£315 (£237–£392)	£62,248 (3.2)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)
Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
U55: Ice and snow sports	62 (2.1)	£531 (£276–£787)	£32,952 (1.7)
Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
U56: Individual athletics	21 (0.72)	£350 (£237–£464)	£7,353 (0.38)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
U57: Acrobatic activities	44 (1.5)	£265 (£227–£303)	£11,662 (0.60)
Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
U58: Dancing			
Dancing	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
U59: Racket sports			
Racket	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
U60: Target and precision sports			
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
U61: Combative sports	20 (0.69)	£389 (£155–£623)	£7,777 (0.40)
Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
U63: Equestrian			

Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
U65: Wheeled motored sports	113 (3.9)	£3,736 (£1,842–£5,631)	£422,216 (22)
Motorcycle	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
U66: Wheeled non-motored sports	759 (26)	£901 (£654–£1,148)	£683,981 (35)
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Skating - roller	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

International Classification of Diseases *10th revision-Australian Modification*, ICD-10-AM; CI, confidence interval; NOS, not otherwise specified

Appendix 3 Acute care costs[†] for boys in the sports cohort

Males	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	940 (41)	£491 (£412–£572)	£462,036 (30)	1,332 (59)	£816 (£605–£1,027)	£1,087,216 (70)
<i>Sports activities</i>						
Bicycle riding	158 (17)	£790 (£543–£1,037)	£124,859 (27)	163 (12)	£799 (£523–£1,075)	£130,177 (12)
Australian rules football	86 (9.1)	£377 (£250–£505)	£32,469 (7.0)	210 (16)	£369 (£292–£446)	£77,398 (7.1)
Football-NOS	81 (8.6)	£398 (£193–£602)	£32,207 (7.0)	195 (15)	£362 (£295–£430)	£70,644 (6.5)
Rugby	47 (5.0)	£283 (£248–£318)	£13,291 (2.9)	223 (17)	£444 (£355–£534)	£99,130 (9.1)
Soccer	96 (10)	£301 (£241–£362)	£28,912 (6.3)	112 (8.4)	£362 (£261–£461)	£40,468 (3.7)
Skateboarding	53 (5.6)	£412 (£264–£560)	£21,853 (4.7)	94 (7.1)	£2,481 (£633–£4,327)	£233,152 (21)
Scooter	88 (9.4)	£512 (£309–£715)	£45,047 (9.8)	30 (2.3)	£468 (£222–£714)	£14,037 (1.3)
Basketball	33 (3.5)	£262 (£216–£307)	£8,641 (1.9)	59 (4.4)	£300 (£220–£380)	£17,704 (1.6)
Motorcycle	39 (4.1)	£1,789 (£381–£3,198)	£69,787 (15)	50 (3.8)	£6,038 (£1,994–£10,082)	£301,916 (28)
Horse riding	7 (0.75)	£747 (£41–£1,453)	£5,227 (1.1)	8 (0.60)	£2,990 (£0–£8,399)	£23,916 (2.2)
Hockey	15 (1.6)	£427 (£0–£857)	£6,415 (1.4)	37 (2.8)	£387 (£191–£583)	£14,316 (1.3)
Cricket	43 (4.6)	£264 (£197–£332)	£11,377 (2.5)	26 (2.0)	£264 (£217–£313)	£6,882 (0.63)
Swimming	33 (3.5)	£241 (£204–£278)	£7,950 (1.7)	11 (0.83)	£240 (£175–£305)	£2,643 (0.24)
Diving	25 (2.7)	£224 (£189–£260)	£5,605 (1.2)	9 (0.68)	£264 (£153–£377)	£2,382 (0.22)
Ice skating	20 (2.1)	£249 (£196–£302)	£4,986 (1.1)	13 (0.98)	£430 (£93–£768)	£5,596 (0.52)
Netball	3 (0.32)	£270 (£0–£621)	£810 (0.18)	2 (0.15)	£331 (£0–£661)	£662 (0.06)
Water sports-NOS	23 (2.4)	£311 (£126–£496)	£7,154 (1.5)	10 (0.75)	£253 (£117–£390)	£2,532 (0.23)
Gymnastics	5 (0.53)	£188 (£188–£188)	£942 (0.20)	7 (0.53)	£240 (£113–£367)	£1,681 (0.16)
Baseball/softball	22 (2.3)	£210 (£185–£235)	£4,627 (1.0)	8 (0.60)	£2,533 (£0–£6,448)	£20,260 (1.9)
Racket	14 (1.5)	£243 (£193–£293)	£3,407 (0.74)	9 (0.68)	£284 (£188–£379)	£2,552 (0.24)

1							
2							
3	Golf	11 (1.2)	£789 (£16–£1,561)	£8,677 (1.9)	4 (0.30)	£280 (£117–£443)	£1,120 (0.10)
4	Surfing	3 (0.32)	£525 (£0–£1,973)	£1,575 (0.34)	11 (0.83)	£394 (£5–£784)	£4,336 (0.40)
5	Boating	2 (0.21)	£209 (£0–£465)	£417 (0.09)	9 (0.68)	£570 (£246–£95)	£5,133 (0.47)
6	Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£188)	£942 (0.09)
7	Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
8	Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£79)	£1,803 (0.17)
9	Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,074)	£740 (0.07)
10	High jump	4 (0.43)	£380 (£154–£606)	£1,520 (0.33)	0		
11	Roller skating	2 (0.21)	£188 (£188–£188)	£377 (0.08)	0		
12	Volleyball	2 (0.21)	£209 (£0–£465)	£417 (0.09)	3 (0.23)	£270 (£0–£661)	£810 (0.08)
13	Cheerleading	0			0		
14	Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£729)	£1,096 (0.10)
15	Lacrosse	0			3 (0.23)	£404 (£0–£1,331)	£1,212 (0.11)
16	Rollerblading	0			0		
17	Boxing	2 (0.21)	£369 (£0–£2,674)	£740 (0.16)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
18	Handball	0			3 (0.23)	£188 (£188–£188)	£565 (0.05)
19	All-terrain vehicle	2 (0.21)	£2,186 (£0–£27,566)	£4,371 (0.95)	0		
20	Touch football	0			2 (0.15)	£331 (£0–£1,331)	£662 (0.06)
21	Skating-NOS	0			0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; NOS, not otherwise specified.

Appendix 4 Acute care costs[†] for girls in the sports cohort

Females	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	346 (55)	£526 (£435–£617)	£182,009 (46)	282 (45)	£746 (£522–£970)	£210,439 (54)
<i>Sports activities</i>						
Bicycle riding	66 (19)	£691 (£390–£991)	£45,573 (25)	22 (7.8)	£1,242 (£403–£2,080)	£27,314 (13)
Australian rules football	2 (0.58)	£188 (£188–£188)	£377 (0.21)	8 (2.8)	£249 (£155–£344)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£441)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,442)	£5,223 (2.5)
Soccer	10 (2.9)	£213 (£158–£268)	£2,129 (1.2)	24 (8.5)	£283 (£191–£374)	£6,777 (3.2)
Scooter	44 (13)	£384 (£270–£499)	£16,904 (9.3)	5 (1.8)	£295 (£113–£477)	£1,472 (0.70)
Rugby	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	9 (3.2)	£297 (£198–£397)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,366)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,643)	£38,095 (18)
Horse riding	44 (13)	£872 (£538–£1,207)	£38,386 (21)	38 (13)	£1,456 (£590–£2,321)	£55,327 (26)
Hockey	8 (2.3)	£260 (£159–£361)	£2,078 (1.1)	19 (6.7)	£252 (£202–£305)	£4,795 (2.3)
Cricket	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
Swimming	22 (6.4)	£259 (£208–£309)	£5,693 (3.1)	6 (2.1)	£236 (£133–£339)	£1,416 (0.67)
Diving	15 (4.3)	£577 (£0–£1,166)	£8,650 (4.8)	12 (4.3)	£717 (£0–£1,784)	£8,597 (4.1)
Ice skating	13 (3.8)	£513 (£37–£988)	£6,662 (3.7)	6 (2.1)	£465 (£28–£903)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£288)	£7,233 (3.4)
Water sports-NOS	9 (2.6)	£216 (£153–£278)	£1,940 (1.1)	3 (1.1)	£202 (£144–£260)	£606 (0.29)
Gymnastics	20 (5.8)	£276 (£212–£339)	£5,513 (3.0)	6 (2.1)	£270 (£137–£403)	£1,620 (0.77)
Baseball/softball	4 (1.2)	£703 (£0–£2,339)	£2,810 (1.5)	0		

1							
2							
3	Racket	2 (0.58)	£188 (£188–£188)	£377 (0.21)	3 (1.1)	£188 (£188–£188)	£565 (0.27)
4	Golf	5 (1.4)	£633 (£0–£1,681)	£3,166 (1.7)	2 (0.71)	£331 (£0–£2,145)	£662 (0.27)
5	Surfing	5 (1.4)	£196 (£174–£219)	£982 (0.54)	1 (0.36)	£188	£188 (0.09)
6	Boating	3 (0.87)	£1,369 (£0–£4,426)	£4,108 (2.3)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
7	Martial Arts	0			3 (1.1)	£483 (£99–£866)	£1,449 (0.69)
8	Dancing	6 (1.7)	£188 (£188–£188)	£1,130 (0.62)	2 (0.71)	£248 (£0–£995)	£494 (0.24)
9	Athletics	1 (0.29)	£188	£188 (0.10)	0		
10	Snow sports	2 (0.58)	£2,533 (£0–£32,325)	£5,066 (2.8)	4 (1.4)	£1,613 (£0–£6,105)	£6,452 (3.1)
11	High jump	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	2 (0.71)	£453 (£197–£711)	£907 (0.43)
12	Skateboarding	10 (2.9)	£602 (£5–£1,198)	£6,018 (3.3)	13 (4.6)	£791 (£119–£1,463)	£10,279 (4.9)
13	Volleyball	0			2 (0.71)	£267 (£0–£1,277)	£535 (0.25)
14	Cheerleading	0			6 (2.1)	£318 (£184–£452)	£1,906 (0.91)
15	Dodgeball	0			1 (0.36)	£188	£188 (0.09)
16	Lacrosse	0			2 (0.71)	£248 (£0–£995)	£494 (0.24)
17	Roller skating	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£188 (£188–£188)	£377 (0.18)
18	Boxing	0			0		
19	Handball	0			0		
20	All-terrain vehicle	1 (0.29)	£433	£433 (0.24)	0		
21	Touch football	0			0		
22	Skating-NOS	1 (0.29)	£188	£188 (0.10)	0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; NOS, not otherwise specified.

BMJ Paediatrics Open

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Journal:	<i>BMJ Paediatrics Open</i>
Manuscript ID	bmjpo-2022-001723.R1
Article Type:	Original research
Date Submitted by the Author:	29-Oct-2022
Complete List of Authors:	<p>Singh, Sonia; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Hoch, Jeffrey; University of California Davis Health System, Center for Healthcare Policy and Research, ; University of California Davis, Department of Public Health Sciences</p> <p>Hearps, Stephen; Murdoch Children's Research Institute, Child Neuropsychology</p> <p>Dalziel, Kim ; The University of Melbourne School of Population and Global Health, Centre for Health Policy</p> <p>Cheek, John; Royal Children's Hospital Melbourne, Emergency Department</p> <p>Holmes, James; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Anderson, Vicki; Murdoch Children's Research Institute</p> <p>Kuppermann, Nathan; University of California Davis School of Medicine, Department of Emergency Medicine; University of California Davis School of Medicine, Department of Pediatrics</p> <p>Babl, Franz; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; The Royal Children's Hospital Melbourne, Emergency Department</p>
Keywords:	Health Economics, Health services research

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Sonia Singh,^{1,2,3} Jeffrey S. Hoch,^{4,5} Stephen J.C. Hearps,² Kim Dalziel,^{2,6} John A. Cheek,^{1,2,7}

James F. Holmes,^{3,5} Vicki Anderson,^{1,2,8} Nathan Kuppermann,^{3,9} and Franz E. Babl^{1,2,7}

1. Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne, Melbourne, VIC, Australia
2. Murdoch Children's Research Institute, Melbourne, VIC, Australia
3. Department of Emergency Medicine, University of California Davis School of Medicine, Sacramento, CA, USA
4. Division of Health Policy and Management, Department of Public Health Sciences, University of California at Davis, Davis, California, USA
5. Center for Healthcare Policy and Research, University of California at Davis, Sacramento, California, USA
6. Centre for Health Policy, The University of Melbourne School of Population and Global Health, Melbourne, VIC, Australia
7. Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia
8. Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia
9. Department of Pediatrics, University of California Davis School of Medicine, Sacramento, CA, USA

Corresponding Author: Dr Sonia Singh

Department of Paediatrics, The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Melbourne, Victoria, Australia

Email: singhsd@student.unimelb.edu.au

Author Affiliations

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1. Sonia Singh, MBBS, MPH, MBA, MSc

Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of

Melbourne, Melbourne, VIC, Australia

Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

Department of Emergency Medicine

University of California Davis School of Medicine, Sacramento, CA, USA

2. Jeffrey S. Hoch, PhD

Division of Health Policy and Management, Department of Public Health Sciences,

University of California at Davis, Davis, California, USA

Center for Healthcare Policy and Research,

University of California at Davis, Sacramento, California, USA

3. Stephen J.C. Hearps, MBIostat

Child Neuropsychology, Murdoch Children's Research Institute, Melbourne, VIC, Australia

4. Kim Dalziel, PhD

Centre for Health Policy, The University of Melbourne School of Population and Global

Health, Melbourne, VIC, 3010, Australia

Health Services, Centre for Community Child Health, Murdoch Children's Research Institute,

Melbourne, VIC, Australia

5. John A. Cheek, MBBS

1
2
3 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
4 Melbourne, Melbourne, VIC, Australia

5
6
7 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

8
9
10 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia

11
12
13
14
15 6. James F. Holmes, MD, MPH

16
17 Department of Emergency Medicine

18
19 University of California Davis School of Medicine, Sacramento, CA, USA

20
21 Center for Healthcare Policy and Research,

22
23
24 University of California at Davis, Sacramento, California, USA

25
26
27
28 7. Vicki Anderson, PhD

29
30 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
31 Melbourne, Melbourne, VIC, Australia

32
33
34 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

35
36
37 Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia

38
39
40
41
42 8. Nathan Kuppermann MD, MPH

43
44 Department of Emergency Medicine

45
46 University of California Davis School of Medicine, Sacramento, CA, USA

47
48
49 Department of Pediatrics

50
51 University of California Davis School of Medicine, Sacramento, CA, USA

52
53
54
55
56 9. Franz E. Babl, MD, MPH, DMedSc

1
2
3 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
4 Melbourne, Melbourne, VIC, Australia
5

6
7
8 Emergency Research, Clinical Sciences, Murdoch Children's Research Institute, Melbourne,
9
10 VIC, Australia
11

12 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Confidential: For Review Only

ABSTRACT

Objective: To estimate traumatic brain injuries (TBIs) and acute care costs due to sports activities.

Methods: A planned secondary analysis of 7,799 children 5 to <18 years old with head injuries enrolled in a prospective multicentre study between 2011 and 2014. Sports-related TBIs were identified by the epidemiology codes for activity, place and injury mechanism. The sports cohort was stratified into two age groups (younger: 5–11 and older: 12–17 years). Acute care costs from the publicly funded Australian health system perspective are presented in 2018 pounds sterling (£).

Results: There were 2,903 children (37%) with sports-related TBIs. Mean age was 12.0 years (95% CI: 11.9–12.1 years); 78% were male. Bicycle riding was associated with the most TBIs (14%), with mean per-patient costs of £802 (95% CI: £644–£960) and 17% of acute costs. The highest acute costs (21%) were from motorcycle-related TBIs (3.8% of injuries), with mean per-patient costs of £3,795 (95% CI: £1,850–£5,739). For younger boys and girls, bicycle riding was associated with the highest TBIs and total costs; however, the mean per-patient costs were highest for motorcycle and horse riding, respectively. For older boys, rugby was associated with the most TBIs. However, motorcycle riding had the highest total and mean per-patient acute costs. For older girls, horse riding was associated with the most TBIs and highest total acute costs, and motorcycle riding with the highest mean per-patient costs.

Conclusion: Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.

