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

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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]

The aim of this study was to estimate the ED and acute hospital costs for children with TBIs due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and age of the child.

METHODS

This was a secondary analysis of the prospective multicentre Australasian Paediatric Head Injury Study (APHIRST), in which 17,841 Australian children <18 years were enrolled between April 2011 and November 2014. There were two mixed and six free-standing children's hospital emergency departments (EDs), all members of the Paediatric Research in Emergency Departments International Collaborative (PREDICT) network. The Human Research Ethics Committee of the Royal Children's Hospital (RCH), Melbourne (reference, 31008A) and the institutional ethics committees at the participating sites approved the study. The detailed methodology of the APHIRST study has been previously published.[12]

Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the activity codes noted on the case report form of the APHIRST study.[13] Helmet use was noted for TBIs from bicycle riding. We considered injuries sports-related if they occurred from organised or recreational sports and not falls from playground equipment or casual play. The research assistants assigned the activity codes at each site based on information recorded by the clinician at the time of the ED visit, obtained from medical record review and during the follow-up call.[13] Epidemiology codes for activity, place and injury mechanism of injury employed by the Victorian Injury Surveillance Unit in Australia were used across all study sites in APHIRST.[8 14 15] These were mapped to the International Classification of Diseases *10th revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71).[9 16] The combined football codes (U 50.01-50.05) included rugby, Australian rules football, touch football, soccer and football-not otherwise specified.[9 16]

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

The costing analysis was conducted from a publicly funded health system perspective, applying direct and indirect costs from the RCH to patient-level data in the Australian cohort (Appendix 1).[7 19] The details of the costing methods and data inputs have been published.[7] Acute care included ED presentations with either discharge or acute admissions until hospital discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All costs were inflated to 2018 Australian dollars ($) using the Reserve Bank of Australia general consumer price index rates from 13 September 2019 and presented as pounds sterling with the average exchange rate of UK £0.60 from 30 June 2018.[20 21] 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 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)
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)
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)

Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
Martial Arts	16 (0.55)	£417 (£122-£711)	£6,662 (0.34)
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
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 sports cohort (Figure 2). In contrast, the combined football sports were associated with primarily mild TBIs and the lowest acute costs.

Sports cohort: Age groups

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

In the younger age group, bicycle riding was associated with the highest proportion of TBIs (17%) and age group-related costs (26%). Although rugby was the most frequent injury mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger age group, mild TBIs from bicycle riding were associated with the highest group-related acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest group-related acute costs (15%) in the older age group.

Sports cohort: Sex

Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and the highest acute costs (27%) for the age group (Figure 3, Appendix 3). For boys in the older age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)

accounted for the highest acute costs (28%) for the age group. Motorcycle riding was associated with the highest mean per-patient costs for boys in both age groups (Appendix 3).

For young girls, bicycle riding was associated with the most TBIs (19%) and the highest acute costs (25%) for the age group (Figure 3, Appendix 4). For girls in the older age group, horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%) for the age group. The highest mean per-patient costs were associated with horse riding and motorcycle riding for younger and older girls, respectively (Appendix 4).

DISCUSSION

This cost of illness study estimates the frequency and economic burden of TBIs from sports activities in children between 5 and 18 years in Australia. While bicycle riding was associated with the most TBIs, motorcycle-related TBIs, with 4% of injuries, were associated with the highest total and mean per-patient acute care costs. When the combined effect of TBI severity and sports activities on the acute care costs were explored, bicycle riding injuries with mild TBIs and motorcycle riding with severe TBIs accounted for similar acute care costs for the sports cohort. Therefore, while motorcycle-related injuries had the most severe TBIs and the highest patient-level costs, the combined effect of injury frequency and TBI severity from bicycle and motorcycle riding contributed to the high economic burden on the health system.

In a recent population-based report, the total acute care costs for *all* sports-related injuries in Australia were AUD $764 million for FY 2019.[22] ED visits for *all* sports injuries accounted for 22% of the total acute care costs (AUD $164 million), and 37% of the ED costs were for children <20 years, who accounted for 25% of the Australian population.[22 23] The acute care costs for sports-related TBIs were AUD $32 million (4% of total costs for all sports injuries), and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-related TBIs accounted for 80% of the acute care costs.[22]

There are few published reports of paediatric sports-related head injuries in Australia.[13 15 18] While one study excluded bicycle, motorcycle and playground injuries,[18] another did not report motorcycle-related head injuries.[13] Australian rules football was associated with the highest proportion of head injuries in the retrospective study,[18] baseball and softball were associated with the most clinically important TBIs in the prospective study.[13] In the current study, we excluded playground injuries. We reported bicycle riding in younger children, rugby in older boys and horse riding in older girls were associated with the most sports-related TBIs.

To our knowledge, no prior studies have compared the acute costs of TBIs from sports activities in children. In this study, bicycle riding was the most frequent injury mechanism for the sports cohort and was associated with the highest costs for younger boys and girls. Additionally, the highest mean per-patient costs were associated with motorcycle riding for younger boys and horse riding for younger girls. While rugby was the most frequent injury mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For older girls, horse riding was associated with the most head injuries and the highest total acute costs, and motorcycle riding with the highest mean per-patient costs. Education programmes on safe riding practices and protective gear are needed to reduce sports-related TBIs.[24]

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

This study is not without some limitations. First, we focused on acute care costs of sports-related TBIs from the Australian publicly funded health system perspective. We did not consider the costs associated with long-term follow-up and rehabilitation, which would increase the total costs of these injuries. Second, the proportion of TBIs due to sports activities is underestimated because not all patients present to EDs after head injuries. Third, we did not collect information regarding helmet use during non-bicycle activities. Fourth, the high acute costs of severe TBIs could be associated with multi-organ injuries. However, since individual cost inputs were applied (Appendix 1), this would only be reflected in the length of hospital stay.[7] Finally, while this was a multicentre study, our results do not reflect 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.

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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.

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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

What is already known on this topic

- Sports activities are frequently associated with traumatic brain injuries in children.

What this study adds

- Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were associated with the highest mean per-patient and total acute care costs.
- Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated with the highest total acute care costs for the sports cohort.
- The highest mean per-patient costs were from horse riding in younger girls and motorcycle riding for older girls and boys in both age groups.

How this study might affect research, practice or policy

- Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.
- While contact sports are common mechanisms of injury, they are not associated with severe TBIs or high acute care costs.

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/bjsm.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

9. 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

10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in Sports- and Recreation-Related Traumatic Brain Injuries Treated in US Emergency Departments: The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma Rehabil* 2015;30(3):185-97. doi:10.1097/HTR.0000000000000156

11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for contact sports-related traumatic brain injuries among children — United States, 2001–2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870-74. doi:10.15585/mmwr.mm6927a4

12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE head injury decision rules in children: a prospective cohort study. *Lancet* 2017;389(10087):2393–402. doi:10.1016/s0140-6736(17)30555-x

13. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain injuries in children. *Med J Aust* 2019;211(8):365–66. doi:10.5694/mja2.50311

14. 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.