Clinical Trial Registration: Australian New Zealand Clinical Trials Registry (ANZCTR)

ACTRN12614000463673

INTRODUCTION

Injuries from sports activities are a global health concern, with children 5–14 years requiring more medical care than other ages.¹ The need for comprehensive surveillance and injury prevention initiatives has been recognised internationally.^{2–4} Sports activities are frequently associated with traumatic brain injuries (TBIs) in children.^{5–7} In Australia, head trauma occurred with 5.8%–44% of all sports-related injuries in children with ED presentations between 1989–1993.⁵ Additionally, an increasing trend in hospitalisations for all sports injuries was reported between 2004 and 2010.⁸ In 2012, the age-standardised incidence rate of hospitalisations for all sports-related injuries in children ≤ 16 years was 281 per 100,000 population with annual costs of the Australian dollar (AUD) \$40 million.⁹ There are no population-based estimates of ED presentations for paediatric sports-related TBIs in Australia. Sports were the second-most common mechanism of injury in a cohort of approximately 18,000 Australian children presenting to ED with head injuries.⁷

In the UK, the annual incidence of head injuries in 2013 was 400 per 100,000 for children younger than 15 years. Sports activities were the second most frequent injury mechanism after falls, with Rugby, football, and horse riding being the most prevalent.⁶ In the US, the incidence of nonfatal sports-related TBIs in children in 2018 was 299 per 100,000.¹⁰ An increasing trend in ED visits for sports-related TBIs was reported between 2001 and 2012, followed by a subsequent decline of 27% by 2018.^{10 11} Contact sports accounted for approximately 45% of injuries, with American football and bicycle riding accounting for the most TBIs.⁴ While playground-related TBIs were the most common mechanism for children younger than 10 years, American football in boys and soccer in girls accounted for the most TBIs for older children.⁴

1
2
3 The aim of this study was to estimate the ED and acute hospital costs for children with TBIs
4 due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and
5 age of the child.
6
7
8
9
10

11 12 **METHODS**

13
14 This was a secondary analysis of the prospective multicentre Australasian Paediatric Head
15 Injury Study (APHIRST), in which 17,841 Australian children <18 years with head injuries
16 of *all* severities were enrolled between April 2011 and November 2014. There were two
17 mixed and six free-standing children's hospital emergency departments (EDs), all members of
18 the Paediatric Research in Emergency Departments International Collaborative (PREDICT)
19 network. The Human Research Ethics Committee of the Royal Children's Hospital (RCH),
20 Melbourne (reference, 31008A) and the institutional ethics committees at the participating
21 sites approved the study. The detailed methodology of the APHIRST study has been
22 previously published.¹² For this analysis, we excluded 2,296 children enrolled in New
23 Zealand to be consistent with the costing methods (Figure 1). The other exclusions have been
24 discussed previously.^{7 12}
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41

42 The costing analysis was conducted from a publicly funded health system perspective,
43 applying direct and indirect costs from the RCH to patient-level data in the Australian cohort
44 (Appendix 1).^{7 13} The details of the costing methods and data inputs have been published.⁷
45 Acute care included ED presentations with either discharge or acute admissions until hospital
46 discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals
47 (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All
48 costs were inflated to 2018 Australian dollars (\$) using the Reserve Bank of Australia general
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 consumer price index rates from 13 September 2019 and presented as pounds sterling with
4
5 the average exchange rate of UK £0.60 from 30 June 2018.^{14 15}
6
7
8
9

10 Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the
11 activity code for sports (activity = S) noted on the case report form of the APHIRST study.¹⁶
12
13

14 The research assistants assigned the activity codes at each site based on information the
15 clinician recorded at the ED visit, obtained from medical record review and during the follow-
16 up call.¹⁶ Epidemiology codes for activity, place and injury mechanism of injury employed by
17 the Victorian Injury Surveillance Unit in Australia were used across all study sites in
18 APHIRST.^{8 17 18} These codes were mapped to the International Classification of Diseases *10th*
19 *revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71) (Appendix
20 2).^{9 19} The combined football codes (U 50.01-50.05) included rugby, Australian rules football,
21 touch football, soccer and football-not otherwise specified.^{9 19}
22
23
24
25
26
27
28
29
30
31
32
33
34

35 We considered injuries sports-related if they occurred from organised or recreational sports.
36 Falls from playground equipment or casual play were excluded. Helmet use was noted for
37 TBIs from bicycle riding. The sports cohort was stratified into two age groups (younger: 5 to
38 11 and older: 12 to 17 years). TBI was defined as any injury to the brain caused by an external
39 force.²⁰ TBI severity was defined as mild, moderate, and severe. Mild TBI was defined as
40 Glasgow Coma Scale (GCS) scores of 13–15 on ED presentation, no neurological deficits,
41 with no evidence of TBI on cranial computed tomography (CT) or magnetic resonance
42 imaging (MRI) if performed.²¹ Moderate TBI included either GCS scores 9–13, or GCS scores
43 13–15 with neurological deficits or evidence of TBI on CT or MRI. Severe TBI was defined
44 as GCS scores ≤ 8 .²¹ Data analysis was performed with Stata (version 15; StataCorp, College
45 Station, TX).
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

RESULTS

Sports cohort: Patient characteristics

Of the 7,799 Australian children between 5 and 18 years with head injuries enrolled in APHIRST, 2,903 (37%) had TBIs from sports activities (Figure 1, Table 1). The mean age for the sports cohort was 12.0 years (95% CI: 11.9–12.1 years), and 78% were male. The acute care costs for sports-related TBIs were £1.9 million, with mean per-patient costs of £669 (95% CI: £566–£772). The acute admission rate was 34%, with mean per-patient costs of £1,559 (95% CI: £1,265–£1,853), which accounted for 80% of acute care costs. Paediatric intensive care unit admissions for 43 children (1.5% of the sports cohort) accounted for 29% of acute care costs, with mean per-patient costs of £13,199 (95% CI: £8,217–£18,180). There were no deaths reported from sports activities.

Table 1 Sports cohort: Demographics and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Ages 5–17 years	7,799 (100)	£749 (£650–£849)	£5,843,060 (100)
Sports cohort	2,903 (37)	£669 (£566–£772)	£1,942,345 (33)
Age group			
Younger (5–11 years)	1,286 (44)	£501 (£438–£564)	£644,045 (33)
Older (12–17 years)	1,617 (56)	£803 (£624–£982)	£1,298,300 (67)
Sex			
Male	2,272 (78)	£682 (£554–£810)	£1,549,252 (80)
Female	628 (22)	£625 (£513–£738)	£392,447 (20)
TBI severity[§]			
Mild	2,727 (93.9)	£443 (£389–£497)	£1,209,200 (62)
Moderate	146 (5.0)	£2,269 (£1,622–£2,916)	£331,272 (17)
Severe	30 (1.0)	£13,395 (£6,400–£20,392)	£401,873 (21)
Disposition			

Discharge from ED	1,902 (66)	£205 (£203–£206)	£389,483 (20)
Admission	995 (34)	£1,559 (£1,265–£1,853)	£1,551,083 (80)
Paediatric ward	267 (9.2)	£4,184 (£3,173–£5,194)	£1,117,009 (59)
PICU	43 (1.5)	£13,199 (£8,217–£18,180)	£567,538 (29)
Death	0 (0)	£0.00	£0.00

TBI, traumatic brain injury; CI, confidence interval; PICU, paediatric intensive care unit; ED, emergency department; NOS, not otherwise specified; GCS, Glasgow Coma Scale

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits, negative neuroimaging; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or positive neuroimaging; Severe TBI, GCS scores ≤ 8 .

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: TBI severity

Most head injuries from sports activities resulted in mild TBIs (94%), which were associated with 62% of the sports-related acute care costs with mean per-patient costs of £443 (95% CI: £389–£497) (Table 1). Moderate TBIs occurred with 5% of injuries, accounting for 17% of sports-related acute costs, with mean per-patient costs of £2,269 (95% CI: £1,622–£2,916). Severe TBIs in 1.0% of the sports cohort accounted for 21% of acute care costs, with mean per-patient costs of £13,395 (95% CI: £6,400–£20,392).

Sports cohort: Mechanisms of injury

The top ten individual sports in decreasing frequency (Figure 2, Table 2) cumulatively accounted for 76% of sports-related TBIs and 87% of acute care costs. Bicycle riding was associated with the most TBIs (14%) and 17% of sports-related acute care costs, with mean per-patient costs of £802 (95% CI: £644–£960). Children with bicycle-related TBIs who were not wearing helmets (48%) with mean per-patient costs of £1,047 (95% CI: £626–£1,468) accounted for 63% of bicycle-related costs. Motorcycle riding was associated with the largest proportion of moderate (9.1%) and severe TBIs (8.2%) for any sport. Further, with 3.8% of

TBIs, motorcycle riding was associated with the highest mean per-patient costs of £3,795 (95% CI: £1,850–£5,739) and acute costs (21%) from individual sports.

Team ball sports were associated with the most sports-related TBIs (45%), which accounted for 25% of acute care costs (Appendix 3). Specifically, the combined football codes (U50.01–50.05) were associated with 39% of sports-related TBIs and accounted for 21% of acute care costs. On the other hand, wheeled non-motored sports, with 26% of TBIs, were associated with the highest acute costs (35%) and wheeled motorsports, with 3.9% of TBIs, were associated with the highest mean per-patient cost.

Table 2 Sports-related TBIs and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Sports cohort	2903 (100)	£669 (£566–£773)	£1,942,345 (100)
Sports activities			
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
No helmet (% bicycle riding)	197 (48)	£1,047 (£626–£1,468)	£206,223 (63)
Australian rules football	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football-NOS	289 (10.0)	£370 (£298–£443)	£107,007 (5.5)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Motorcycle riding	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)

1				
2				
3				
4	Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
5	Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
6				
7	Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)
8				
9	Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
10				
11	Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
12				
13	Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
14				
15	Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
16				
17	Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
18				
19	Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
20				
21	Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
22				
23	Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
24				
25	Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
26				
27	Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
28				
29	High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
30				
31	Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
32				
33	Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
34				
35	Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
36				
37	Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
38				
39	Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
40				
41	Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
42				
43	Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
44				
45	All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
46				
47	Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
48				
49	Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
50				
51	Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

TBI, traumatic brain injury; NOS, not otherwise specified

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: Mechanisms of injury and TBI severity

By TBI severity, mild TBIs from bicycle riding (93% of bicycle riding injuries and 13% of the sports cohort) and severe TBIs from motorcycle riding (8% of motorcycle riding injuries

1
2
3 and 0.31% of the sports cohort) accounted for the highest acute care costs (11%) for the
4 sports cohort (Figure 2). In contrast, the combined football sports were associated with
5
6 primarily mild TBIs and the lowest acute costs.
7
8
9

10 11 12 **Sports cohort: Age groups**

13
14 In Figure 2, the top ten mechanisms of injury in decreasing frequency are shown for the
15 younger and older age groups, which accounted for 70% and 86% of sports-related TBIs,
16
17 respectively and 79% and 91% of associated acute care costs. Of the 1,286 children (44%) in
18
19 the younger age group, 73% were male. Similarly, 82% of the 1,617 children in the older age
20
21 group were male.
22
23
24
25

26
27 In the younger age group, bicycle riding was associated with the highest proportion of TBIs
28
29 (17%) and age group-related costs (26%). Although rugby was the most frequent injury
30
31 mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related
32
33 TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger
34
35 age group, mild TBIs from bicycle riding were associated with the highest group-related
36
37 acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest
38
39 group-related acute costs (15%) for sports injuries in the older age group.
40
41
42
43
44
45

46 47 **Sports cohort: Sex**

48
49 Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care
50
51 costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and
52
53 the highest acute costs (27%) for the age group (Figure 3, Appendix 4). For boys in the older
54
55 age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)
56
57
58
59
60

1
2
3 accounted for the highest acute costs (28%) for the age group. Motorcycle riding was
4 associated with the highest mean per-patient costs for boys in both age groups (Appendix 4).
5
6
7
8
9

10 For young girls, bicycle riding was associated with the most TBIs (19%) and the highest
11 acute costs (25%) for the age group (Figure 3, Appendix 5). For girls in the older age group,
12 horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%)
13 for the age group. The highest mean per-patient costs were associated with horse riding and
14 motorcycle riding for younger and older girls, respectively (Appendix 5).
15
16
17
18
19
20
21
22
23

24 DISCUSSION

25
26 This cost of illness study estimates the frequency and economic burden of TBIs from sports
27 activities in children between 5 and 18 years presenting to eight tertiary EDs in Australia.
28
29

30 While bicycle riding was associated with the most TBIs, motorcycle-related TBIs, with 4% of
31 injuries, were associated with the highest total and mean per-patient acute care costs. When
32 the combined effect of TBI severity and sports activities on the acute care costs were
33 explored, bicycle riding injuries with mild TBIs and motorcycle riding with severe TBIs
34 accounted for similar acute care costs for the sports cohort. Therefore, while motorcycle-
35 related injuries had the most severe TBIs and the highest patient-level costs, the combined
36 effect of injury frequency and TBI severity from bicycle and motorcycle riding contributed to
37 the high economic burden on the health system.
38
39
40
41
42
43
44
45
46
47
48
49
50

51 In a recent population-based report, the total acute care costs for *all* sports-related injuries in
52 Australia were AUD \$764 million for FY 2019.²² ED visits for *all* sports injuries accounted
53 for 22% of the total acute care costs (AUD \$164 million), and 37% of the ED costs were for
54 children <20 years, who accounted for 25% of the Australian population.^{22 23} The acute care
55
56
57
58
59
60

1
2
3 costs for sports-related TBIs were AUD \$32 million (4% of total costs for all sports injuries),
4
5 and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-
6
7 related TBIs accounted for 80% of the acute care costs.²²
8
9
10

11
12 There are few published reports of paediatric sports-related head injuries in Australia.^{16 18 21}
13
14 While one study excluded bicycle, motorcycle and playground injuries,²¹ another did not
15
16 report motorcycle-related head injuries.¹⁶ Australian rules football was associated with the
17
18 highest proportion of head injuries in the retrospective study,²¹ baseball and softball were
19
20 associated with the most clinically important TBIs in the prospective study.¹⁶ In the current
21
22 study, we excluded playground injuries. We reported bicycle riding in younger children,
23
24 rugby in older boys and horse riding in older girls were associated with the most sports-
25
26 related TBIs.
27
28
29
30

31
32
33 To our knowledge, no prior studies have compared the acute costs of TBIs from sports
34
35 activities in children. In this study, bicycle riding was the most frequent injury mechanism for
36
37 the sports cohort and was associated with the highest costs for younger boys and girls.
38
39 Additionally, the highest mean per-patient costs were associated with motorcycle riding for
40
41 younger boys and horse riding for younger girls. While rugby was the most frequent injury
42
43 mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For
44
45 older girls, horse riding was associated with the most head injuries and the highest total acute
46
47 costs, and motorcycle riding with the highest mean per-patient costs. Education programmes
48
49 on safe riding practices and protective gear are needed to reduce sports-related TBIs.²⁴
50
51
52
53
54
55

56
57 Prior research has shown that helmet laws and the proper use of helmets reduce head injuries
58
59 and fatalities from bicycle riding.²⁵⁻³⁰ For the sports cohort, 52% of children with TBIs from
60

1
2
3 bicycle riding were reported to be wearing helmets, accounting for 37% of bicycle-related
4 acute care costs. Although we only obtained information regarding helmet use with bicycle
5 riding, the effect of helmet use on reducing TBIs with other wheeled sports is strongly
6 supported by research.^{31 32} The impact of helmet legislation on reducing fatalities from
7 motorcycle and bicycle riding has been shown globally.³³ In Australia, helmets are required
8 for motorcycle and bicycle riding for all ages.³⁴ In the UK, helmet use is required for
9 motorcycle riding for all ages.³⁵ Helmets are only recommended for riding bicycles, all-
10 terrain vehicles, scooters or skateboards. In the US, state and local laws are responsible for
11 helmet legislation, and there are no helmet laws for bicycle riding in 29 states and motorcycle
12 riding in 3 states.^{28 36} While helmet laws are necessary for reducing mortality from sports
13 activities, our results indicate that additional strategies are required to reduce head injury
14 severity.

15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33 This study is not without some limitations. First, we focused on acute care costs of sports-
34 related TBIs from the Australian publicly funded health system perspective. We did not
35 consider the number of contact hours associated with individual sports or the costs associated
36 with long-term follow-up and rehabilitation, which would increase the total costs of these
37 injuries. Second, we did not collect information regarding helmet use during non-bicycle
38 activities. Third, the high acute costs of severe TBIs could be associated with multi-organ
39 injuries which we did not evaluate. However, because individual cost inputs were applied
40 (Appendix 1), this would only be reflected in the length of hospital stay.⁷ Fourth, the
41 proportion of TBIs due to sports activities is likely underestimated because not all patients
42 present to tertiary EDs after head injuries. Prior research has shown that about 25% of ED
43 presentations for children in Australia occur at tertiary referral centres.³⁷ APHIRST enrolled
44 children across ten tertiary referral hospitals in Australia and New Zealand, possibly
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 underrepresenting rural and indigenous populations. Additionally, the rates of mild TBIs are
4 likely underestimated because most of these children are not seen in EDs and are managed at
5 home or by general practitioners.³⁸ Therefore, the acute care costs and TBIs reported with
6 sports, and other mechanisms may not be generalisable beyond tertiary referral EDs.
7
8
9
10
11
12
13

14 **CONCLUSION**

15
16 Sports activities are common mechanisms of TBIs in children and have a significant
17 economic impact on patients and the health system. Injury prevention strategies should focus
18 on age and sex-related sports activities to reduce the burden of TBIs in children. We highlight
19 the effect of TBI severity on the associated acute costs of head injuries from wheeled sports
20 in children. This has implications for resource allocations for population-based injury
21 surveillance and targeted injury prevention programmes.
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

ACKNOWLEDGMENTS

We thank the participating families and emergency department staff at participating sites. We thank Meredith L. Borland (Perth Children's Hospital, Perth, WA); Stuart R. Dalziel (Starship Children's Health, Auckland, New Zealand and Departments of Surgery and Paediatrics: Child and Youth Health, University of Auckland, Auckland, New Zealand); Ed Oakley (Royal Children's Hospital, Melbourne, VIC); Amit Kochar (Women's & Children's Hospital, Adelaide, SA); Natalie Phillips and Yuri Gilhotra (Queensland Children's Hospital, Brisbane, QLD); Sarah Dalton and Mary McCaskill (The Children's Hospital at Westmead, Sydney, NSW); Jeremy Furyk (The Townsville Hospital, Townsville, QLD); Jocelyn Neutze (Kidzfirst Middlemore Hospital, Auckland, New Zealand); Mark Lyttle (Bristol Royal Hospital for Children, Bristol, UK and Academic Department of Emergency Care, University of the West of England, Bristol, UK); Silvia Bressan (Department of Women's and Children's Health, University of Padova, Padova, Italy); and Louise Crowe (Murdoch Children's Research Institute, Melbourne, VIC) for their involvement with obtaining the data and prior data analysis.

FUNDING SOURCES/DISCLOSURES

Funding and support: The study was funded by grants from the National Health and Medical Research Council (project grant GNT1046727, Centre of Research Excellence for Pediatric Emergency Medicine GNT1058560), Canberra, Australia; the Murdoch Children's Research Institute, Melbourne, Australia; the Emergency Medicine Foundation (EMPJ-11162), Brisbane, Australia; Perpetual Philanthropic Services (2012/1140), Australia; Auckland Medical Research Foundation (No. 3112011) and the A + Trust (Auckland District Health Board), Auckland, New Zealand; WA Health Targeted Research Funds 2013, Perth,

1
2
3 Australia; the Townsville Hospital and Health Service Private Practice Research and
4
5 Education Trust Fund, Townsville, Australia; and supported by the Victorian Government's
6
7 Infrastructure Support Program, Melbourne, Australia. The funding organisations were not
8
9 involved in the collection of the data, their analysis and interpretation, or in the approval or
10
11 rejection of the publication of the completed manuscript.
12
13

14
15
16
17 **Clinical Trial Registration:** Australian New Zealand Clinical Trials Registry (ANZCTR)
18
19 ACTRN12614000463673
20
21

22
23
24 **Competing interests:** No relevant disclosures.
25
26

27
28 **Financial Disclosure:** The authors have no financial relationships relevant to this article to
29
30 disclose.
31
32

33
34
35 **Patient and public involvement:** Patients and the public were not involved in
36
37 the design, or conduct, or reporting, or dissemination plans of this research.
38
39

40
41
42 **Patient consent for publication:** Not required.
43
44

45
46
47 **Provenance and peer review:** Not commissioned; externally peer reviewed
48
49

50
51 **Data availability statement:** All data relevant to the study are included in the article or
52
53 uploaded as supplementary information.
54
55

AUTHOR CONTRIBUTIONS

SS conceptualised the study, conducted the analysis, wrote the first draft of the manuscript, and reviewed and revised the manuscript. FEB conceptualised and designed, coordinated and supervised data collection of APHIRST, contributed to data interpretation, and critically reviewed and revised the manuscript. SS, JAC, and KD acquired the cost data and conducted the analysis. SJCH had full access to the data, analysed the data, contributed to data interpretation, and critically reviewed and revised the manuscript. JSH, KD, JAC, JFH, VA, and NK contributed to the interpretation of the data and reviewed and revised the article critically. All authors revised the paper critically and approved the final manuscript as submitted.

ORCID iDs

Sonia Singh [0000-0003-2430-0262](https://orcid.org/0000-0003-2430-0262)

Jeffrey S. Hoch [0000-0002-4880-4281](https://orcid.org/0000-0002-4880-4281)

Stephen J.C. Hearps [0000-0003-2984-1172](https://orcid.org/0000-0003-2984-1172)

Kim Dalziel [0000-0003-4972-8871](https://orcid.org/0000-0003-4972-8871)

John A. Cheek [0000-0002-3615-3821](https://orcid.org/0000-0002-3615-3821)

James F Holmes [0000-0003-3270-2720](https://orcid.org/0000-0003-3270-2720)

Vicki Anderson [0000-0001-5233-3147](https://orcid.org/0000-0001-5233-3147)

Nathan Kuppermann [0000-0002-7854-4943](https://orcid.org/0000-0002-7854-4943)

Franz E Babl [0000-0002-1107-2187](https://orcid.org/0000-0002-1107-2187)

FIGURE LEGENDS

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort
TBI, traumatic brain injury

Figure 2. Sports-related TBI severity[§] and acute care costs[†] by age groups

Top ten sports activities in decreasing order of injury frequency

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

[§]TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤ 8
TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

(Please use colour for Figure 2)

Figure 3. Acute care costs[†] of sports-related TBIs stratified by age and sex

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

1
2
3 *What is already known on this topic*
4

- 5 • Sports activities are frequently associated with traumatic brain injuries in children.
6
7
8

9 *What this study adds*
10

- 11 • Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were
12 associated with the highest mean per-patient and total acute care costs.
13
14 • Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated
15 with the highest total acute care costs for the sports cohort.
16
17 • The highest mean per-patient costs were from horse riding in younger girls and
18 motorcycle riding for older girls and boys in both age groups.
19
20
21

22 *How this study might affect research, practice or policy*
23

- 24 • Injury prevention strategies should focus on age and sex-related sports activities to reduce
25 the burden of TBIs in children.
26
27 • While contact sports are common mechanisms of injury, they are not associated with
28 severe TBIs or high acute care costs.
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

REFERENCES

1. Finch C, Cassell E. The public health impact of injury during sport and active recreation. *J Sci Med Sport* 2006;9(6):490–7. doi:10.1016/j.jsams.2006.03.002
2. Australian Institute of Health and Welfare. National sports injury data strategy: draft consultation report. Cat. No. INJCAT 222. Canberra: Australian Institute of Health and Welfare, 2022.
3. Timpka T, Finch CF, Goulet C, et al. Meeting the global demand of sports safety. The intersection of science and policy in sports safety. *Sports Med* 2008;38(10):795–805. doi:10.2165/00007256-200838100-00001
4. Sarmiento K, Thomas KE, Daugherty J, et al. Emergency department visits for sports- and recreation-related traumatic brain injuries among children—United States, 2010–2016. *MMWR Morb Mortal Wkly Rep* 2019;68:237–42. doi:10.15585/mmwr.mm6810a2
5. Finch C, Valuri G, Ozanne-Smith J. Sport and active recreation injuries in Australia: evidence from emergency department presentations. *Br J Sports Med* 1998;32:220–25. doi:10.1136/bjism.32.3.220
6. Trefan L, Houston R, Pearson G, et al. Epidemiology of children with head injury: a national overview. *Arch Dis Child* 2016;101(6):527–32. doi:10.1136/archdischild-2015-308424
7. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274–80. doi:10.1111/jpc.15699
8. Finch CF, Wong Shee A, Clapperton A. Time to add a new priority target for child injury prevention? The case for an excess burden associated with sport and exercise injury: population-based study. *BMJ Open* 2014;4(7):e005043. doi:10.1136/bmjopen-2014-005043

- 1
2
3 9. Lystad RP, Curtis K, Browne GJ, et al. Incidence, costs, and temporal trends of sports
4
5 injury-related hospitalisations in Australian children over a 10-year period: A nationwide
6
7 population-based cohort study. *J Sci Med Sport* 2019;22(2):175–80.
8
9 doi:10.1016/j.jsams.2018.07.010
10
11
- 12 10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in Sports- and Recreation-Related
13
14 Traumatic Brain Injuries Treated in US Emergency Departments: The National Electronic
15
16 Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma*
17
18 *Rehabil* 2015;30(3):185–97. doi:10.1097/HTR.000000000000156
19
20
- 21 11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for
22
23 contact sports-related traumatic brain injuries among children—United States, 2001–
24
25 2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870–74. doi:10.15585/mmwr.mm6927a4
26
27
- 28 12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE
29
30 head injury decision rules in children: a prospective cohort study. *Lancet*
31
32 2017;389(10087):2393–402. doi:10.1016/s0140-6736(17)30555-x
33
34
- 35 13. Singh S, Babl FE, Huang L, et al. Paediatric traumatic brain injury severity and acute care
36
37 costs. *Arch Dis Child* 2022;107:497–99. doi:10.1136/archdischild-2021-322966
38
39
- 40 14. The Reserve Bank of Australia inflation calculator: Reserve Bank of Australia. Available:
41
42 <https://www.rba.gov.au/calculator/> [Accessed September 19 2018].
43
44
- 45 15. Australian Taxation Office. Foreign currency exchange rates for financial year ending
46
47 2018. Available: [https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-](https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-June-2018/)
48
49 [June-2018/](https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-June-2018/) [Accessed August 31 2020].
50
51
- 52 16. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain
53
54 injuries in children. *Med J Aust* 2019;211(8):365–66. doi:10.5694/mja2.50311
55
56
57
58
59
60

17. Australian Institute of Health and Welfare. Injury surveillance National Minimum Data Set. National Health Data Dictionary. Version 12. AIHW Cat. No. HWI 57. Canberra: Australian Institute of Health and Welfare, 2003.
18. Fernando DT, Berecki-Gisolf J, Finch CF. Sports injuries in Victoria, 2012–13 to 2014–15: evidence from emergency department records. *Med J Aust* 2018;208(6):255–60. doi:10.5694/mja17.00872
19. AIHW: Kreisfeld R, Harrison JE. Hospitalised sports injury in Australia, 2016–17. Injury Research and Statistics Series No.131. Cat. No. INJCAT 211. Canberra: Australian Institute of Health and Welfare, 2020.
20. Centers for Disease Control and Prevention. *Traumatic brain injury and concussion* Atlanta, GA: National Center for Injury Prevention and Control; [updated March 07, 2022]. Available: <https://www.cdc.gov/traumaticbraininjury/concussion/symptoms.html> [Accessed April 09 2022].
21. Crowe LM, Anderson V, Catroppa C, et al. Head injuries related to sports and recreation activities in school-age children and adolescents: data from a referral centre in Victoria, Australia. *Emerg Med Australas* 2010;22(1):56–61. doi:10.1111/j.1742-6723.2009.01249.x
22. Australian Institute of Health and Welfare. Economics of sports injury and participation – Preliminary results. Cat. No. INJCAT 224. Canberra: Australian Institute of Health and Welfare, 2022.
23. Australian Demographic Statistics (June 2019). Table 7: Population by age and sex tables [data cubes] Canberra: Australian Bureau of Statistics; 2019. Available: <https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument> [Accessed July 18 2020].

- 1
2
3 24. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged
4 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance
5 Unit, Monash University Accident Research Centre, 2016.
6
7
8
9
10 25. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a*
11 *formal review. June 2020.* ACT: Australian Transport Safety Bureau, 2000.
12
13
14 26. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid*
15 *Anal Prev* 2001;33:345–52. doi:10.1016/s0001-4575(00)00048-8
16
17
18
19 27. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta,
20 GA: National Center for Injury Prevention and Control. Available:
21 <https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html> [Accessed
22 09 Apr 2022].
23
24
25
26
27
28 28. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and*
29 *countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National
30 Transportation Safety Board, 2019.
31
32
33
34 29. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to
35 increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76–82.
36
37
38
39
40
41
42
43 30. Olivier J, Creighton P. Bicycle injuries and helmet use: a systematic review and meta-
44 analysis. *Int J Epidemiol* 2017;46(1):278–92. doi:10.1093/ije/dyw153
45
46
47 31. Institute of Medicine (IOM) and National Research Council (NRC). *Sports-related*
48 *concussions in youth: Improving the science, changing the culture.* Washington, DC: The
49 National Academies Press, 2014.
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
32. Weiss H, Agimi Y, Steiner C. Youth motorcycle-related brain injury by state helmet law type: United States, 2005–2007. *Pediatrics* 2010;126(6):1149–55.
doi:10.1542/peds.2010-0902
33. Cassidy JD, Carroll LJ, Peloso PM, et al. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabil Med* 2004(Suppl. 43):28–60.
doi:10.1080/16501960410023732
34. Kaddis M, Stockton K, Kimble R. Trauma in children due to wheeled recreational devices. *J Paediatr Child Health* 2016;52(1):30–3. doi:10.1111/jpc.12986
35. The highway code: Department of Transport. UK Government; 2015, updated 2021.
Available: <https://www.highwaycodeuk.co.uk> [Accessed 04 Jun 2021].
36. Centers for Disease Control and Prevention. Universal motorcycle helmet laws Atlanta, GA: National Center for Injury Prevention and Control. Available:
<https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/mchelmet.html> [Accessed 09 Apr 2022].
37. Lim JC, Borland ML, Middleton PM, et al. Where are children seen in Australian emergency departments? Implications for research efforts. *Emerg Med Australas* 2021;33(4):631–39. doi:10.1111/1742-6723.13698
38. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of Health Care Entry for Youth With Concussion Within a Large Pediatric Care Network. *JAMA Pediatr* 2016;170(7):e160294. doi:10.1001/jamapediatrics.2016.0294

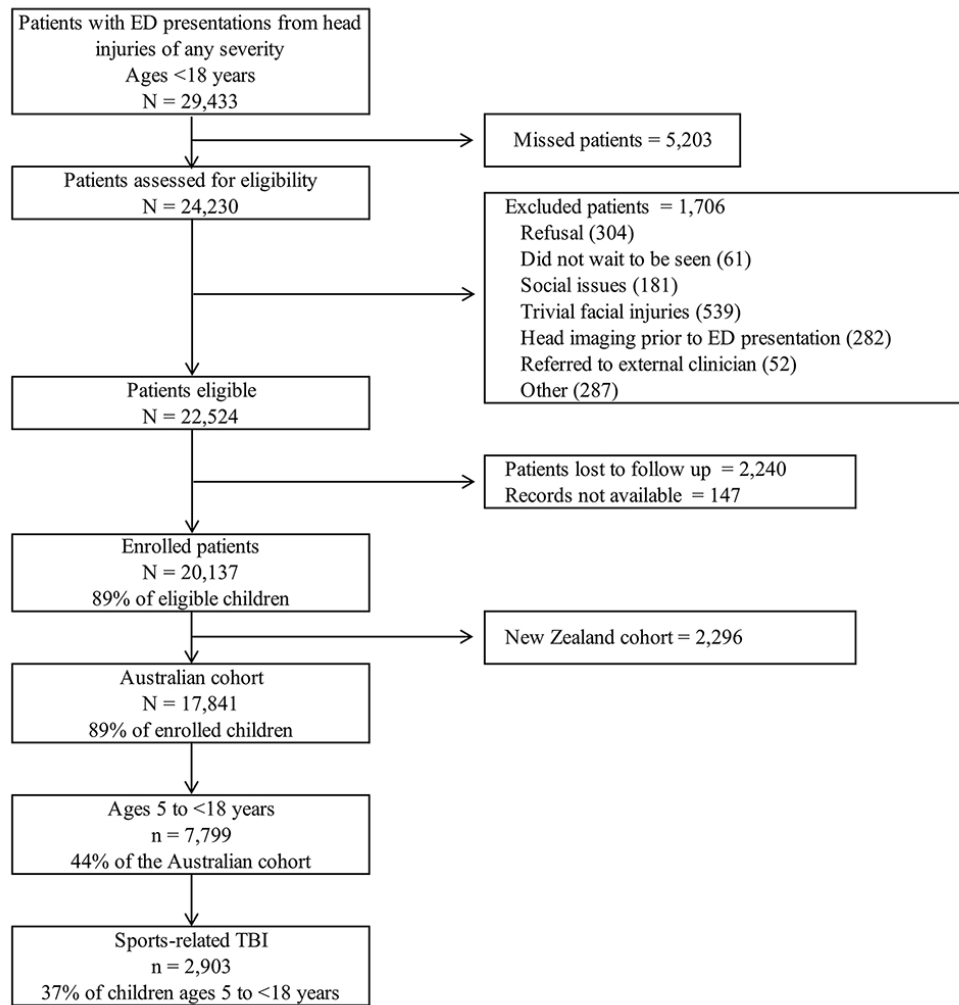


Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort TBI, traumatic brain injury