15. 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

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:

https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument [Accessed 18 Jul 2020].

24. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance Unit, Monash University Accident Research Centre, 2016.
25. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a formal review. June 2020*. ACT: Australian Transport Safety Bureau, 2000.
26. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid Anal Prev* 2001;33:345–52.
27. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta, GA: National Center for Injury Prevention and Control. Available: https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html [Accessed 09 Apr 2022].
28. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National Transportation Safety Board, 2019.
29. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76-82. doi:10.1136/ip.2005.010942
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.

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].

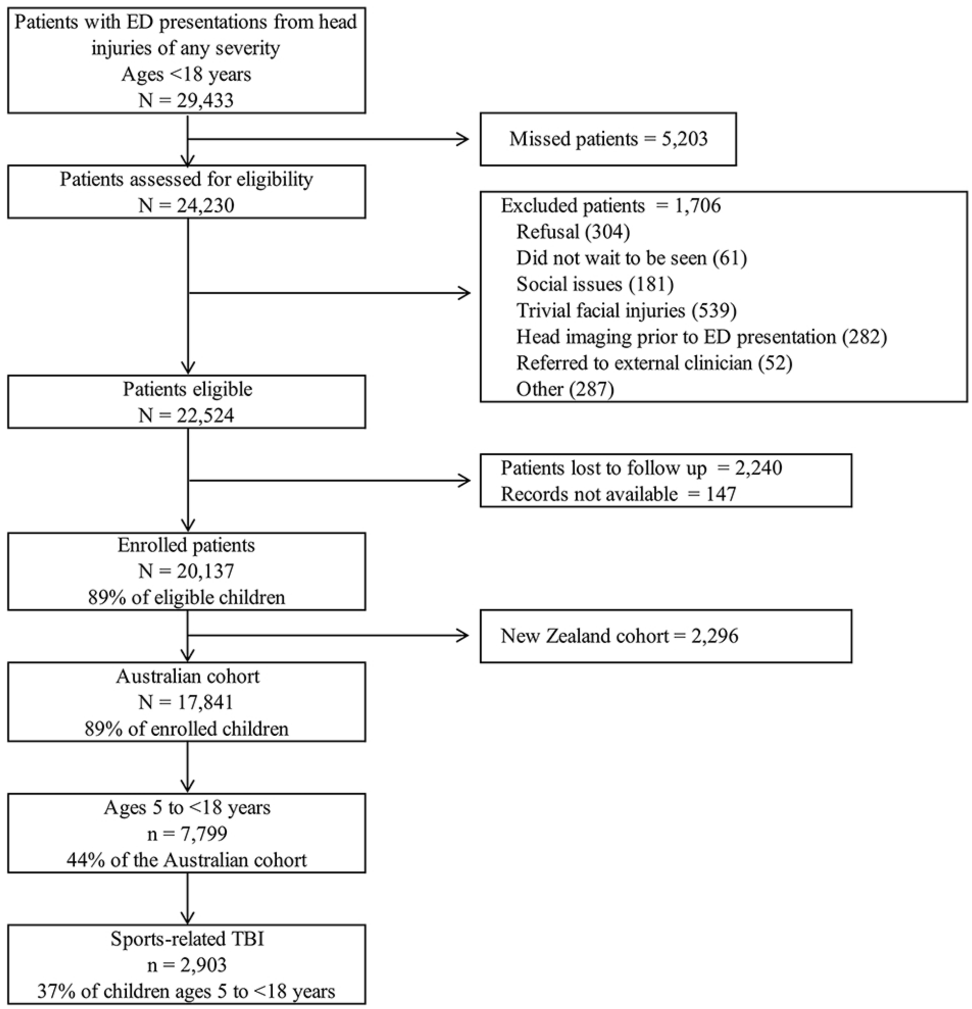

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort
TBI, traumatic brain injury

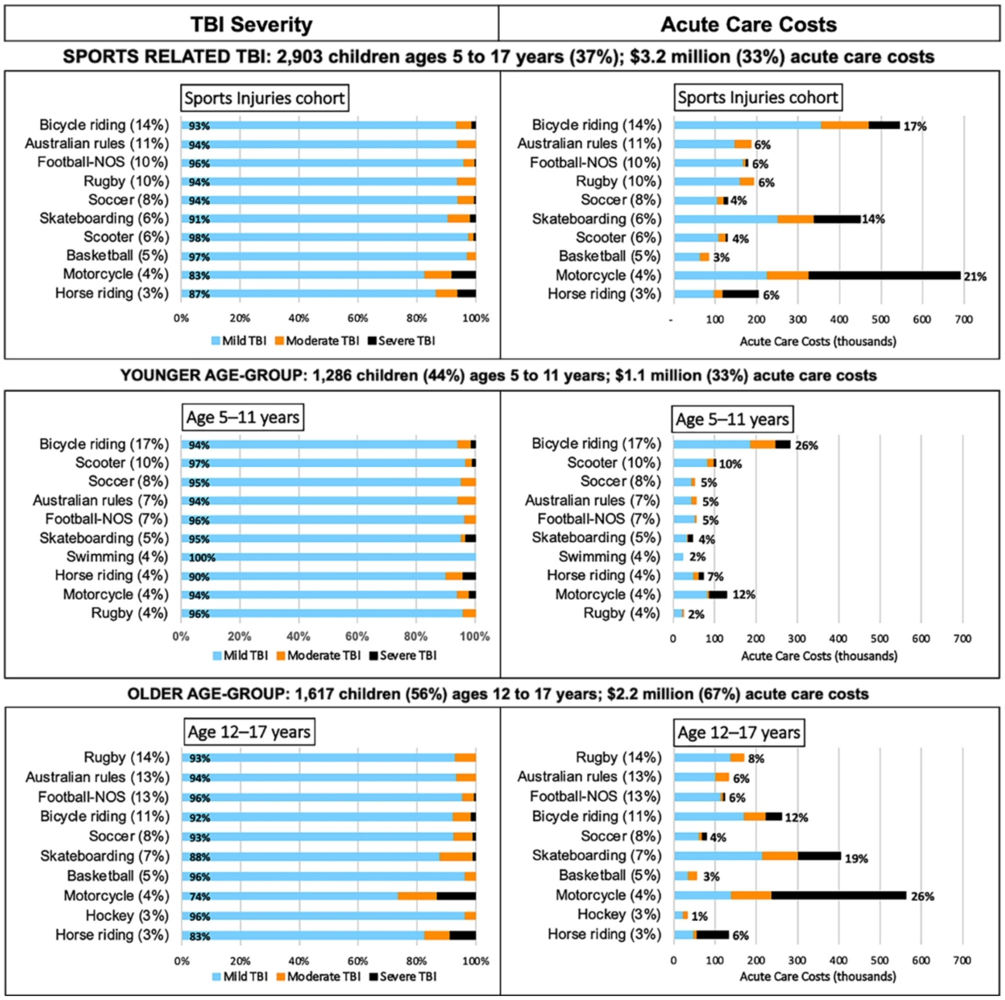

Figure 2. Sports-related TBI severity§ and acute care costs† by age groups
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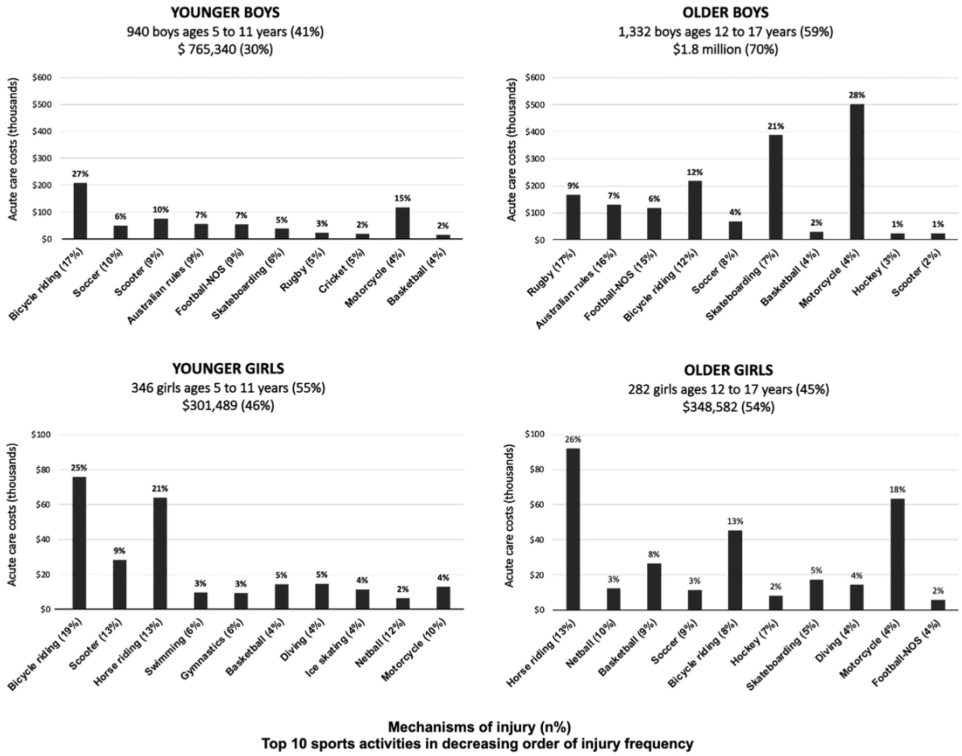

Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

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

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

	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)
U50: Team ball sports	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)
U50.01-05: Football	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)
U50.1-50.3: Basketball and Netball	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)
U51: Team bat sports	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)
U53: Boating sports			
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)
Sports activities						
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–£1,631)	£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–£895)	£5,133 (0.47)
Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£188)	£942 (0.09)
Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£379)	£1,803 (0.17)
Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,674)	£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–£621)	£810 (0.08)
Cheerleading	0			0		
Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£749)	£1,096 (0.10)
Lacrosse	0			3 (0.23)	£404 (£0–£1,031)	£1,212 (0.11)
Rollerblading	0			0		
Boxing	2 (0.21)	£369 (£0–£2,674)	£740 (0.16)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
Handball	0			3 (0.23)	£188 (£188–£188)	£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–£1,631)	£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 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–£971)	£210,439 (54)
Sports activities						
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–£345)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£440)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,402)	£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–£397)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,369)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,633)	£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–£303)	£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–£901)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£289)	£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–£2,144)	£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–£1,27[illegible])	£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.

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

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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]

The aim of this study was to estimate the ED and acute hospital costs for children with TBIs due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and age of the child.

METHODS

This was a secondary analysis of the prospective multicentre Australasian Paediatric Head Injury Study (APHIRST), in which 17,841 Australian children <18 years with head injuries of *all* severities were enrolled between April 2011 and November 2014. There were two mixed and six free-standing children's hospital emergency departments (EDs), all members of the Paediatric Research in Emergency Departments International Collaborative (PREDICT) network. The Human Research Ethics Committee of the Royal Children's Hospital (RCH), Melbourne (reference, 31008A) and the institutional ethics committees at the participating sites approved the study. The detailed methodology of the APHIRST study has been previously published.[12] For this analysis, we excluded 2,296 children enrolled in New Zealand to be consistent with the costing methods (Figure 1). The other exclusions have been discussed previously.[7 12]

The costing analysis was conducted from a publicly funded health system perspective, applying direct and indirect costs from the RCH to patient-level data in the Australian cohort (Appendix 1).[7 13] The details of the costing methods and data inputs have been published.[7] Acute care included ED presentations with either discharge or acute admissions until hospital discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All costs were inflated to 2018 Australian dollars ($) using the Reserve Bank of Australia general consumer price index rates from 13 September 2019 and presented as pounds sterling with the average exchange rate of UK £0.60 from 30 June 2018.[14 15]

Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the activity code for sports (activity = S) noted on the case report form of the APHIRST study.[16] The research assistants assigned the activity codes at each site based on information the clinician recorded at the ED visit, obtained from medical record review and during the follow-up call.[16] Epidemiology codes for activity, place and injury mechanism of injury employed by the Victorian Injury Surveillance Unit in Australia were used across all study sites in APHIRST.[8 17 18] These codes were mapped to the International Classification of Diseases *10th revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71) (Appendix 2).[9 19] The combined football codes (U 50.01-50.05) included rugby, Australian rules football, touch football, soccer and football-not otherwise specified.[9 19]

We considered injuries sports-related if they occurred from organised or recreational sports. Falls from playground equipment or casual play were excluded. Helmet use was noted for TBIs from bicycle riding. The sports cohort was stratified into two age groups (younger: 5 to 11 and older: 12 to 17 years). TBI was defined as any injury to the brain caused by an external force.[20] TBI severity was defined as mild, moderate, and severe. Mild TBI was defined as Glasgow Coma Scale (GCS) scores of 13–15 on ED presentation, no neurological deficits, with no evidence of TBI on cranial computed tomography (CT) or magnetic resonance imaging (MRI) if performed.[21] Moderate TBI included either GCS scores 9–13, or GCS scores 13–15 with neurological deficits or evidence of TBI on CT or MRI. Severe TBI was defined as GCS scores ≤8.[21] 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)
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)

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)
Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
Martial Arts	16 (0.55)	£417 (£122-£711)	£6,662 (0.34)
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
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 sports cohort (Figure 2). In contrast, the combined football sports were associated with primarily mild TBIs and the lowest acute costs.