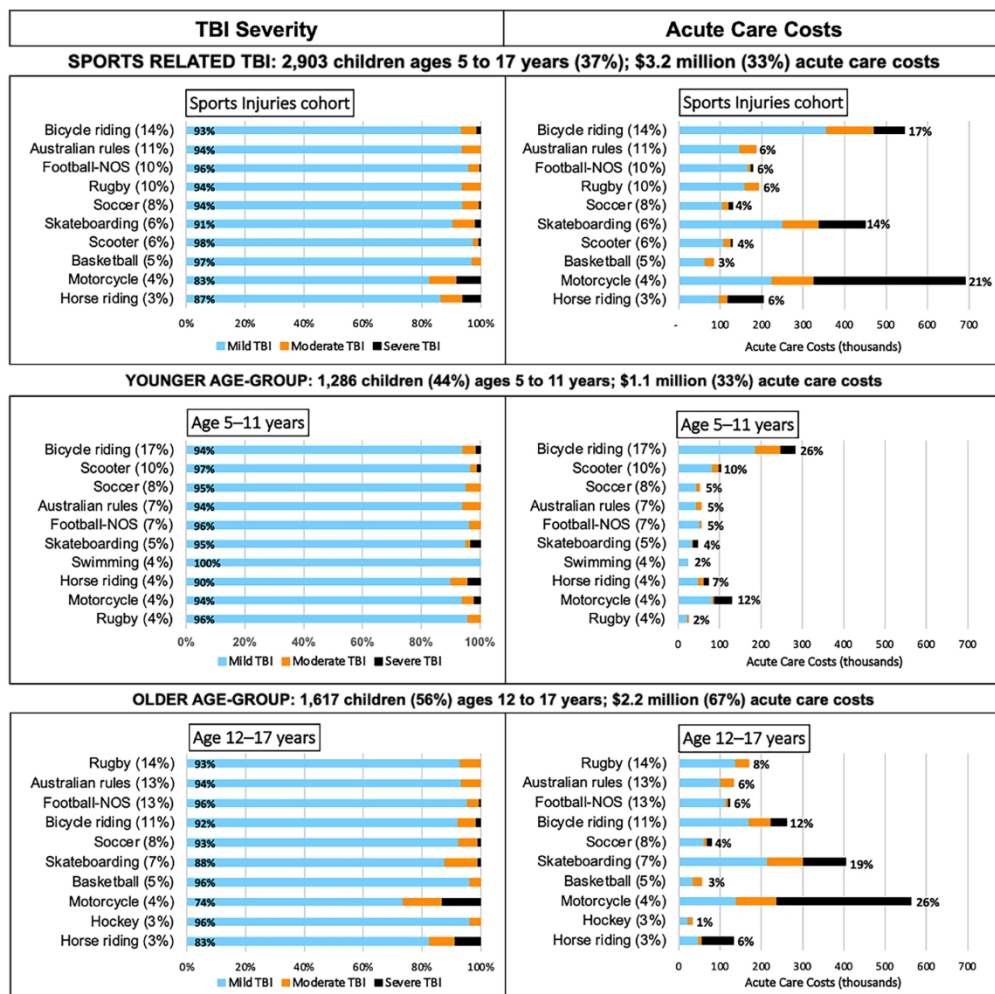


Figure 2. Sports-related TBI severity§ and acute care costs† by age groups

Top ten sports activities in decreasing order of injury frequency

†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤8

TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

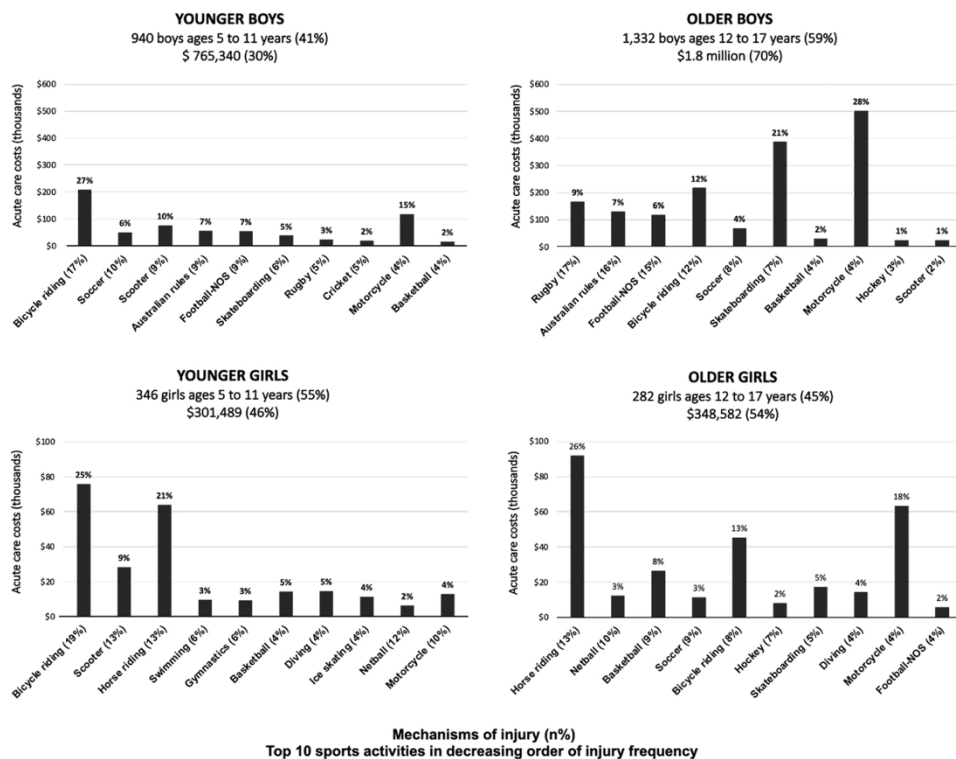


Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
 †Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Appendix 1 Source: the author: Acute care cost[†] inputs¹

	Mean cost	95% CI	Source
ED visit	£188	£183–£194	RCH data
Admission			
SSU/day	£245	£223–£267	RCH data
Ward/day	£969	£944–£994	RCH data
ICU/day	£2,456	£2,287_£2,624	RCH data
Intervention			
Intubation	£177	£4–£351	Dalziel et al. ²
Neurosurgery	£1,442	£1,300–£1,584	RCH data
Radiology			
Cranial CT	£118	£2–£233	MBS schedule (2018) ³
Brain MRI	£243	£5–£482	MBS schedule (2018)
Skull X-ray	£39	£1–£78	MBS schedule (2018)
Cranial Ultrasound	£66	£1–£130	MBS schedule (2018)
Follow up			
GP visit	£40	£1–£80	MBS schedule (2018)

[†]Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; RCH, Royal Children's Hospital; ED, emergency department; SSU, short stay unit; ICU, intensive care unit; CT, computed tomography; MRI, magnetic resonance imaging; GP, general practitioner; MBS, Medicare Benefits Schedule

Appendix 2 Overview of ICD-10-AM external cause codes for sporting activities.^{4,5}

ICD-10-AM code	Activity	Examples
U50	Team ball sports	Football; basketball; handball; netball; volleyball
U50.01-05	Football	Australian rules; rugby; soccer; touch football; football-NOS
U51	Team bat or stick sports	Baseball; softball; T-ball; cricket; hockey
U52	Team water sports	Synchronised swimming; water polo
U53	Boating sports	Canoeing; kayaking; rowing; sailing
U54	Individual water sports	Diving; swimming; water skiing; surfing; windsurfing; fishing
U55	Ice and snow sports	Ice skating; skiing; snowboarding; curling; bobsledding
U56	Individual athletic activities	Aerobics; running; walking; track; and field
U57	Acrobatic sports	Gymnastics
U58	Aesthetic activities	Dancing; marching
U59	Racquet sports	Badminton; racquetball; squash; tennis; table tennis
U60	Target and precision sports	Archery; bowling; golf; shooting; billiards
U61	Combative sports	Boxing; kickboxing; fencing; judo; karate; wrestling
U62	Power sports	Powerlifting; weightlifting; strength training; wood chopping
U63	Equestrian activities	Showjumping; dressage; steeplechase; horse racing; rodeo; polo
U64	Adventure sports	Rock climbing; abseiling; rafting; hiking; bungee jumping
U65	Wheeled motor sports	Motorcycling; motor car racing; go-carting; all-terrain vehicle riding
U66	Wheeled non motored sports	Cycling; rollerblading; roller skating; skateboarding; scooter riding
U67	Multidiscipline sports	Biathlon (winter); triathlon; modern pentathlon; decathlon
U68	Aero sports	Paragliding; sky diving; hot air ballooning; aerobatics; parasailing
U69	Other school-related recreational activities	School physical education class; school free play
U70	Other specified sport and exercise activity	CrossFit; use of fitness equipment
U71	Unspecified sports and exercise activity	

International Classification of Diseases *10th revision-Australian Modification*, ICD-10-AM; NOS, not otherwise specified
 Reprinted (adapted) from the Journal of Science and Medicine in Sport, 2019;22(2), Lystad RP, Curtis K, Browne GJ, Mitchell RJ. Incidence, costs, and temporal trends of sports injury-related hospitalisations in Australian children over a 10-year period: A nationwide population-based cohort study, Appendix A, Copyright (2019), with permission from Elsevier.

Appendix 3 Acute care costs[†] for sports-related TBIs using the ICD-10-AM external cause codes

Sports Cohort	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs	2,903 (100)	£669 (£566–£773)	£1,942,345 (100)
<i>U50: Team ball sports</i>	1,315 (45)	£366 (£334–£398)	£481,241 (25)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
<i>U50.01-05: Football</i>	1,120 (39)	£369 (£336–£403)	£413,952 (21)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
AFL	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football - not specified	289 (10)	£370 (£298–£443)	£107,007 (5.5)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
<i>U50.1-50.3: Basketball and Netball</i>	179 (6.2)	£354 (£245–£462)	£63,301 (3.3)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
<i>U51: Team bat sports</i>	193 (6.6)	£396 (£244–£548)	£76,476 (3.9)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
<i>U53: Boating sports</i>			
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)

U54: Individual water sports	198 (6.8)	£315 (£237–£392)	£62,248 (3.2)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)
Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
U55: Ice and snow sports	62 (2.1)	£531 (£276–£787)	£32,952 (1.7)
Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
U56: Individual athletics	21 (0.72)	£350 (£237–£464)	£7,353 (0.38)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
U57: Acrobatic activities	44 (1.5)	£265 (£227–£303)	£11,662 (0.60)
Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
U58: Dancing			
Dancing	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
U59: Racket sports			
Racket	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
U60: Target and precision sports			
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
U61: Combative sports	20 (0.69)	£389 (£155–£623)	£7,777 (0.40)
Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
U63: Equestrian			

Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
U65: Wheeled motored sports	113 (3.9)	£3,736 (£1,842–£5,631)	£422,216 (22)
Motorcycle	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
U66: Wheeled non-motored sports	759 (26)	£901 (£654–£1,148)	£683,981 (35)
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Skating - roller	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

International Classification of Diseases *10th revision-Australian Modification*, ICD-10-AM; CI, confidence interval; NOS, not otherwise specified

Appendix 4 Acute care costs[†] for boys in the sports cohort

Males	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	940 (41)	£491 (£412–£572)	£462,036 (30)	1,332 (59)	£816 (£605–£1,027)	£1,087,216 (70)
<i>Sports activities</i>						
Bicycle riding	158 (17)	£790 (£543–£1,037)	£124,859 (27)	163 (12)	£799 (£523–£1,075)	£130,177 (12)
Australian rules football	86 (9.1)	£377 (£250–£505)	£32,469 (7.0)	210 (16)	£369 (£292–£446)	£77,398 (7.1)
Football-NOS	81 (8.6)	£398 (£193–£602)	£32,207 (7.0)	195 (15)	£362 (£295–£430)	£70,644 (6.5)
Rugby	47 (5.0)	£283 (£248–£318)	£13,291 (2.9)	223 (17)	£444 (£355–£534)	£99,130 (9.1)
Soccer	96 (10)	£301 (£241–£362)	£28,912 (6.3)	112 (8.4)	£362 (£261–£461)	£40,468 (3.7)
Skateboarding	53 (5.6)	£412 (£264–£560)	£21,853 (4.7)	94 (7.1)	£2,481 (£633–£4,327)	£233,152 (21)
Scooter	88 (9.4)	£512 (£309–£715)	£45,047 (9.8)	30 (2.3)	£468 (£222–£714)	£14,037 (1.3)
Basketball	33 (3.5)	£262 (£216–£307)	£8,641 (1.9)	59 (4.4)	£300 (£220–£380)	£17,704 (1.6)
Motorcycle	39 (4.1)	£1,789 (£381–£3,198)	£69,787 (15)	50 (3.8)	£6,038 (£1,994–£10,082)	£301,916 (28)
Horse riding	7 (0.75)	£747 (£41–£1,453)	£5,227 (1.1)	8 (0.60)	£2,990 (£0–£8,399)	£23,916 (2.2)
Hockey	15 (1.6)	£427 (£0–£857)	£6,415 (1.4)	37 (2.8)	£387 (£191–£583)	£14,316 (1.3)
Cricket	43 (4.6)	£264 (£197–£332)	£11,377 (2.5)	26 (2.0)	£264 (£217–£313)	£6,882 (0.63)
Swimming	33 (3.5)	£241 (£204–£278)	£7,950 (1.7)	11 (0.83)	£240 (£175–£305)	£2,643 (0.24)
Diving	25 (2.7)	£224 (£189–£260)	£5,605 (1.2)	9 (0.68)	£264 (£153–£377)	£2,382 (0.22)
Ice skating	20 (2.1)	£249 (£196–£302)	£4,986 (1.1)	13 (0.98)	£430 (£93–£768)	£5,596 (0.52)
Netball	3 (0.32)	£270 (£0–£621)	£810 (0.18)	2 (0.15)	£331 (£0–£661)	£662 (0.06)
Water sports-NOS	23 (2.4)	£311 (£126–£496)	£7,154 (1.5)	10 (0.75)	£253 (£117–£390)	£2,532 (0.23)
Gymnastics	5 (0.53)	£188 (£188–£188)	£942 (0.20)	7 (0.53)	£240 (£113–£367)	£1,681 (0.16)
Baseball/softball	22 (2.3)	£210 (£185–£235)	£4,627 (1.0)	8 (0.60)	£2,533 (£0–£6,448)	£20,260 (1.9)
Racket	14 (1.5)	£243 (£193–£293)	£3,407 (0.74)	9 (0.68)	£284 (£188–£379)	£2,552 (0.24)

Golf	11 (1.2)	£789 (£16–£1,561)	£8,677 (1.9)	4 (0.30)	£280 (£117–£443)	£1,120 (0.10)
Surfing	3 (0.32)	£525 (£0–£1,973)	£1,575 (0.34)	11 (0.83)	£394 (£5–£784)	£4,336 (0.40)
Boating	2 (0.21)	£209 (£0–£465)	£417 (0.09)	9 (0.68)	£570 (£246–£95)	£5,133 (0.47)
Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£88)	£942 (0.09)
Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£88)	£377 (0.04)
Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£79)	£1,803 (0.17)
Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,74)	£740 (0.07)
High jump	4 (0.43)	£380 (£154–£606)	£1,520 (0.33)	0		
Roller skating	2 (0.21)	£188 (£188–£188)	£377 (0.08)	0		
Volleyball	2 (0.21)	£209 (£0–£465)	£417 (0.09)	3 (0.23)	£270 (£0–£61)	£810 (0.08)
Cheerleading	0			0		
Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£79)	£1,096 (0.10)
Lacrosse	0			3 (0.23)	£404 (£0–£1,31)	£1,212 (0.11)
Rollerblading	0			0		
Boxing	2 (0.21)	£369 (£0–£2,674)	£740 (0.16)	2 (0.15)	£188 (£188–£88)	£377 (0.04)
Handball	0			3 (0.23)	£188 (£188–£88)	£565 (0.05)
All-terrain vehicle	2 (0.21)	£2,186 (£0–£27,566)	£4,371 (0.95)	0		
Touch football	0			2 (0.15)	£331 (£0–£1,31)	£662 (0.06)
Skating-NOS	0			0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; NOS, not otherwise specified.

Appendix 5 Acute care costs[†] for girls in the sports cohort

Females	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	346 (55)	£526 (£435–£617)	£182,009 (46)	282 (45)	£746 (£522–£970)	£210,439 (54)
<i>Sports activities</i>						
Bicycle riding	66 (19)	£691 (£390–£991)	£45,573 (25)	22 (7.8)	£1,242 (£403–£2,080)	£27,314 (13)
Australian rules football	2 (0.58)	£188 (£188–£188)	£377 (0.21)	8 (2.8)	£249 (£155–£344)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£441)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,422)	£5,223 (2.5)
Soccer	10 (2.9)	£213 (£158–£268)	£2,129 (1.2)	24 (8.5)	£283 (£191–£374)	£6,777 (3.2)
Scooter	44 (13)	£384 (£270–£499)	£16,904 (9.3)	5 (1.8)	£295 (£113–£476)	£1,472 (0.70)
Rugby	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	9 (3.2)	£297 (£198–£395)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,366)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,623)	£38,095 (18)
Horse riding	44 (13)	£872 (£538–£1,207)	£38,386 (21)	38 (13)	£1,456 (£590–£2,321)	£55,327 (26)
Hockey	8 (2.3)	£260 (£159–£361)	£2,078 (1.1)	19 (6.7)	£252 (£202–£305)	£4,795 (2.3)
Cricket	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
Swimming	22 (6.4)	£259 (£208–£309)	£5,693 (3.1)	6 (2.1)	£236 (£133–£339)	£1,416 (0.67)
Diving	15 (4.3)	£577 (£0–£1,166)	£8,650 (4.8)	12 (4.3)	£717 (£0–£1,782)	£8,597 (4.1)
Ice skating	13 (3.8)	£513 (£37–£988)	£6,662 (3.7)	6 (2.1)	£465 (£28–£903)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£288)	£7,233 (3.4)
Water sports-NOS	9 (2.6)	£216 (£153–£278)	£1,940 (1.1)	3 (1.1)	£202 (£144–£260)	£606 (0.29)
Gymnastics	20 (5.8)	£276 (£212–£339)	£5,513 (3.0)	6 (2.1)	£270 (£137–£403)	£1,620 (0.77)
Baseball/softball	4 (1.2)	£703 (£0–£2,339)	£2,810 (1.5)	0		

2022-001723 on 31 January 2023. Downloaded from <http://bmjpaediatricsopen.bmj.com/> on April 19, 2024 by guest. Protected by copyright.