Sports cohort: Age groups

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

In the younger age group, bicycle riding was associated with the highest proportion of TBIs (17%) and age group-related costs (26%). Although rugby was the most frequent injury mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger age group, mild TBIs from bicycle riding were associated with the highest group-related acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest group-related acute costs (15%) for sports injuries in the older age group.

Sports cohort: Sex

Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and the highest acute costs (27%) for the age group (Figure 3, Appendix 4). For boys in the older age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)

accounted for the highest acute costs (28%) for the age group. Motorcycle riding was associated with the highest mean per-patient costs for boys in both age groups (Appendix 4).

For young girls, bicycle riding was associated with the most TBIs (19%) and the highest acute costs (25%) for the age group (Figure 3, Appendix 5). For girls in the older age group, horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%) for the age group. The highest mean per-patient costs were associated with horse riding and motorcycle riding for younger and older girls, respectively (Appendix 5).

DISCUSSION

This cost of illness study estimates the frequency and economic burden of TBIs from sports activities in children between 5 and 18 years presenting to eight tertiary EDs in Australia. While bicycle riding was associated with the most TBIs, motorcycle-related TBIs, with 4% of injuries, were associated with the highest total and mean per-patient acute care costs. When the combined effect of TBI severity and sports activities on the acute care costs were explored, bicycle riding injuries with mild TBIs and motorcycle riding with severe TBIs accounted for similar acute care costs for the sports cohort. Therefore, while motorcycle-related injuries had the most severe TBIs and the highest patient-level costs, the combined effect of injury frequency and TBI severity from bicycle and motorcycle riding contributed to the high economic burden on the health system.

In a recent population-based report, the total acute care costs for *all* sports-related injuries in Australia were AUD $764 million for FY 2019.[22] ED visits for *all* sports injuries accounted for 22% of the total acute care costs (AUD $164 million), and 37% of the ED costs were for children <20 years, who accounted for 25% of the Australian population.[22 23] The acute care costs for sports-related TBIs were AUD $32 million (4% of total costs for all sports injuries), and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-related TBIs accounted for 80% of the acute care costs.[22]

There are few published reports of paediatric sports-related head injuries in Australia.[16 18 21] While one study excluded bicycle, motorcycle and playground injuries,[21] another did not report motorcycle-related head injuries.[16] Australian rules football was associated with the highest proportion of head injuries in the retrospective study,[21] baseball and softball were associated with the most clinically important TBIs in the prospective study.[16] In the current study, we excluded playground injuries. We reported bicycle riding in younger children, rugby in older boys and horse riding in older girls were associated with the most sports-related TBIs.

To our knowledge, no prior studies have compared the acute costs of TBIs from sports activities in children. In this study, bicycle riding was the most frequent injury mechanism for the sports cohort and was associated with the highest costs for younger boys and girls. Additionally, the highest mean per-patient costs were associated with motorcycle riding for younger boys and horse riding for younger girls. While rugby was the most frequent injury mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For older girls, horse riding was associated with the most head injuries and the highest total acute costs, and motorcycle riding with the highest mean per-patient costs. Education programmes on safe riding practices and protective gear are needed to reduce sports-related TBIs.[24]

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

This study is not without some limitations. First, we focused on acute care costs of sports-related TBIs from the Australian publicly funded health system perspective. We did not consider the number of contact hours associated with individual sports or the costs associated with long-term follow-up and rehabilitation, which would increase the total costs of these injuries. Second, we did not collect information regarding helmet use during non-bicycle activities. Third, the high acute costs of severe TBIs could be associated with multi-organ injuries which we did not evaluate. However, because individual cost inputs were applied (Appendix 1), this would only be reflected in the length of hospital stay.[7] Fourth, the proportion of TBIs due to sports activities is likely underestimated because not all patients present to tertiary EDs after head injuries. Prior research has shown that about 25% of ED presentations for children in Australia occur at tertiary referral centres.[37] APHIRST enrolled children across ten tertiary referral hospitals in Australia and New Zealand, possibly underrepresenting rural and indigenous populations. Additionally, the rates of mild TBIs are likely underestimated because most of these children are not seen in EDs and are managed at home or by general practitioners.[38] Therefore, the acute care costs and TBIs reported with sports, and other mechanisms may not be generalisable beyond tertiary referral EDs.

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.

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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.

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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

What is already known on this topic

- Sports activities are frequently associated with traumatic brain injuries in children.

What this study adds

- Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were associated with the highest mean per-patient and total acute care costs.
- Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated with the highest total acute care costs for the sports cohort.
- The highest mean per-patient costs were from horse riding in younger girls and motorcycle riding for older girls and boys in both age groups.

How this study might affect research, practice or policy

- Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.
- While contact sports are common mechanisms of injury, they are not associated with severe TBIs or high acute care costs.

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/bjsm.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

9. 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

10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in Sports- and Recreation-Related Traumatic Brain Injuries Treated in US Emergency Departments: The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma Rehabil* 2015;30(3):185–97. doi:10.1097/HTR.0000000000000156

11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for contact sports-related traumatic brain injuries among children—United States, 2001–2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870–74. doi:10.15585/mmwr.mm6927a4

12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE head injury decision rules in children: a prospective cohort study. *Lancet* 2017;389(10087):2393–402. doi:10.1016/s0140-6736(17)30555-x

13. 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

14. The Reserve Bank of Australia inflation calculator: Reserve Bank of Australia. Available: https://www.rba.gov.au/calculator/ [Accessed September 19 2018].

15. 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 August 31 2020].

16. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain injuries in children. *Med J Aust* 2019;211(8):365–66. doi:10.5694/mja2.50311

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].

24. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance Unit, Monash University Accident Research Centre, 2016.

25. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a formal review. June 2020*. ACT: Australian Transport Safety Bureau, 2000.

26. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid Anal Prev* 2001;33:345–52. doi:10.1016/s0001-4575(00)00048-8

27. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta, GA: National Center for Injury Prevention and Control. Available: https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html [Accessed 09 Apr 2022].

28. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National Transportation Safety Board, 2019.

29. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76–82. doi:10.1136/ip.2005.010942

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.

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

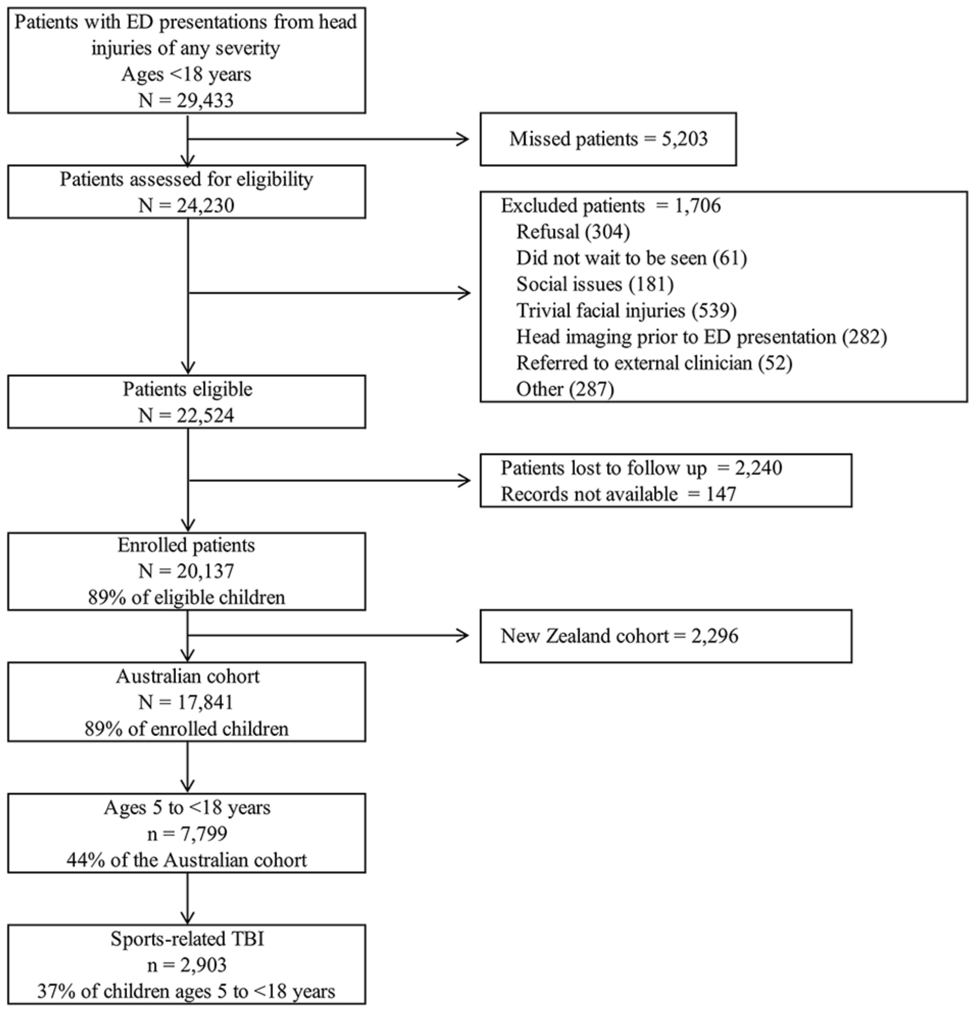

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort
TBI, traumatic brain injury

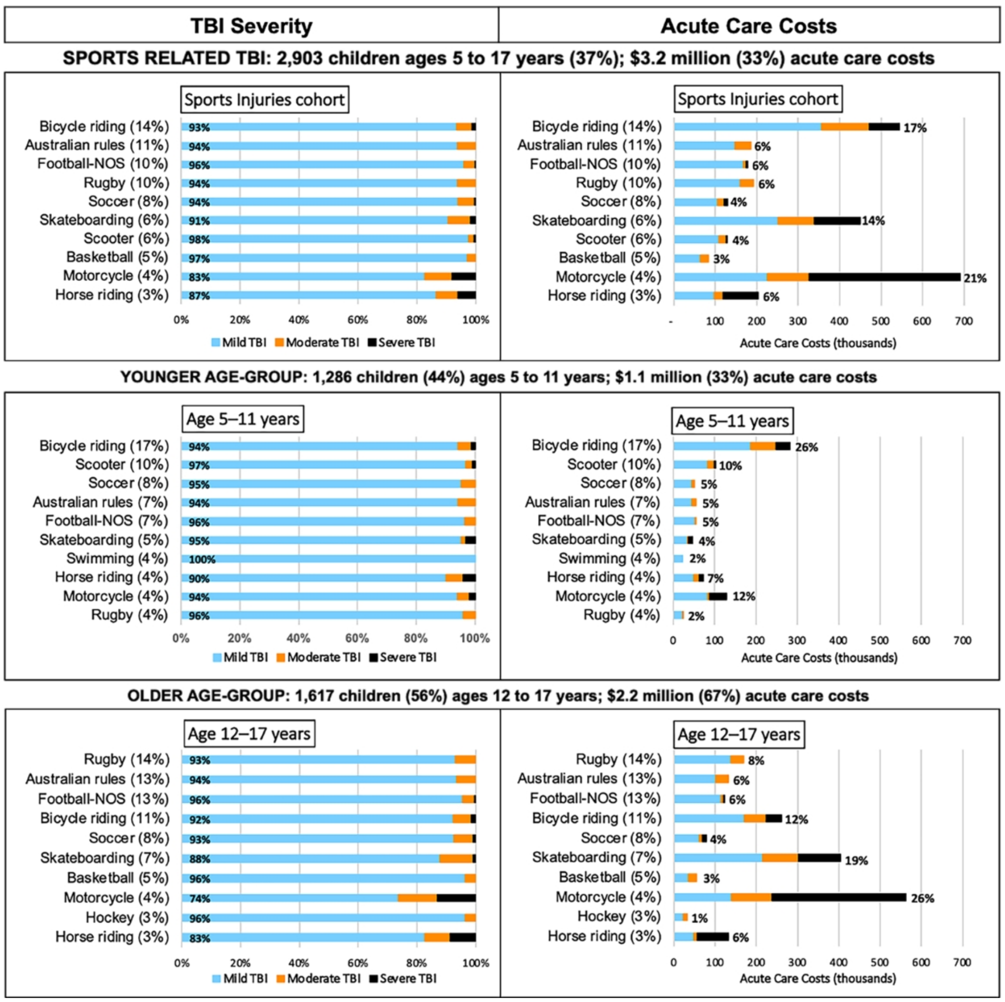

Figure 2. Sports-related TBI severity§ and acute care costs† by age groups
Top ten sports activities in decreasing order of injury frequency
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019
§TBI Severity: Mild TBI, 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