Racket	2 (0.58)	£188 (£188–£188)	£377 (0.21)	3 (1.1)	£188 (£188–£188)	£565 (0.27)
Golf	5 (1.4)	£633 (£0–£1,681)	£3,166 (1.7)	2 (0.71)	£331 (£0–£2,145)	£662 (0.27)
Surfing	5 (1.4)	£196 (£174–£219)	£982 (0.54)	1 (0.36)	£188	£188 (0.09)
Boating	3 (0.87)	£1,369 (£0–£4,426)	£4,108 (2.3)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
Martial Arts	0			3 (1.1)	£483 (£99–£866)	£1,449 (0.69)
Dancing	6 (1.7)	£188 (£188–£188)	£1,130 (0.62)	2 (0.71)	£248 (£0–£995)	£494 (0.24)
Athletics	1 (0.29)	£188	£188 (0.10)	0		
Snow sports	2 (0.58)	£2,533 (£0–£32,325)	£5,066 (2.8)	4 (1.4)	£1,613 (£0–£6,105)	£6,452 (3.1)
High jump	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	2 (0.71)	£453 (£197–£711)	£907 (0.43)
Skateboarding	10 (2.9)	£602 (£5–£1,198)	£6,018 (3.3)	13 (4.6)	£791 (£119–£1,463)	£10,279 (4.9)
Volleyball	0			2 (0.71)	£267 (£0–£1,277)	£535 (0.25)
Cheerleading	0			6 (2.1)	£318 (£184–£452)	£1,906 (0.91)
Dodgeball	0			1 (0.36)	£188	£188 (0.09)
Lacrosse	0			2 (0.71)	£248 (£0–£995)	£494 (0.24)
Roller skating	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£188 (£188–£188)	£377 (0.18)
Boxing	0			0		
Handball	0			0		
All-terrain vehicle	1 (0.29)	£433	£433 (0.24)	0		
Touch football	0			0		
Skating-NOS	1 (0.29)	£188	£188 (0.10)	0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018. CI, confidence interval; NOS, not otherwise specified.

REFERENCES

1. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274–80. doi:10.1111/jpc.15699
2. Dalziel K, Cheek JA, Fanning L, et al. A cost-effectiveness analysis comparing clinical decision rules PECARN, CATCH, and CHALICE with usual care for the management of pediatric head injury. *Ann Emerg Med* 2019;73(5):429–39. doi:10.1016/j.annemergmed.2018.09.030
3. Australian Government. MBS online: Medicare benefits schedule, 2018. Available: <http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/Home> [Accessed September 18 2019].
4. AIHW: Kreisfeld R, Harrison JE. Hospitalised sports injury in Australia, 2016–17. Injury Research and Statistics Series No.131, Cat. No. INJCAT 211. Canberra: Australian Institute of Health and Welfare, 2020.
5. Lystad RP, Curtis K, Browne GJ, et al. Incidence, costs, and temporal trends of sports injury-related hospitalisations in Australian children over a 10-year period: A nationwide population-based cohort study. *J Sci Med Sport* 2019;22(2):175–80. doi:10.1016/j.jsams.2018.07.010

BMJ Paediatrics Open

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Journal:	<i>BMJ Paediatrics Open</i>
Manuscript ID	bmjpo-2022-001723.R2
Article Type:	Original research
Date Submitted by the Author:	10-Dec-2022
Complete List of Authors:	<p>Singh, Sonia; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Hoch, Jeffrey; University of California Davis Health System, Center for Healthcare Policy and Research, ; University of California Davis, Department of Public Health Sciences</p> <p>Hearps, Stephen; Murdoch Children's Research Institute, Child Neuropsychology</p> <p>Dalziel, Kim ; The University of Melbourne School of Population and Global Health, Centre for Health Policy</p> <p>Cheek, John; Royal Children's Hospital Melbourne, Emergency Department</p> <p>Holmes, James; University of California Davis School of Medicine, Department of Emergency Medicine</p> <p>Anderson, Vicki; Murdoch Children's Research Institute</p> <p>Kuppermann, Nathan; University of California Davis School of Medicine, Department of Emergency Medicine; University of California Davis School of Medicine, Department of Pediatrics</p> <p>Babl, Franz; The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Department of Paediatrics; The Royal Children's Hospital Melbourne, Emergency Department</p>
Keywords:	Health Economics, Health services research

SCHOLARONE™
Manuscripts



I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our [licence](#).

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which [Creative Commons](#) licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Sonia Singh,^{1,2,3} Jeffrey S. Hoch,^{4,5} Stephen J.C. Hearps,² Kim Dalziel,^{2,6} John A. Cheek,^{1,2,7}

James F. Holmes,^{3,5} Vicki Anderson,^{1,2,8} Nathan Kuppermann,^{3,9} and Franz E. Babl^{1,2,7}

1. Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne, Melbourne, VIC, Australia
2. Murdoch Children's Research Institute, Melbourne, VIC, Australia
3. Department of Emergency Medicine, University of California Davis School of Medicine, Sacramento, CA, USA
4. Division of Health Policy and Management, Department of Public Health Sciences, University of California at Davis, Davis, California, USA
5. Center for Healthcare Policy and Research, University of California at Davis, Sacramento, California, USA
6. Centre for Health Policy, The University of Melbourne School of Population and Global Health, Melbourne, VIC, Australia
7. Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia
8. Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia
9. Department of Pediatrics, University of California Davis School of Medicine, Sacramento, CA, USA

Corresponding Author: Dr Sonia Singh

Department of Paediatrics, The University of Melbourne Faculty of Medicine Dentistry and Health Sciences, Melbourne, Victoria, Australia

Email: singhsd@student.unimelb.edu.au

Author Affiliations

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1. Sonia Singh, MBBS, MPH, MBA, MSc

Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of

Melbourne, Melbourne, VIC, Australia

Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

Department of Emergency Medicine

University of California Davis School of Medicine, Sacramento, CA, USA

2. Jeffrey S. Hoch, PhD

Division of Health Policy and Management, Department of Public Health Sciences,

University of California at Davis, Davis, California, USA

Center for Healthcare Policy and Research,

University of California at Davis, Sacramento, California, USA

3. Stephen J.C. Hearps, MBIostat

Child Neuropsychology, Murdoch Children's Research Institute, Melbourne, VIC, Australia

4. Kim Dalziel, PhD

Centre for Health Policy, The University of Melbourne School of Population and Global

Health, Melbourne, VIC, 3010, Australia

Health Services, Centre for Community Child Health, Murdoch Children's Research Institute,

Melbourne, VIC, Australia

5. John A. Cheek, MBBS

1
2
3 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
4 Melbourne, Melbourne, VIC, Australia

5
6
7 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

8
9
10 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia

11
12
13
14
15 6. James F. Holmes, MD, MPH

16
17 Department of Emergency Medicine

18
19 University of California Davis School of Medicine, Sacramento, CA, USA

20
21 Center for Healthcare Policy and Research,

22
23
24 University of California at Davis, Sacramento, California, USA

25
26
27
28 7. Vicki Anderson, PhD

29
30 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
31 Melbourne, Melbourne, VIC, Australia

32
33
34 Clinical Sciences, Murdoch Children's Research Institute, Melbourne, VIC, Australia

35
36
37 Department of Psychology, Royal Children's Hospital, Melbourne, VIC, Australia

38
39
40
41
42 8. Nathan Kuppermann MD, MPH

43
44 Department of Emergency Medicine

45
46
47 University of California Davis School of Medicine, Sacramento, CA, USA

48
49 Department of Pediatrics

50
51
52 University of California Davis School of Medicine, Sacramento, CA, USA

53
54
55
56 9. Franz E. Babl, MD, MPH, DMedSc

1
2
3 Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of
4 Melbourne, Melbourne, VIC, Australia
5

6
7
8 Emergency Research, Clinical Sciences, Murdoch Children's Research Institute, Melbourne,
9
10 VIC, Australia
11

12 Emergency Department, Royal Children's Hospital, Melbourne, VIC, Australia
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Confidential: For Review Only

ABSTRACT

Objective: To estimate traumatic brain injuries (TBIs) and acute care costs due to sports activities.

Methods: A planned secondary analysis of 7,799 children 5 to <18 years old with head injuries enrolled in a prospective multicentre study between 2011 and 2014. Sports-related TBIs were identified by the epidemiology codes for activity, place and injury mechanism. The sports cohort was stratified into two age groups (younger: 5–11 and older: 12–17 years). Acute care costs from the publicly funded Australian health system perspective are presented in 2018 pounds sterling (£).

Results: There were 2,903 children (37%) with sports-related TBIs. Mean age was 12.0 years (95% CI: 11.9–12.1 years); 78% were male. Bicycle riding was associated with the most TBIs (14%), with mean per-patient costs of £802 (95% CI: £644–£960) and 17% of acute costs. The highest acute costs (21%) were from motorcycle-related TBIs (3.8% of injuries), with mean per-patient costs of £3,795 (95% CI: £1,850–£5,739). For younger boys and girls, bicycle riding was associated with the highest TBIs and total costs; however, the mean per-patient costs were highest for motorcycle and horse riding, respectively. For older boys, rugby was associated with the most TBIs. However, motorcycle riding had the highest total and mean per-patient acute costs. For older girls, horse riding was associated with the most TBIs and highest total acute costs, and motorcycle riding with the highest mean per-patient costs.

Conclusion: Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.

Clinical Trial Registration: Australian New Zealand Clinical Trials Registry (ANZCTR)

ACTRN12614000463673

INTRODUCTION

Injuries from sports activities are a global health concern, with children 5–14 years requiring more medical care than other ages.¹ The need for comprehensive surveillance and injury prevention initiatives has been recognised internationally.^{2–4} Sports activities are frequently associated with traumatic brain injuries (TBIs) in children.^{5–7} In Australia, head trauma occurred with 5.8%–44% of all sports-related injuries in children with ED presentations between 1989–1993.⁵ Additionally, an increasing trend in hospitalisations for all sports injuries was reported between 2004 and 2010.⁸ In 2012, the age-standardised incidence rate of hospitalisations for all sports-related injuries in children ≤ 16 years was 281 per 100,000 population with annual costs of the Australian dollar (AUD) \$40 million.⁹ There are no population-based estimates of ED presentations for paediatric sports-related TBIs in Australia. Sports were the second-most common mechanism of injury in a cohort of approximately 18,000 Australian children presenting to ED with head injuries.⁷

In the UK, the annual incidence of head injuries in 2013 was 400 per 100,000 for children younger than 15 years. Sports activities were the second most frequent injury mechanism after falls, with Rugby, football, and horse riding being the most prevalent.⁶ In the US, the incidence of nonfatal sports-related TBIs in children in 2018 was 299 per 100,000.¹⁰ An increasing trend in ED visits for sports-related TBIs was reported between 2001 and 2012, followed by a subsequent decline of 27% by 2018.^{10 11} Contact sports accounted for approximately 45% of injuries, with American football and bicycle riding accounting for the most TBIs.⁴ While playground-related TBIs were the most common mechanism for children younger than 10 years, American football in boys and soccer in girls accounted for the most TBIs for older children.⁴

1
2
3 The aim of this study was to estimate the ED and acute hospital costs for children with TBIs
4 due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and
5 age of the child.
6
7
8
9

10 11 12 **METHODS**

13
14 This was a secondary analysis of the prospective multicentre Australasian Paediatric Head
15 Injury Study (APHIRST), in which 17,841 Australian children <18 years with head injuries
16 of *all* severities were enrolled between April 2011 and November 2014. There were two
17 mixed and six free-standing children's hospital emergency departments (EDs), all members of
18 the Paediatric Research in Emergency Departments International Collaborative (PREDICT)
19 network. The Human Research Ethics Committee of the Royal Children's Hospital (RCH),
20 Melbourne (reference, 31008A) and the institutional ethics committees at the participating
21 sites approved the study. The detailed methodology of the APHIRST study has been
22 previously published.¹² For this analysis, we excluded 2,296 children enrolled in New
23 Zealand to be consistent with the costing methods (Figure 1). The other exclusions have been
24 discussed previously.^{7 12}
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41

42 The costing analysis was conducted from a publicly funded health system perspective,
43 applying direct and indirect costs from the RCH to patient-level data in the Australian cohort
44 (Appendix 1).^{7 13} The details of the costing methods and data inputs have been published.⁷
45 Acute care included ED presentations with either discharge or acute admissions until hospital
46 discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals
47 (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All
48 costs were inflated to 2018 Australian dollars (\$) using the Reserve Bank of Australia general
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 consumer price index rates from 13 September 2019 and presented as pounds sterling with
4
5 the average exchange rate of UK £0.60 from 30 June 2018.^{14 15}
6
7
8
9

10 Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the
11
12 activity code for sports (activity = S) noted on the case report form of the APHIRST study.¹⁶
13

14 The research assistants assigned the activity codes at each site based on information the
15
16 clinician recorded at the ED visit, obtained from medical record review and during the follow-
17
18 up call.¹⁶ Epidemiology codes for activity, place and injury mechanism of injury employed by
19
20 the Victorian Injury Surveillance Unit in Australia were used across all study sites in
21
22 APHIRST.^{8 17 18} These codes were mapped to the International Classification of Diseases *10th*
23
24 *revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71) (Appendix
25
26 2).^{9 19} The combined football codes (U 50.01-50.05) included rugby, Australian rules football,
27
28 touch football, soccer and football-not otherwise specified.^{9 19}
29
30
31
32
33
34

35 We considered injuries sports-related if they occurred from organised or recreational sports.
36
37 Falls from playground equipment or casual play were excluded. Helmet use was noted for
38
39 TBIs from bicycle riding. The sports cohort was stratified into two age groups (younger: 5 to
40
41 11 and older: 12 to 17 years) based on the reported differences in physical activity levels in
42
43 Australian children.²⁰ TBI was defined as any injury to the brain caused by an external force.²¹
44
45 TBI severity was defined as mild, moderate, and severe. Mild TBI was defined as Glasgow
46
47 Coma Scale (GCS) scores of 13–15 on ED presentation, no neurological deficits, with no
48
49 evidence of TBI on cranial computed tomography (CT) or magnetic resonance imaging (MRI)
50
51 if performed.²² Moderate TBI included either GCS scores 9–13, or GCS scores 13–15 with
52
53 neurological deficits or evidence of TBI on CT or MRI. Severe TBI was defined as GCS
54
55
56
57
58
59
60

scores ≤ 8 .²² Data analysis was performed with Stata (version 15; StataCorp, College Station, TX).

RESULTS

Sports cohort: Patient characteristics

Of the 7,799 Australian children between 5 and 18 years with head injuries enrolled in APHIRST, 2,903 (37%) had TBIs from sports activities (Figure 1, Table 1). The mean age for the sports cohort was 12.0 years (95% CI: 11.9–12.1 years), and 78% were male. The acute care costs for sports-related TBIs were £1.9 million, with mean per-patient costs of £669 (95% CI: £566–£772). The acute admission rate was 34%, with mean per-patient costs of £1,559 (95% CI: £1,265–£1,853), which accounted for 80% of acute care costs. Paediatric intensive care unit admissions for 43 children (1.5% of the sports cohort) accounted for 29% of acute care costs, with mean per-patient costs of £13,199 (95% CI: £8,217–£18,180). There were no deaths reported from sports activities.

Table 1 Sports cohort: Demographics and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Ages 5–17 years	7,799 (100)	£749 (£650–£849)	£5,843,060 (100)
Sports cohort	2,903 (37)	£669 (£566–£772)	£1,942,345 (33)
Age group			
Younger (5–11 years)	1,286 (44)	£501 (£438–£564)	£644,045 (33)
Older (12–17 years)	1,617 (56)	£803 (£624–£982)	£1,298,300 (67)
Sex			
Male	2,272 (78)	£682 (£554–£810)	£1,549,252 (80)
Female	628 (22)	£625 (£513–£738)	£392,447 (20)
TBI severity[§]			
Mild	2,727 (93.9)	£443 (£389–£497)	£1,209,200 (62)
Moderate	146 (5.0)	£2,269 (£1,622–£2,916)	£331,272 (17)
Severe	30 (1.0)	£13,395 (£6,400–£20,392)	£401,873 (21)

Disposition

Discharge from ED	1,902 (66)	£205 (£203–£206)	£389,483 (20)
Admission	995 (34)	£1,559 (£1,265–£1,853)	£1,551,083 (80)
Paediatric ward	267 (9.2)	£4,184 (£3,173–£5,194)	£1,117,009 (59)
PICU	43 (1.5)	£13,199 (£8,217–£18,180)	£567,538 (29)
Death	0 (0)	£0.00	£0.00

TBI, traumatic brain injury; CI, confidence interval; PICU, paediatric intensive care unit; ED, emergency department; NOS, not otherwise specified; GCS, Glasgow Coma Scale

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits, negative neuroimaging; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or positive neuroimaging; Severe TBI, GCS scores ≤8.