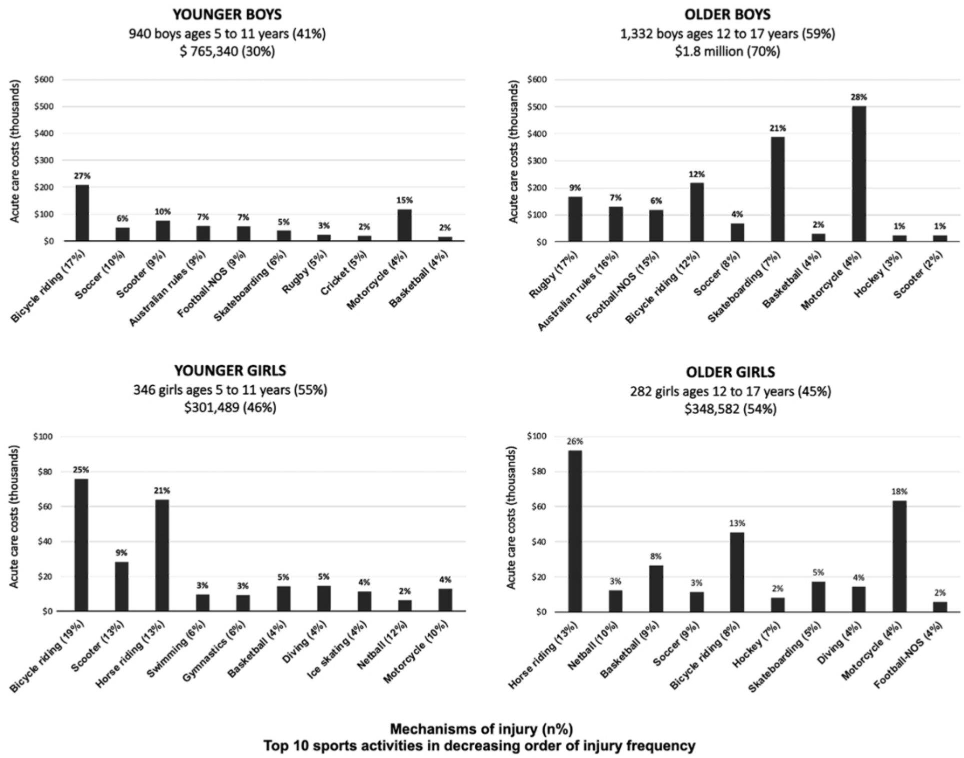

Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

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

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

	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; bungy 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)
U50: Team ball sports	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)
U50.01-05: Football	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)
U50.1-50.3: Basketball and Netball	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)
U51: Team bat sports	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)
U53: Boating sports			
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)
Sports activities						
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–£1,631)	£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–£895)	£5,133 (0.47)
Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£188)	£942 (0.09)
Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£379)	£1,803 (0.17)
Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,674)	£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–£621)	£810 (0.08)
Cheerleading	0			0		
Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£749)	£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–£188)	£377 (0.04)
Handball	0			3 (0.23)	£188 (£188–£188)	£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–£1,631)	£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–£971)	£210,439 (54)
Sports activities						
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–£345)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£440)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,402)	£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–£397)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,369)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,633)	£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–£303)	£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–£901)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£289)	£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–£2,144)	£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–£1,27[illegible])	£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

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

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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]

The aim of this study was to estimate the ED and acute hospital costs for children with TBIs due to sports activities in Australia, stratified by mechanisms of injury, TBI severity, sex, and age of the child.

METHODS

This was a secondary analysis of the prospective multicentre Australasian Paediatric Head Injury Study (APHIRST), in which 17,841 Australian children <18 years with head injuries of *all* severities were enrolled between April 2011 and November 2014. There were two mixed and six free-standing children's hospital emergency departments (EDs), all members of the Paediatric Research in Emergency Departments International Collaborative (PREDICT) network. The Human Research Ethics Committee of the Royal Children's Hospital (RCH), Melbourne (reference, 31008A) and the institutional ethics committees at the participating sites approved the study. The detailed methodology of the APHIRST study has been previously published.[12] For this analysis, we excluded 2,296 children enrolled in New Zealand to be consistent with the costing methods (Figure 1). The other exclusions have been discussed previously.[7 12]

The costing analysis was conducted from a publicly funded health system perspective, applying direct and indirect costs from the RCH to patient-level data in the Australian cohort (Appendix 1).[7 13] The details of the costing methods and data inputs have been published.[7] Acute care included ED presentations with either discharge or acute admissions until hospital discharge. The total acute care costs and mean per-patient cost with 95% confidence intervals (CIs) for sports-related TBIs were estimated by sex, child-age groups, and injury severity. All costs were inflated to 2018 Australian dollars ($) using the Reserve Bank of Australia general consumer price index rates from 13 September 2019 and presented as pounds sterling with the average exchange rate of UK £0.60 from 30 June 2018.[14 15]

Sports-related TBIs for children ages 5 to <18 years (sports cohort) were identified using the activity code for sports (activity = S) noted on the case report form of the APHIRST study.[16] The research assistants assigned the activity codes at each site based on information the clinician recorded at the ED visit, obtained from medical record review and during the follow-up call.[16] Epidemiology codes for activity, place and injury mechanism of injury employed by the Victorian Injury Surveillance Unit in Australia were used across all study sites in APHIRST.[8 17 18] These codes were mapped to the International Classification of Diseases *10th revision-Australian Modification* (ICD-10-AM) sports activity codes (U50-U71) (Appendix 2).[9 19] The combined football codes (U 50.01-50.05) included rugby, Australian rules football, touch football, soccer and football-not otherwise specified.[9 19]

We considered injuries sports-related if they occurred from organised or recreational sports. Falls from playground equipment or casual play were excluded. Helmet use was noted for TBIs from bicycle riding. The sports cohort was stratified into two age groups (younger: 5 to 11 and older: 12 to 17 years) based on the reported differences in physical activity levels in Australian children.[20] TBI was defined as any injury to the brain caused by an external force.[21] TBI severity was defined as mild, moderate, and severe. Mild TBI was defined as Glasgow Coma Scale (GCS) scores of 13–15 on ED presentation, no neurological deficits, with no evidence of TBI on cranial computed tomography (CT) or magnetic resonance imaging (MRI) if performed.[22] Moderate TBI included either GCS scores 9–13, or GCS scores 13–15 with neurological deficits or evidence of TBI on CT or MRI. Severe TBI was defined as GCS 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)
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)