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: TBI severity

Most head injuries from sports activities resulted in mild TBIs (94%), which were associated with 62% of the sports-related acute care costs with mean per-patient costs of £443 (95% CI: £389–£497) (Table 1). Moderate TBIs occurred with 5% of injuries, accounting for 17% of sports-related acute costs, with mean per-patient costs of £2,269 (95% CI: £1,622–£2,916). Severe TBIs in 1.0% of the sports cohort accounted for 21% of acute care costs, with mean per-patient costs of £13,395 (95% CI: £6,400–£20,392).

Sports cohort: Mechanisms of injury

The top ten individual sports in decreasing frequency (Figure 2, Table 2) cumulatively accounted for 76% of sports-related TBIs and 87% of acute care costs. Bicycle riding was associated with the most TBIs (14%) and 17% of sports-related acute care costs, with mean per-patient costs of £802 (95% CI: £644–£960). Children with bicycle-related TBIs who were not wearing helmets (48%) with mean per-patient costs of £1,047 (95% CI: £626–£1,468) accounted for 63% of bicycle-related costs. Motorcycle riding was associated with the largest proportion of moderate (9.1%) and severe TBIs (8.2%) for any sport. Further, with 3.8% of

TBIs, motorcycle riding was associated with the highest mean per-patient costs of £3,795 (95% CI: £1,850–£5,739) and acute costs (21%) from individual sports.

Team ball sports were associated with the most sports-related TBIs (45%), which accounted for 25% of acute care costs (Appendix 3). Specifically, the combined football codes (U50.01–50.05) were associated with 39% of sports-related TBIs and accounted for 21% of acute care costs. On the other hand, wheeled non-motored sports, with 26% of TBIs, were associated with the highest acute costs (35%) and wheeled motorsports, with 3.9% of TBIs, were associated with the highest mean per-patient cost.

Table 2 Sports-related TBIs and acute care costs[†]

	N (%)	Mean cost (95% CI)	Total cost (%)
Sports cohort	2903 (100)	£669 (£566–£773)	£1,942,345 (100)
<i>Sports activities</i>			
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
No helmet (% bicycle riding)	197 (48)	£1,047 (£626–£1,468)	£206,223 (63)
Australian rules football	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football-NOS	289 (10.0)	£370 (£298–£443)	£107,007 (5.5)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Motorcycle riding	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)

1				
2				
3				
4	Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
5	Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
6				
7	Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)
8				
9	Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
10				
11	Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
12				
13	Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
14				
15	Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
16				
17	Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
18				
19	Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
20				
21	Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
22				
23	Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
24				
25	Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
26				
27	Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
28				
29	High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
30				
31	Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
32				
33	Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
34				
35	Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
36				
37	Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
38				
39	Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
40				
41	Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
42				
43	Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
44				
45	All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
46				
47	Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
48				
49	Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
50				
51	Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

TBI, traumatic brain injury; NOS, not otherwise specified

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

Sports cohort: Mechanisms of injury and TBI severity

By TBI severity, mild TBIs from bicycle riding (93% of bicycle riding injuries and 13% of the sports cohort) and severe TBIs from motorcycle riding (8% of motorcycle riding injuries

1
2
3 and 0.31% of the sports cohort) accounted for the highest acute care costs (11%) for the
4 sports cohort (Figure 2). In contrast, the combined football sports were associated with
5
6 primarily mild TBIs and the lowest acute costs.
7
8
9

10 11 12 **Sports cohort: Age groups**

13
14 In Figure 2, the top ten mechanisms of injury in decreasing frequency are shown for the
15 younger and older age groups, which accounted for 70% and 86% of sports-related TBIs,
16
17 respectively and 79% and 91% of associated acute care costs. Of the 1,286 children (44%) in
18
19 the younger age group, 73% were male. Similarly, 82% of the 1,617 children in the older age
20
21 group were male.
22
23
24
25

26
27 In the younger age group, bicycle riding was associated with the highest proportion of TBIs
28
29 (17%) and age group-related costs (26%). Although rugby was the most frequent injury
30
31 mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related
32
33 TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger
34
35 age group, mild TBIs from bicycle riding were associated with the highest group-related
36
37 acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest
38
39 group-related acute costs (15%) for sports injuries in the older age group.
40
41
42
43
44
45

46 47 **Sports cohort: Sex**

48
49 Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care
50
51 costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and
52
53 the highest acute costs (27%) for the age group (Figure 3, Appendix 4). For boys in the older
54
55 age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)
56
57
58
59
60

1
2
3 accounted for the highest acute costs (28%) for the age group. Motorcycle riding was
4
5 associated with the highest mean per-patient costs for boys in both age groups (Appendix 4).
6
7
8
9

10 For young girls, bicycle riding was associated with the most TBIs (19%) and the highest
11
12 acute costs (25%) for the age group (Figure 3, Appendix 5). For girls in the older age group,
13
14 horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%)
15
16 for the age group. The highest mean per-patient costs were associated with horse riding and
17
18 motorcycle riding for younger and older girls, respectively (Appendix 5).
19
20
21
22
23

24 **DISCUSSION**

25
26 This cost of illness study estimates the frequency and economic burden of TBIs from sports
27
28 activities in children between 5 and 18 years presenting to eight tertiary EDs in Australia.
29

30 While bicycle riding was associated with the most TBIs, motorcycle-related TBIs, with 4% of
31
32 injuries, were associated with the highest total and mean per-patient acute care costs. When
33
34 the combined effect of TBI severity and sports activities on the acute care costs were
35
36 explored, bicycle riding injuries with mild TBIs and motorcycle riding with severe TBIs
37
38 accounted for similar acute care costs for the sports cohort. Therefore, while motorcycle-
39
40 related injuries had the most severe TBIs and the highest patient-level costs, the combined
41
42 effect of injury frequency and TBI severity from bicycle and motorcycle riding contributed to
43
44 the high economic burden on the health system.
45
46
47
48
49
50

51 In a recent population-based report, the total acute care costs for *all* sports-related injuries in
52
53 Australia were AUD \$764 million for FY 2019.²³ ED visits for *all* sports injuries accounted
54
55 for 22% of the total acute care costs (AUD \$164 million), and 37% of the ED costs were for
56
57 children <20 years, who accounted for 25% of the Australian population.^{23 24} The acute care
58
59
60

1
2
3 costs for sports-related TBIs were AUD \$32 million (4% of total costs for all sports injuries),
4
5 and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-
6
7 related TBIs accounted for 80% of the acute care costs.²³
8
9

10
11
12 There are few published reports of paediatric sports-related head injuries in Australia.^{16 18 22}
13
14 While one study excluded bicycle, motorcycle and playground injuries,²² another did not
15
16 report motorcycle-related head injuries.¹⁶ Australian rules football was associated with the
17
18 highest proportion of head injuries in the retrospective study,²² baseball and softball were
19
20 associated with the most clinically important TBIs in the prospective study.¹⁶ In the current
21
22 study, we excluded playground injuries. We reported bicycle riding in younger children,
23
24 rugby in older boys and horse riding in older girls were associated with the most sports-
25
26 related TBIs.
27
28
29

30
31
32
33 To our knowledge, no prior studies have compared the acute costs of TBIs from sports
34
35 activities in children. In this study, bicycle riding was the most frequent injury mechanism for
36
37 the sports cohort and was associated with the highest costs for younger boys and girls.
38
39 Additionally, the highest mean per-patient costs were associated with motorcycle riding for
40
41 younger boys and horse riding for younger girls. While rugby was the most frequent injury
42
43 mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For
44
45 older girls, horse riding was associated with the most head injuries and the highest total acute
46
47 costs, and motorcycle riding with the highest mean per-patient costs. Education programmes
48
49 on safe riding practices and protective gear are needed to reduce sports-related TBIs.²⁵
50
51
52
53

54
55
56 Prior research has shown that helmet laws and the proper use of helmets reduce head injuries
57
58 and fatalities from bicycle riding.²⁶⁻³¹ For the sports cohort, 52% of children with TBIs from
59
60

1
2
3 bicycle riding were reported to be wearing helmets, accounting for 37% of bicycle-related
4 acute care costs. Although we only obtained information regarding helmet use with bicycle
5 riding, the effect of helmet use on reducing TBIs with other wheeled sports is strongly
6 supported by research.^{32 33} The impact of helmet legislation on reducing fatalities from
7 motorcycle and bicycle riding has been shown globally.³⁴ In Australia, helmets are required
8 for motorcycle and bicycle riding for all ages.³⁵ In the UK, helmet use is required for
9 motorcycle riding for all ages.³⁶ Helmets are only recommended for riding bicycles, all-
10 terrain vehicles, scooters or skateboards. In the US, state and local laws are responsible for
11 helmet legislation, and there are no helmet laws for bicycle riding in 29 states and motorcycle
12 riding in 3 states.^{29 37} While helmet laws are necessary for reducing mortality from sports
13 activities, our results indicate that additional strategies are required to reduce head injury
14 severity.

15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33 This study is not without some limitations. First, we focused on acute care costs of sports-
34 related TBIs from the Australian publicly funded health system perspective. We did not
35 consider the number of contact hours associated with individual sports or the costs associated
36 with long-term follow-up and rehabilitation, which would increase the total costs of these
37 injuries. Second, we did not collect information regarding helmet use during non-bicycle
38 activities or if the TBIs occurred from recreational or organised sports. Third, the high acute
39 costs of severe TBIs could be associated with multi-organ injuries which we did not evaluate.
40 However, because individual cost inputs were applied (Appendix 1), this would only be
41 reflected in the length of hospital stay.⁷ Fourth, the proportion of TBIs due to sports activities
42 is likely underestimated because not all patients present to tertiary EDs after head injuries.
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000

1
2
3 in Australia and New Zealand, possibly underrepresenting rural and indigenous populations.
4
5 Additionally, the rates of mild TBIs are likely underestimated because most of these children
6
7 are not seen in EDs and are managed at home or by general practitioners.³⁹ Therefore, the
8
9 acute care costs and TBIs reported with sports, and other mechanisms may not be
10
11 generalisable beyond tertiary referral EDs.
12
13
14
15
16

17 **CONCLUSION**

18
19 Sports activities are common mechanisms of TBIs in children and have a significant
20
21 economic impact on patients and the health system. Injury prevention strategies should focus
22
23 on age and sex-related sports activities to reduce the burden of TBIs in children. We highlight
24
25 the effect of TBI severity on the associated acute costs of head injuries from wheeled sports
26
27 in children. This has implications for resource allocations for population-based injury
28
29 surveillance and targeted injury prevention programmes.
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

ACKNOWLEDGMENTS

We thank the participating families and emergency department staff at participating sites. We thank Meredith L. Borland (Perth Children's Hospital, Perth, WA); Stuart R. Dalziel (Starship Children's Health, Auckland, New Zealand and Departments of Surgery and Paediatrics: Child and Youth Health, University of Auckland, Auckland, New Zealand); Ed Oakley (Royal Children's Hospital, Melbourne, VIC); Amit Kochar (Women's & Children's Hospital, Adelaide, SA); Natalie Phillips and Yuri Gilhotra (Queensland Children's Hospital, Brisbane, QLD); Sarah Dalton and Mary McCaskill (The Children's Hospital at Westmead, Sydney, NSW); Jeremy Furyk (The Townsville Hospital, Townsville, QLD); Jocelyn Neutze (Kidzfirst Middlemore Hospital, Auckland, New Zealand); Mark Lyttle (Bristol Royal Hospital for Children, Bristol, UK and Academic Department of Emergency Care, University of the West of England, Bristol, UK); Silvia Bressan (Department of Women's and Children's Health, University of Padova, Padova, Italy); and Louise Crowe (Murdoch Children's Research Institute, Melbourne, VIC) for their involvement with obtaining the data and prior data analysis.

FUNDING SOURCES/DISCLOSURES

Funding and support: The study was funded by grants from the National Health and Medical Research Council (project grant GNT1046727, Centre of Research Excellence for Pediatric Emergency Medicine GNT1058560), Canberra, Australia; the Murdoch Children's Research Institute, Melbourne, Australia; the Emergency Medicine Foundation (EMPJ-11162), Brisbane, Australia; Perpetual Philanthropic Services (2012/1140), Australia; Auckland Medical Research Foundation (No. 3112011) and the A + Trust (Auckland District Health Board), Auckland, New Zealand; WA Health Targeted Research Funds 2013, Perth,

1
2
3 Australia; the Townsville Hospital and Health Service Private Practice Research and
4
5 Education Trust Fund, Townsville, Australia; and supported by the Victorian Government's
6
7 Infrastructure Support Program, Melbourne, Australia. The funding organisations were not
8
9 involved in the collection of the data, their analysis and interpretation, or in the approval or
10
11 rejection of the publication of the completed manuscript.
12
13

14
15
16
17 **Clinical Trial Registration:** Australian New Zealand Clinical Trials Registry (ANZCTR)
18
19 ACTRN12614000463673
20
21

22
23
24 **Competing interests:** No relevant disclosures.
25
26

27
28 **Financial Disclosure:** The authors have no financial relationships relevant to this article to
29
30 disclose.
31
32

33
34
35 **Patient and public involvement:** Patients and the public were not involved in
36
37 the design, or conduct, or reporting, or dissemination plans of this research.
38
39

40
41
42 **Patient consent for publication:** Not required.
43
44

45
46
47 **Provenance and peer review:** Not commissioned; externally peer reviewed
48
49

50
51 **Data availability statement:** All data relevant to the study are included in the article or
52
53 uploaded as supplementary information.
54
55

AUTHOR CONTRIBUTIONS

SS conceptualised the study, conducted the analysis, wrote the first draft of the manuscript, and reviewed and revised the manuscript. FEB conceptualised and designed, coordinated and supervised data collection of APHIRST, contributed to data interpretation, and critically reviewed and revised the manuscript. SS, JAC, and KD acquired the cost data and conducted the analysis. SJCH had full access to the data, analysed the data, contributed to data interpretation, and critically reviewed and revised the manuscript. JSH, KD, JAC, JFH, VA, and NK contributed to the interpretation of the data and reviewed and revised the article critically. All authors revised the paper critically and approved the final manuscript as submitted.

ORCID iDs

Sonia Singh [0000-0003-2430-0262](https://orcid.org/0000-0003-2430-0262)

Jeffrey S. Hoch [0000-0002-4880-4281](https://orcid.org/0000-0002-4880-4281)

Stephen J.C. Hearps [0000-0003-2984-1172](https://orcid.org/0000-0003-2984-1172)

Kim Dalziel [0000-0003-4972-8871](https://orcid.org/0000-0003-4972-8871)

John A. Cheek [0000-0002-3615-3821](https://orcid.org/0000-0002-3615-3821)

James F Holmes [0000-0003-3270-2720](https://orcid.org/0000-0003-3270-2720)

Vicki Anderson [0000-0001-5233-3147](https://orcid.org/0000-0001-5233-3147)

Nathan Kuppermann [0000-0002-7854-4943](https://orcid.org/0000-0002-7854-4943)

Franz E Babl [0000-0002-1107-2187](https://orcid.org/0000-0002-1107-2187)

FIGURE LEGENDS

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort TBI, traumatic brain injury

Figure 2. Sports-related TBI severity[§] and acute care costs[†] by age groups

Top ten sports activities in decreasing order of injury frequency

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

[§]TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤ 8
TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

(Please use colour for Figure 2)

Figure 3. Acute care costs[†] of sports-related TBIs stratified by age and sex

[†]Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

1
2
3 *What is already known on this topic*
4

- 5 • Sports activities are frequently associated with traumatic brain injuries in children.
6
7
8

9 *What this study adds*
10

- 11 • Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were
12 associated with the highest mean per-patient and total acute care costs.
13
14 • Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated
15 with the highest total acute care costs for the sports cohort.
16
17 • The highest mean per-patient costs were from horse riding in younger girls and
18 motorcycle riding for older girls and boys in both age groups.
19
20
21

22 *How this study might affect research, practice or policy*
23

- 24 • Injury prevention strategies should focus on age and sex-related sports activities to reduce
25 the burden of TBIs in children.
26
27 • While contact sports are common mechanisms of injury, they are not associated with
28 severe TBIs or high acute care costs.
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

REFERENCES

1. Finch C, Cassell E. The public health impact of injury during sport and active recreation. *J Sci Med Sport* 2006;9(6):490-7. doi:10.1016/j.jsams.2006.03.002
2. Australian Institute of Health and Welfare. National sports injury data strategy: draft consultation report. Cat. No. INJCAT 222. Canberra: Australian Institute of Health and Welfare, 2022.
3. Timpka T, Finch CF, Goulet C, et al. Meeting the global demand of sports safety. The intersection of science and policy in sports safety. *Sports Med* 2008;38(10):795-805. doi:10.2165/00007256-200838100-00001
4. Sarmiento K, Thomas KE, Daugherty J, et al. Emergency department visits for sports- and recreation-related traumatic brain injuries among children—United States, 2010–2016. *MMWR Morb Mortal Wkly Rep* 2019;68:237-42. doi:10.15585/mmwr.mm6810a2
5. Finch C, Valuri G, Ozanne-Smith J. Sport and active recreation injuries in Australia: evidence from emergency department presentations. *Br J Sports Med* 1998;32:220-25. doi:10.1136/bjism.32.3.220
6. Trefan L, Houston R, Pearson G, et al. Epidemiology of children with head injury: a national overview. *Arch Dis Child* 2016;101(6):527-32. doi:10.1136/archdischild-2015-308424
7. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274-80. doi:10.1111/jpc.15699
8. Finch CF, Wong Shee A, Clapperton A. Time to add a new priority target for child injury prevention? The case for an excess burden associated with sport and exercise injury: population-based study. *BMJ Open* 2014;4(7):e005043. doi:10.1136/bmjopen-2014-005043

- 1
2
3 9. Lystad RP, Curtis K, Browne GJ, et al. Incidence, costs, and temporal trends of sports
4
5 injury-related hospitalisations in Australian children over a 10-year period: A nationwide
6
7 population-based cohort study. *J Sci Med Sport* 2019;22(2):175-80.
8
9 doi:10.1016/j.jsams.2018.07.010
10
11
- 12 10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in sports- and recreation-related
13
14 traumatic brain injuries treated in US emergency departments: The National Electronic
15
16 Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma*
17
18 *Rehabil* 2015;30(3):185-97. doi:10.1097/HTR.000000000000156
19
20
- 21 11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for
22
23 contact sports-related traumatic brain injuries among children—United States, 2001–
24
25 2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870-74. doi:10.15585/mmwr.mm6927a4
26
27
- 28 12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE
29
30 head injury decision rules in children: a prospective cohort study. *Lancet*
31
32 2017;389(10087):2393-402. doi:10.1016/s0140-6736(17)30555-x
33
34
- 35 13. Singh S, Babl FE, Huang L, et al. Paediatric traumatic brain injury severity and acute care
36
37 costs. *Arch Dis Child* 2022;107:497-99. doi:10.1136/archdischild-2021-322966
38
39
- 40 14. The Reserve Bank of Australia inflation calculator: Reserve Bank of Australia. Available:
41
42 <https://www.rba.gov.au/calculator/> [Accessed September 19 2018].
43
44
- 45 15. Australian Taxation Office. Foreign currency exchange rates for financial year ending
46
47 2018. Available: [https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-](https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-June-2018/)
48
49 [June-2018/](https://www.ato.gov.au/Tax-professionals/TP/Financial-year-ending-30-June-2018/) [Accessed August 31 2020].
50
51
- 52 16. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain
53
54 injuries in children. *Med J Aust* 2019;211(8):365-66. doi:10.5694/mja2.50311
55
56
57
58
59
60

17. Australian Institute of Health and Welfare. Injury surveillance National Minimum Data Set. National Health Data Dictionary. Version 12. AIHW Cat. No. HWI 57. Canberra: Australian Institute of Health and Welfare, 2003.
18. Fernando DT, Berecki-Gisolf J, Finch CF. Sports injuries in Victoria, 2012–13 to 2014–15: evidence from emergency department records. *Med J Aust* 2018;208(6):255-60. doi:10.5694/mja17.00872
19. AIHW: Kreisfeld R, Harrison JE. Hospitalised sports injury in Australia, 2016–17. Injury Research and Statistics Series No.131. Cat. No. INJCAT 211. Canberra: Australian Institute of Health and Welfare, 2020.
20. Australian Bureau of Statistics. 2011-2012. *Australian health survey: physical activity*. July 2013. Canberra: Australian Bureau of Statistics, 2013.
21. Centers for Disease Control and Prevention. *Traumatic brain injury and concussion* Atlanta, GA: National Center for Injury Prevention and Control; [updated March 07, 2022]. Available: <https://www.cdc.gov/traumaticbraininjury/concussion/symptoms.html> [Accessed April 09 2022].
22. Crowe LM, Anderson V, Catroppa C, et al. Head injuries related to sports and recreation activities in school-age children and adolescents: data from a referral centre in Victoria, Australia. *Emerg Med Australas* 2010;22(1):56-61. doi:10.1111/j.1742-6723.2009.01249.x
23. Australian Institute of Health and Welfare. Economics of sports injury and participation – Preliminary results. Cat. No. INJCAT 224. Canberra: Australian Institute of Health and Welfare, 2022.
24. Australian Demographic Statistics (June 2019). Table 7: Population by age and sex tables [data cubes] Canberra: Australian Bureau of Statistics; 2019. Available:

- 1
2
3 [https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDo](https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument)
4 [cument](https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument) [Accessed July 18 2020].
5
6
7
8 25. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged
9 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance
10 Unit, Monash University Accident Research Centre, 2016.
11
12
13
14 26. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a*
15 *formal review. June 2020.* ACT: Australian Transport Safety Bureau, 2000.
16
17
18
19 27. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid*
20 *Anal Prev* 2001;33:345-52. doi:10.1016/s0001-4575(00)00048-8
21
22
23
24 28. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta,
25 GA: National Center for Injury Prevention and Control. Available:
26 <https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html> [Accessed
27 09 Apr 2022].
28
29
30
31
32
33 29. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and*
34 *countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National
35 Transportation Safety Board, 2019.
36
37
38
39
40 30. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to
41 increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76-82.
42
43
44
45
46
47
48
49
50
51
52 31. Olivier J, Creighton P. Bicycle injuries and helmet use: a systematic review and meta-
53 analysis. *Int J Epidemiol* 2017;46(1):278-92. doi:10.1093/ije/dyw153
54
55
56
57
58
59
60 32. Institute of Medicine (IOM) and National Research Council (NRC). *Sports-related*
concussions in youth: Improving the science, changing the culture. Washington, DC: The
National Academies Press, 2014.

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
33. Weiss H, Agimi Y, Steiner C. Youth motorcycle-related brain injury by state helmet law type: United States, 2005–2007. *Pediatrics* 2010;126(6):1149-55. doi:10.1542/peds.2010-0902
34. Cassidy JD, Carroll LJ, Peloso PM, et al. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabil Med* 2004(Suppl. 43):28-60. doi:10.1080/16501960410023732
35. Kaddis M, Stockton K, Kimble R. Trauma in children due to wheeled recreational devices. *J Paediatr Child Health* 2016;52(1):30-3. doi:10.1111/jpc.12986
36. The highway code: Department of Transport. UK Government; 2015, updated 2021. Available: <https://www.highwaycodeuk.co.uk> [Accessed 04 Jun 2021].
37. Centers for Disease Control and Prevention. Universal motorcycle helmet laws Atlanta, GA: National Center for Injury Prevention and Control. Available: <https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/mchelmet.html> [Accessed 09 Apr 2022].
38. Lim JC, Borland ML, Middleton PM, et al. Where are children seen in Australian emergency departments? Implications for research efforts. *Emerg Med Australas* 2021;33(4):631-39. doi:10.1111/1742-6723.13698
39. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of Health Care Entry for Youth With Concussion Within a Large Pediatric Care Network. *JAMA Pediatr* 2016;170(7):e160294. doi:10.1001/jamapediatrics.2016.0294

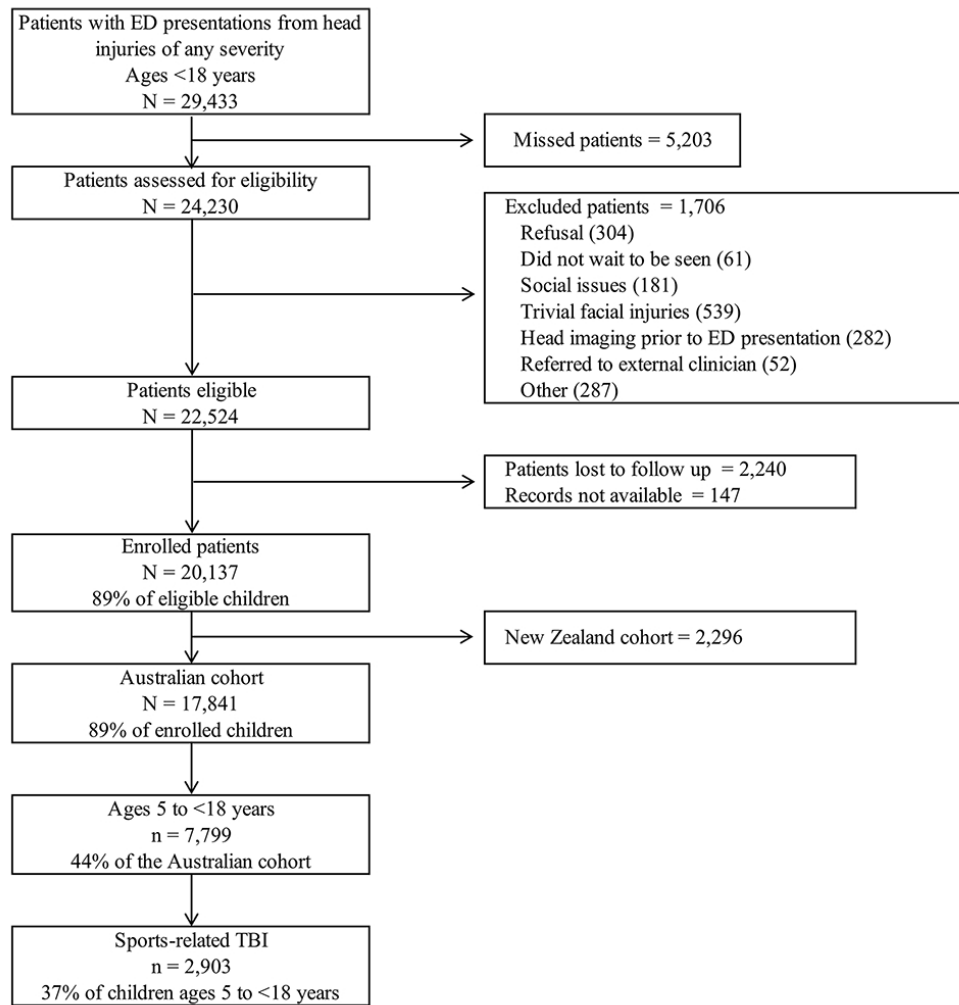


Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort TBI, traumatic brain injury

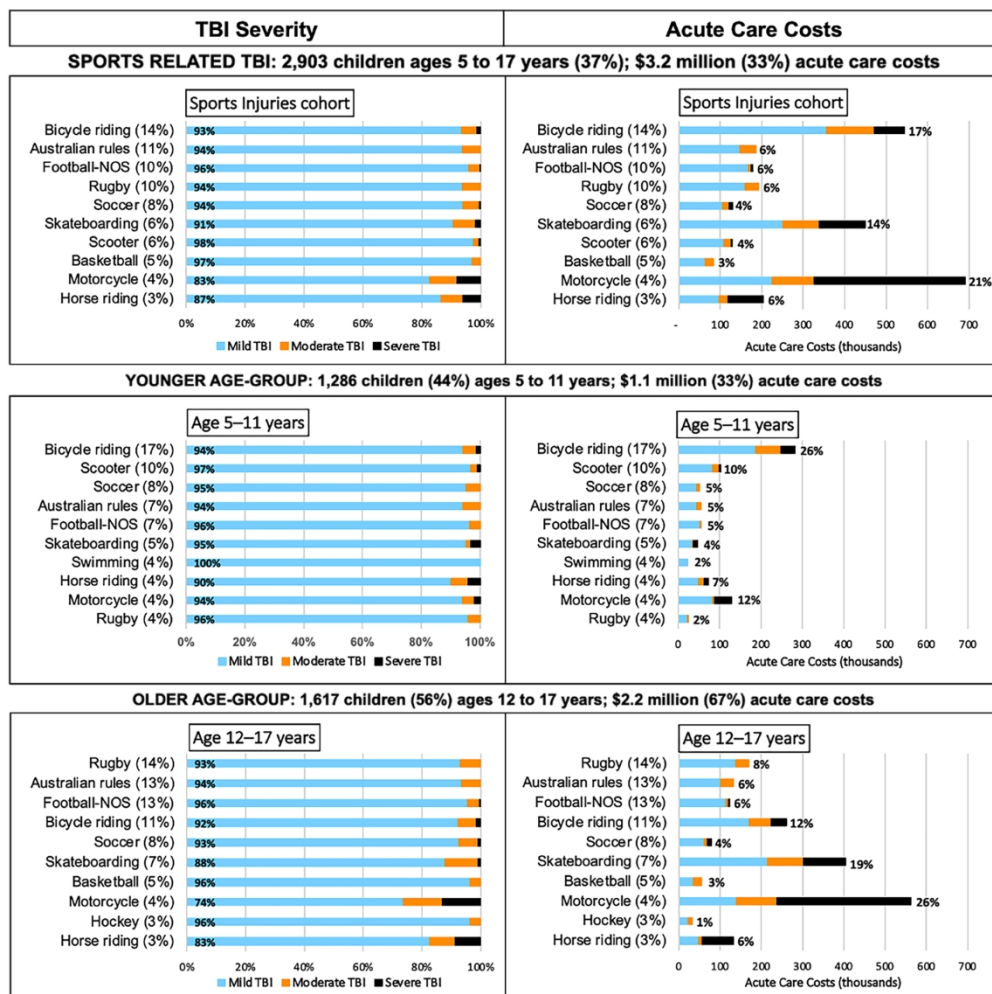


Figure 2. Sports-related TBI severity§ and acute care costs† by age groups

Top ten sports activities in decreasing order of injury frequency

†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

§TBI Severity: Mild TBI, GCS scores 13–15, no neurological deficits and no evidence of TBI on CT; Moderate TBI, GCS scores 9–12, or GCS scores 13–15 with neurological deficits or TBI on CT; Severe TBI, GCS scores ≤8

TBI, traumatic brain injury; NOS, not otherwise specified; GCS, Glasgow Coma Scale; CT, cranial tomography

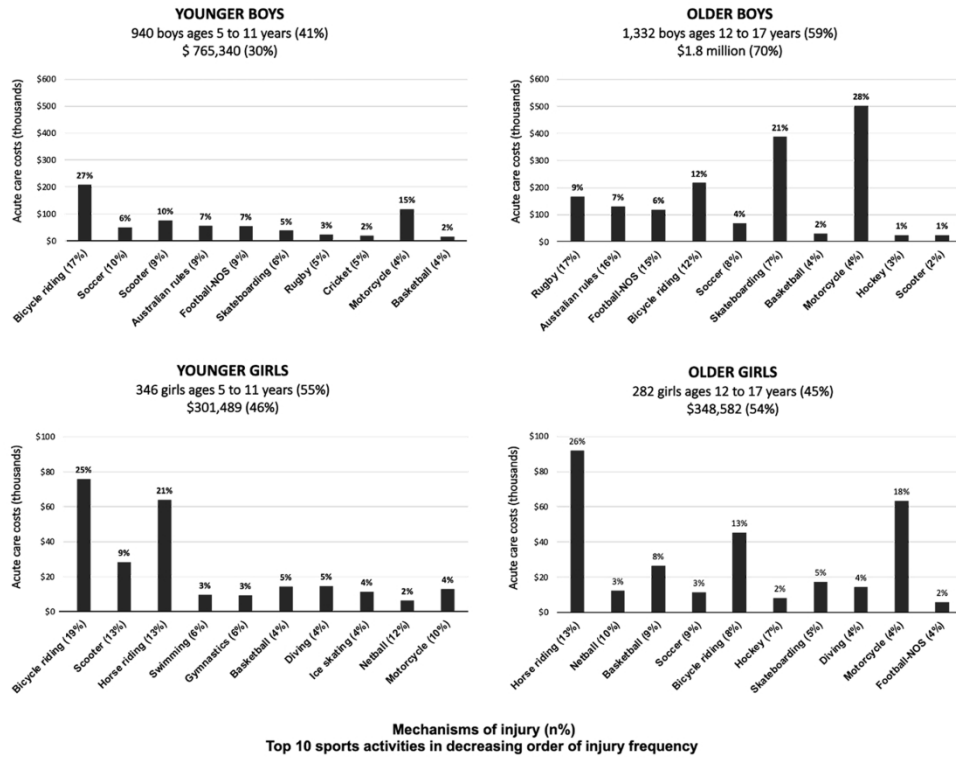


Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

Sports-related Traumatic Brain Injuries and Acute Care Costs in Children

Appendix 1 Source: the author: Acute care cost[†] inputs¹

	Mean cost	95% CI	Source
ED visit	£188	£183–£194	RCH data
Admission			
SSU/day	£245	£223–£267	RCH data
Ward/day	£969	£944–£994	RCH data
ICU/day	£2,456	£2,287_£2,624	RCH data
Intervention			
Intubation	£177	£4–£351	Dalziel et al. ²
Neurosurgery	£1,442	£1,300–£1,584	RCH data
Radiology			
Cranial CT	£118	£2–£233	MBS schedule (2018) ³
Brain MRI	£243	£5–£482	MBS schedule (2018)
Skull X-ray	£39	£1–£78	MBS schedule (2018)
Cranial Ultrasound	£66	£1–£130	MBS schedule (2018)
Follow up			
GP visit	£40	£1–£80	MBS schedule (2018)