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)
Gymnastics	38 (1.3)	£257 (£216–£298)	£9,756 (0.50)
Baseball/softball	34 (1.2)	£814 (£0–£1,649)	£27,697 (1.4)
Racket	28 (0.97)	£246 (£209–£284)	£6,900 (0.36)
Golf	22 (0.76)	£619 (£219–£1,019)	£13,624 (0.70)
Surfing	20 (0.69)	£354 (£132–£577)	£7,082 (0.37)
Martial Arts	16 (0.55)	£417 (£122-£711)	£6,662 (0.34)
Boating	16 (0.55)	£630 (£270–£989)	£10,075 (0.52)
Dancing	15 (0.52)	£199 (£182–£216)	£2,983 (0.15)
Athletics	13 (0.45)	£328 (£143–£513)	£4,265 (0.22)
Snow sports	9 (0.31)	£1,414 (£0–£3,148)	£12,732 (0.66)
High jump	8 (0.28)	£386 (£287–£485)	£3,089 (0.16)
Roller skating	7 (0.24)	£188 (£188–£188)	£1,318 (0.07)
Volleyball	7 (0.24)	£252 (£161–£343)	£1,762 (0.09)
Dodgeball	6 (0.21)	£276 (£132–£421)	£1,661 (0.09)
Cheerleading	6 (0.21)	£318 (£184–£452)	£1,906 (0.10)
Rollerblading	5 (0.17)	£1,158 (£0–£3,849)	£5,788 (0.30)
Lacrosse	5 (0.17)	£341 (£0–£689)	£1,706 (0.09)
Boxing	4 (0.14)	£279 (£0–£567)	£1,116 (0.06)
All-terrain vehicle	3 (0.10)	£1,602 (£0–£7,164)	£4,805 (0.25)
Handball	3 (0.10)	£188 (£188–£188)	£565 (0.03)
Touch football	2 (0.07)	£331 (£0–£1,631)	£662 (0.03)
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 sports cohort (Figure 2). In contrast, the combined football sports were associated with primarily mild TBIs and the lowest acute costs.

Sports cohort: Age groups

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

In the younger age group, bicycle riding was associated with the highest proportion of TBIs (17%) and age group-related costs (26%). Although rugby was the most frequent injury mechanism in the older age group (14%), with 8% of acute care costs, motorcycle-related TBIs (3.8%) were associated with the highest age group-related costs (26%). For the younger age group, mild TBIs from bicycle riding were associated with the highest group-related acute costs (18%). Severe TBIs from motorcycle riding were associated with the highest group-related acute costs (15%) for sports injuries in the older age group.

Sports cohort: Sex

Boys accounted for 78% of the sports cohort and were associated with 80% of the acute care costs (Table 1). For young boys, bicycle riding was associated with the most TBIs (17%) and the highest acute costs (27%) for the age group (Figure 3, Appendix 4). For boys in the older age group, rugby had the most TBIs (17%); however, motorcycle-related TBIs (3.8%)

accounted for the highest acute costs (28%) for the age group. Motorcycle riding was associated with the highest mean per-patient costs for boys in both age groups (Appendix 4).

For young girls, bicycle riding was associated with the most TBIs (19%) and the highest acute costs (25%) for the age group (Figure 3, Appendix 5). For girls in the older age group, horse riding was associated with the most TBIs (13%) and the highest total acute costs (26%) for the age group. The highest mean per-patient costs were associated with horse riding and motorcycle riding for younger and older girls, respectively (Appendix 5).

DISCUSSION

This cost of illness study estimates the frequency and economic burden of TBIs from sports activities in children between 5 and 18 years presenting to eight tertiary EDs in Australia. While bicycle riding was associated with the most TBIs, motorcycle-related TBIs, with 4% of injuries, were associated with the highest total and mean per-patient acute care costs. When the combined effect of TBI severity and sports activities on the acute care costs were explored, bicycle riding injuries with mild TBIs and motorcycle riding with severe TBIs accounted for similar acute care costs for the sports cohort. Therefore, while motorcycle-related injuries had the most severe TBIs and the highest patient-level costs, the combined effect of injury frequency and TBI severity from bicycle and motorcycle riding contributed to the high economic burden on the health system.

In a recent population-based report, the total acute care costs for *all* sports-related injuries in Australia were AUD $764 million for FY 2019.[23] ED visits for *all* sports injuries accounted for 22% of the total acute care costs (AUD $164 million), and 37% of the ED costs were for children <20 years, who accounted for 25% of the Australian population.[23 24] The acute care costs for sports-related TBIs were AUD $32 million (4% of total costs for all sports injuries), and 95% were incurred at public hospitals. Similar to our results, acute admissions for sports-related TBIs accounted for 80% of the acute care costs.[23]

There are few published reports of paediatric sports-related head injuries in Australia.[16 18 22] While one study excluded bicycle, motorcycle and playground injuries,[22] another did not report motorcycle-related head injuries.[16] Australian rules football was associated with the highest proportion of head injuries in the retrospective study,[22] baseball and softball were associated with the most clinically important TBIs in the prospective study.[16] In the current study, we excluded playground injuries. We reported bicycle riding in younger children, rugby in older boys and horse riding in older girls were associated with the most sports-related TBIs.

To our knowledge, no prior studies have compared the acute costs of TBIs from sports activities in children. In this study, bicycle riding was the most frequent injury mechanism for the sports cohort and was associated with the highest costs for younger boys and girls. Additionally, the highest mean per-patient costs were associated with motorcycle riding for younger boys and horse riding for younger girls. While rugby was the most frequent injury mechanism for older boys, motorcycle riding had the highest mean and total acute costs. For older girls, horse riding was associated with the most head injuries and the highest total acute costs, and motorcycle riding with the highest mean per-patient costs. Education programmes on safe riding practices and protective gear are needed to reduce sports-related TBIs.[25]

Prior research has shown that helmet laws and the proper use of helmets reduce head injuries and fatalities from bicycle riding.[26-31] For the sports cohort, 52% of children with TBIs from bicycle riding were reported to be wearing helmets, accounting for 37% of bicycle-related acute care costs. Although we only obtained information regarding helmet use with bicycle riding, the effect of helmet use on reducing TBIs with other wheeled sports is strongly supported by research.[32 33] The impact of helmet legislation on reducing fatalities from motorcycle and bicycle riding has been shown globally.[34] In Australia, helmets are required for motorcycle and bicycle riding for all ages.[35] In the UK, helmet use is required for motorcycle riding for all ages.[36] Helmets are only recommended for riding bicycles, all-terrain vehicles, scooters or skateboards. In the US, state and local laws are responsible for helmet legislation, and there are no helmet laws for bicycle riding in 29 states and motorcycle riding in 3 states.[29 37] While helmet laws are necessary for reducing mortality from sports activities, our results indicate that additional strategies are required to reduce head injury severity.

This study is not without some limitations. First, we focused on acute care costs of sports-related TBIs from the Australian publicly funded health system perspective. We did not consider the number of contact hours associated with individual sports or the costs associated with long-term follow-up and rehabilitation, which would increase the total costs of these injuries. Second, we did not collect information regarding helmet use during non-bicycle activities or if the TBIs occurred from recreational or organised sports. Third, the high acute costs of severe TBIs could be associated with multi-organ injuries which we did not evaluate. However, because individual cost inputs were applied (Appendix 1), this would only be reflected in the length of hospital stay.[7] Fourth, the proportion of TBIs due to sports activities is likely underestimated because not all patients present to tertiary EDs after head injuries. Prior research has shown that about 25% of ED presentations for children in Australia occur at tertiary referral centres.[38] APHIRST enrolled children across ten tertiary referral hospitals in Australia and New Zealand, possibly underrepresenting rural and indigenous populations. Additionally, the rates of mild TBIs are likely underestimated because most of these children are not seen in EDs and are managed at home or by general practitioners.[39] Therefore, the acute care costs and TBIs reported with sports, and other mechanisms may not be generalisable beyond tertiary referral EDs.