[†]Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; RCH, Royal Children's Hospital; ED, emergency department; SSU, short stay unit; ICU, intensive care unit; CT, computed tomography; MRI, magnetic resonance imaging; GP, general practitioner; MBS, Medicare Benefits Schedule

Appendix 2 Overview of ICD-10-AM external cause codes for sporting activities.^{4,5}

ICD-10-AM code	Activity	Examples
U50	Team ball sports	Football; basketball; handball; netball; volleyball
U50.01-05	Football	Australian rules; rugby; soccer; touch football; football-NOS
U51	Team bat or stick sports	Baseball; softball; T-ball; cricket; hockey
U52	Team water sports	Synchronised swimming; water polo
U53	Boating sports	Canoeing; kayaking; rowing; sailing
U54	Individual water sports	Diving; swimming; water skiing; surfing; windsurfing; fishing
U55	Ice and snow sports	Ice skating; skiing; snowboarding; curling; bobsledding
U56	Individual athletic activities	Aerobics; running; walking; track; and field
U57	Acrobatic sports	Gymnastics
U58	Aesthetic activities	Dancing; marching
U59	Racquet sports	Badminton; racquetball; squash; tennis; table tennis
U60	Target and precision sports	Archery; bowling; golf; shooting; billiards
U61	Combative sports	Boxing; kickboxing; fencing; judo; karate; wrestling
U62	Power sports	Powerlifting; weightlifting; strength training; wood chopping
U63	Equestrian activities	Showjumping; dressage; steeplechase; horse racing; rodeo; polo
U64	Adventure sports	Rock climbing; abseiling; rafting; hiking; bungee jumping
U65	Wheeled motor sports	Motorcycling; motor car racing; go-carting; all-terrain vehicle riding
U66	Wheeled non motored sports	Cycling; rollerblading; roller skating; skateboarding; scooter riding
U67	Multidiscipline sports	Biathlon (winter); triathlon; modern pentathlon; decathlon
U68	Aero sports	Paragliding; sky diving; hot air ballooning; aerobatics; parasailing
U69	Other school-related recreational activities	School physical education class; school free play
U70	Other specified sport and exercise activity	CrossFit; use of fitness equipment
U71	Unspecified sports and exercise activity	

International Classification of Diseases *10th revision-Australian Modification*, ICD-10-AM; NOS, not otherwise specified
 Reprinted (adapted) from the Journal of Science and Medicine in Sport, 2019;22(2), Lystad RP, Curtis K, Browne GJ, Mitchell RJ. Incidence, costs, and temporal trends of sports injury-related hospitalisations in Australian children over a 10-year period: A nationwide population-based cohort study, Appendix A, Copyright (2019), with permission from Elsevier.

Appendix 3 Acute care costs[†] for sports-related TBIs using the ICD-10-AM external cause codes

Sports Cohort	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs	2,903 (100)	£669 (£566–£773)	£1,942,345 (100)
<i>U50: Team ball sports</i>	1,315 (45)	£366 (£334–£398)	£481,241 (25)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
<i>U50.01-05: Football</i>	1,120 (39)	£369 (£336–£403)	£413,952 (21)
Rugby	281 (9.7)	£412 (£340–£484)	£115,758 (6.0)
AFL	306 (11)	£367 (£303–£430)	£112,240 (5.8)
Football - not specified	289 (10)	£370 (£298–£443)	£107,007 (5.5)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
Soccer	242 (8.3)	£324 (£271–£376)	£78,285 (4.0)
<i>U50.1-50.3: Basketball and Netball</i>	179 (6.2)	£354 (£245–£462)	£63,301 (3.3)
Basketball	132 (4.5)	£384 (£237–£531)	£50,657 (2.6)
Netball	47 (1.6)	£269 (£220–£318)	£12,644 (0.65)
<i>U51: Team bat sports</i>	193 (6.6)	£396 (£244–£548)	£76,476 (3.9)
Hockey	80 (2.8)	£348 (£232–£464)	£27,832 (1.4)
Cricket	74 (2.5)	£260 (£218–£302)	£19,242 (0.99)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
<i>U53: Boating sports</i>			
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)

U54: Individual water sports	198 (6.8)	£315 (£237–£392)	£62,248 (3.2)
Swimming	72 (2.5)	£246 (£222–£270)	£17,701 (0.91)
Diving	61 (2.1)	£414 (£181–£647)	£25,233 (1.3)
Water sports (unspecified)	45 (1.6)	£272 (£176–£368)	£12,232 (0.63)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
U55: Ice and snow sports	62 (2.1)	£531 (£276–£787)	£32,952 (1.7)
Ice skating	53 (1.8)	£382 (£244–£519)	£20,220 (1.0)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
U56: Individual athletics	21 (0.72)	£350 (£237–£464)	£7,353 (0.38)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
U57: Acrobatic activities	44 (1.5)	£265 (£227–£303)	£11,662 (0.60)
Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
U58: Dancing			
Dancing	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
U59: Racket sports			
Racket	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
U60: Target and precision sports			
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
U61: Combative sports	20 (0.69)	£389 (£155–£623)	£7,777 (0.40)
Martial Arts	16 (0.55)	£417 (£122–£711)	£6,662 (0.34)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
U63: Equestrian			

Horse riding	97 (3.3)	£1,267 (£747–£1,786)	£122,856 (6.3)
U65: Wheeled motored sports	113 (3.9)	£3,736 (£1,842–£5,631)	£422,216 (22)
Motorcycle	110 (3.8)	£3,795 (£1,850–£5,739)	£417,411 (21)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
U66: Wheeled non-motored sports	759 (26)	£901 (£654–£1,148)	£683,981 (35)
Bicycle riding	409 (14)	£802 (£644–£960)	£327,924 (17)
Skateboarding	170 (5.9)	£1,596 (£570–£2,622)	£271,302 (14)
Scooter	167 (5.8)	£464 (£346–£582)	£77,460 (4.0)
Skating - roller	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Skating (unspecified)	1 (0.03)	£188	£188 (0.01)

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

International Classification of Diseases *10th revision-Australian Modification*, ICD-10-AM; CI, confidence interval; NOS, not otherwise specified

Appendix 4 Acute care costs[†] for boys in the sports cohort

Males	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	940 (41)	£491 (£412–£572)	£462,036 (30)	1,332 (59)	£816 (£605–£1,027)	£1,087,216 (70)
<i>Sports activities</i>						
Bicycle riding	158 (17)	£790 (£543–£1,037)	£124,859 (27)	163 (12)	£799 (£523–£1,075)	£130,177 (12)
Australian rules football	86 (9.1)	£377 (£250–£505)	£32,469 (7.0)	210 (16)	£369 (£292–£446)	£77,398 (7.1)
Football-NOS	81 (8.6)	£398 (£193–£602)	£32,207 (7.0)	195 (15)	£362 (£295–£430)	£70,644 (6.5)
Rugby	47 (5.0)	£283 (£248–£318)	£13,291 (2.9)	223 (17)	£444 (£355–£534)	£99,130 (9.1)
Soccer	96 (10)	£301 (£241–£362)	£28,912 (6.3)	112 (8.4)	£362 (£261–£461)	£40,468 (3.7)
Skateboarding	53 (5.6)	£412 (£264–£560)	£21,853 (4.7)	94 (7.1)	£2,481 (£633–£4,327)	£233,152 (21)
Scooter	88 (9.4)	£512 (£309–£715)	£45,047 (9.8)	30 (2.3)	£468 (£222–£714)	£14,037 (1.3)
Basketball	33 (3.5)	£262 (£216–£307)	£8,641 (1.9)	59 (4.4)	£300 (£220–£380)	£17,704 (1.6)
Motorcycle	39 (4.1)	£1,789 (£381–£3,198)	£69,787 (15)	50 (3.8)	£6,038 (£1,994–£10,082)	£301,916 (28)
Horse riding	7 (0.75)	£747 (£41–£1,453)	£5,227 (1.1)	8 (0.60)	£2,990 (£0–£8,399)	£23,916 (2.2)
Hockey	15 (1.6)	£427 (£0–£857)	£6,415 (1.4)	37 (2.8)	£387 (£191–£583)	£14,316 (1.3)
Cricket	43 (4.6)	£264 (£197–£332)	£11,377 (2.5)	26 (2.0)	£264 (£217–£313)	£6,882 (0.63)
Swimming	33 (3.5)	£241 (£204–£278)	£7,950 (1.7)	11 (0.83)	£240 (£175–£305)	£2,643 (0.24)
Diving	25 (2.7)	£224 (£189–£260)	£5,605 (1.2)	9 (0.68)	£264 (£153–£377)	£2,382 (0.22)
Ice skating	20 (2.1)	£249 (£196–£302)	£4,986 (1.1)	13 (0.98)	£430 (£93–£768)	£5,596 (0.52)
Netball	3 (0.32)	£270 (£0–£621)	£810 (0.18)	2 (0.15)	£331 (£0–£662)	£662 (0.06)
Water sports-NOS	23 (2.4)	£311 (£126–£496)	£7,154 (1.5)	10 (0.75)	£253 (£117–£390)	£2,532 (0.23)
Gymnastics	5 (0.53)	£188 (£188–£188)	£942 (0.20)	7 (0.53)	£240 (£113–£367)	£1,681 (0.16)
Baseball/softball	22 (2.3)	£210 (£185–£235)	£4,627 (1.0)	8 (0.60)	£2,533 (£0–£6,448)	£20,260 (1.9)
Racket	14 (1.5)	£243 (£193–£293)	£3,407 (0.74)	9 (0.68)	£284 (£188–£379)	£2,552 (0.24)

Golf	11 (1.2)	£789 (£16–£1,561)	£8,677 (1.9)	4 (0.30)	£280 (£117–£443)	£1,120 (0.10)
Surfing	3 (0.32)	£525 (£0–£1,973)	£1,575 (0.34)	11 (0.83)	£394 (£5–£784)	£4,336 (0.40)
Boating	2 (0.21)	£209 (£0–£465)	£417 (0.09)	9 (0.68)	£570 (£246–£95)	£5,133 (0.47)
Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£88)	£942 (0.09)
Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£88)	£377 (0.04)
Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£79)	£1,803 (0.17)
Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,074)	£740 (0.07)
High jump	4 (0.43)	£380 (£154–£606)	£1,520 (0.33)	0		
Roller skating	2 (0.21)	£188 (£188–£188)	£377 (0.08)	0		
Volleyball	2 (0.21)	£209 (£0–£465)	£417 (0.09)	3 (0.23)	£270 (£0–£661)	£810 (0.08)
Cheerleading	0			0		
Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£729)	£1,096 (0.10)
Lacrosse	0			3 (0.23)	£404 (£0–£1,331)	£1,212 (0.11)
Rollerblading	0			0		
Boxing	2 (0.21)	£369 (£0–£2,674)	£740 (0.16)	2 (0.15)	£188 (£188–£88)	£377 (0.04)
Handball	0			3 (0.23)	£188 (£188–£88)	£565 (0.05)
All-terrain vehicle	2 (0.21)	£2,186 (£0–£27,566)	£4,371 (0.95)	0		
Touch football	0			2 (0.15)	£331 (£0–£1,331)	£662 (0.06)
Skating-NOS	0			0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; NOS, not otherwise specified.

Appendix 5 Acute care costs[†] for girls in the sports cohort

Females	5 to 11 years			12 to 17 years		
	N (%)	Mean cost (95% CI)	Total cost (%)	N (%)	Mean cost (95% CI)	Total cost (%)
Sports-related costs n (%)	346 (55)	£526 (£435–£617)	£182,009 (46)	282 (45)	£746 (£522–£970)	£210,439 (54)
<i>Sports activities</i>						
Bicycle riding	66 (19)	£691 (£390–£991)	£45,573 (25)	22 (7.8)	£1,242 (£403–£2,080)	£27,314 (13)
Australian rules football	2 (0.58)	£188 (£188–£188)	£377 (0.21)	8 (2.8)	£249 (£155–£344)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£441)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,422)	£5,223 (2.5)
Soccer	10 (2.9)	£213 (£158–£268)	£2,129 (1.2)	24 (8.5)	£283 (£191–£374)	£6,777 (3.2)
Scooter	44 (13)	£384 (£270–£499)	£16,904 (9.3)	5 (1.8)	£295 (£113–£476)	£1,472 (0.70)
Rugby	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	9 (3.2)	£297 (£198–£395)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,366)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,623)	£38,095 (18)
Horse riding	44 (13)	£872 (£538–£1,207)	£38,386 (21)	38 (13)	£1,456 (£590–£2,321)	£55,327 (26)
Hockey	8 (2.3)	£260 (£159–£361)	£2,078 (1.1)	19 (6.7)	£252 (£202–£305)	£4,795 (2.3)
Cricket	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
Swimming	22 (6.4)	£259 (£208–£309)	£5,693 (3.1)	6 (2.1)	£236 (£133–£339)	£1,416 (0.67)
Diving	15 (4.3)	£577 (£0–£1,166)	£8,650 (4.8)	12 (4.3)	£717 (£0–£1,782)	£8,597 (4.1)
Ice skating	13 (3.8)	£513 (£37–£988)	£6,662 (3.7)	6 (2.1)	£465 (£28–£903)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£288)	£7,233 (3.4)
Water sports-NOS	9 (2.6)	£216 (£153–£278)	£1,940 (1.1)	3 (1.1)	£202 (£144–£260)	£606 (0.29)
Gymnastics	20 (5.8)	£276 (£212–£339)	£5,513 (3.0)	6 (2.1)	£270 (£137–£403)	£1,620 (0.77)
Baseball/softball	4 (1.2)	£703 (£0–£2,339)	£2,810 (1.5)	0		

Racket	2 (0.58)	£188 (£188–£188)	£377 (0.21)	3 (1.1)	£188 (£188–£188)	£565 (0.27)
Golf	5 (1.4)	£633 (£0–£1,681)	£3,166 (1.7)	2 (0.71)	£331 (£0–£2,145)	£662 (0.27)
Surfing	5 (1.4)	£196 (£174–£219)	£982 (0.54)	1 (0.36)	£188	£188 (0.09)
Boating	3 (0.87)	£1,369 (£0–£4,426)	£4,108 (2.3)	2 (0.71)	£209 (£0–£465)	£417 (0.20)
Martial Arts	0			3 (1.1)	£483 (£99–£866)	£1,449 (0.69)
Dancing	6 (1.7)	£188 (£188–£188)	£1,130 (0.62)	2 (0.71)	£248 (£0–£995)	£494 (0.24)
Athletics	1 (0.29)	£188	£188 (0.10)	0		
Snow sports	2 (0.58)	£2,533 (£0–£32,325)	£5,066 (2.8)	4 (1.4)	£1,613 (£0–£6,105)	£6,452 (3.1)
High jump	2 (0.58)	£331 (£0–£1,631)	£662 (0.36)	2 (0.71)	£453 (£197–£711)	£907 (0.43)
Skateboarding	10 (2.9)	£602 (£5–£1,198)	£6,018 (3.3)	13 (4.6)	£791 (£119–£1,463)	£10,279 (4.9)
Volleyball	0			2 (0.71)	£267 (£0–£1,277)	£535 (0.25)
Cheerleading	0			6 (2.1)	£318 (£184–£452)	£1,906 (0.91)
Dodgeball	0			1 (0.36)	£188	£188 (0.09)
Lacrosse	0			2 (0.71)	£248 (£0–£995)	£494 (0.24)
Roller skating	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£188 (£188–£188)	£377 (0.18)
Boxing	0			0		
Handball	0			0		
All-terrain vehicle	1 (0.29)	£433	£433 (0.24)	0		
Touch football	0			0		
Skating-NOS	1 (0.29)	£188	£188 (0.10)	0		

†Costs inflated to 2018 Australian dollars and presented as pounds sterling using the average exchange rate of £0.60 on 30 June 2018.

CI, confidence interval; NOS, not otherwise specified.

REFERENCES

1. Singh S, Babl FE, Hearps SJC, et al. Trends of paediatric head injury and acute care costs in Australia. *J Paediatr Child Health* 2022;58(2):274–80. doi:10.1111/jpc.15699
2. Dalziel K, Cheek JA, Fanning L, et al. A cost-effectiveness analysis comparing clinical decision rules PECARN, CATCH, and CHALICE with usual care for the management of pediatric head injury. *Ann Emerg Med* 2019;73(5):429–39. doi:10.1016/j.annemergmed.2018.09.030
3. Australian Government. MBS online: Medicare benefits schedule, 2018. Available: <http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/Home> [Accessed September 18 2019].
4. AIHW: Kreisfeld R, Harrison JE. Hospitalised sports injury in Australia, 2016–17. Injury Research and Statistics Series No.131, Cat. No. INJCAT 211. Canberra: Australian Institute of Health and Welfare, 2020.
5. Lystad RP, Curtis K, Browne GJ, et al. Incidence, costs, and temporal trends of sports injury-related hospitalisations in Australian children over a 10-year period: A nationwide population-based cohort study. *J Sci Med Sport* 2019;22(2):175–80. doi:10.1016/j.jsams.2018.07.010