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.

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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.

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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

What is already known on this topic

- Sports activities are frequently associated with traumatic brain injuries in children.

What this study adds

- Bicycle riding had the most sports-related TBIs, and motorcycle-related TBIs were associated with the highest mean per-patient and total acute care costs.
- Mild TBIs from bicycle riding and severe TBIs from motorcycle riding were associated with the highest total acute care costs for the sports cohort.
- The highest mean per-patient costs were from horse riding in younger girls and motorcycle riding for older girls and boys in both age groups.

How this study might affect research, practice or policy

- Injury prevention strategies should focus on age and sex-related sports activities to reduce the burden of TBIs in children.
- While contact sports are common mechanisms of injury, they are not associated with severe TBIs or high acute care costs.

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/bjsm.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

9. 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

10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in sports- and recreation-related traumatic brain injuries treated in US emergency departments: The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma Rehabil* 2015;30(3):185-97. doi:10.1097/HTR.0000000000000156

11. Waltzman D, Womack LS, Thomas KE, et al. Trends in emergency department visits for contact sports-related traumatic brain injuries among children—United States, 2001–2018. *MMWR Morb Mortal Wkly Rep* 2020;69:870-74. doi:10.15585/mmwr.mm6927a4

12. Babl FE, Borland M, Phillips N, et al. Accuracy of PECARN, CATCH, and CHALICE head injury decision rules in children: a prospective cohort study. *Lancet* 2017;389(10087):2393-402. doi:10.1016/s0140-6736(17)30555-x

13. 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

14. The Reserve Bank of Australia inflation calculator: Reserve Bank of Australia. Available: https://www.rba.gov.au/calculator/ [Accessed September 19 2018].

15. 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 August 31 2020].

16. Eapen N, Davis GA, Borland ML, et al. Clinically important sport-related traumatic brain injuries in children. *Med J Aust* 2019;211(8):365-66. doi:10.5694/mja2.50311

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:

https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202019?OpenDocument [Accessed July 18 2020].

25. Day L, Clapperton A, Berecki-Gisolf J. Off-road motorcycle injury among children aged 0–17 years in Victoria. Hazard Edition 81. Melbourne: Victorian Injury Surveillance Unit, Monash University Accident Research Centre, 2016.
26. Attewell R, Glase K, McFadden M. CR 195: *Bicycle helmets and injury prevention: a formal review. June 2020*. ACT: Australian Transport Safety Bureau, 2000.
27. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid Anal Prev* 2001;33:345-52. doi:10.1016/s0001-4575(00)00048-8
28. Centers for Disease Control and Prevention. Bicycle helmet laws for children Atlanta, GA: National Center for Injury Prevention and Control. Available: https://www.cdc.gov/motorvehiclesafety/calculator/factsheet/bikehelmet.html [Accessed 09 Apr 2022].
29. National Transportation Safety Board. *Bicyclist safety on US roadways: crash risks and countermeasures.* Safety Research Report NTSB/SS–19/01. Washington, DC: National Transportation Safety Board, 2019.
30. Karkhaneh M, Kalenga JC, Hagel BE, et al. Effectiveness of bicycle helmet legislation to increase helmet use: a systematic review. *Inj Prev* 2006;12(2):76-82. doi:10.1136/ip.2005.010942
31. 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
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.

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

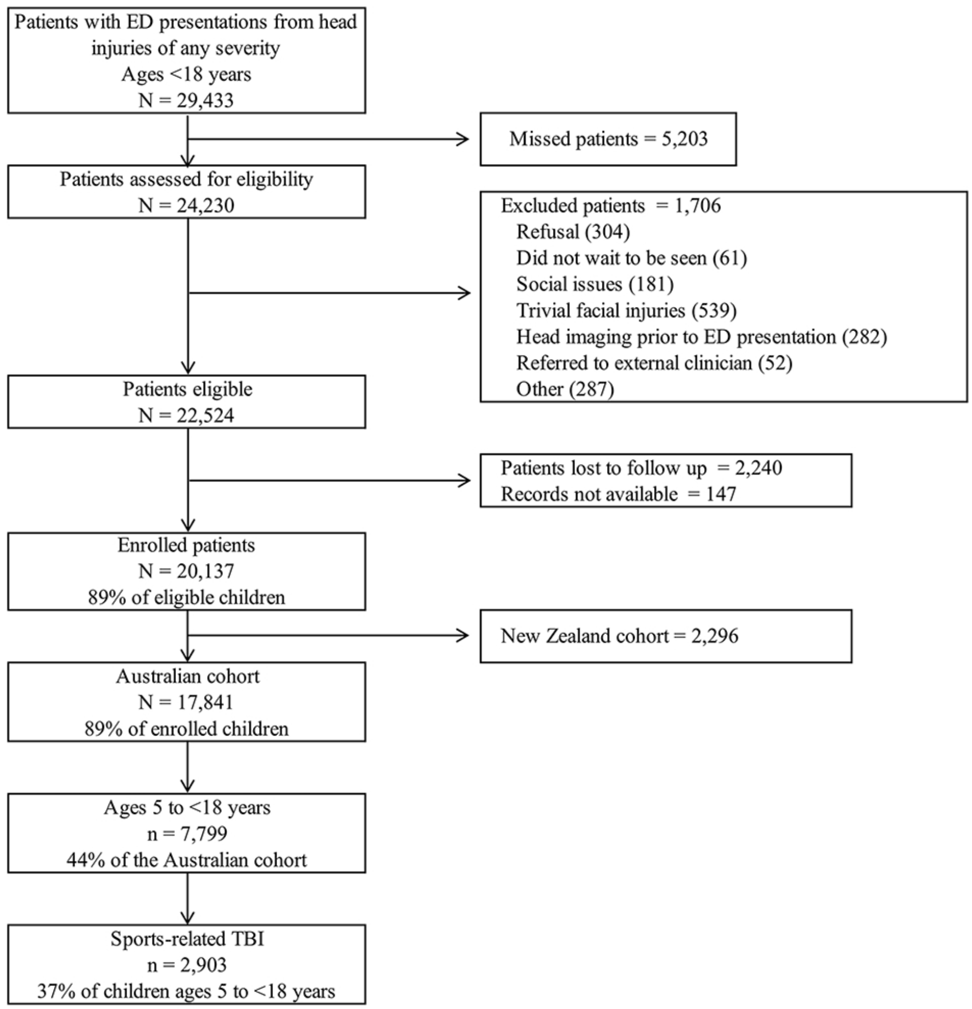

Figure 1. Patient flowchart: The Australasian Paediatric Head Injury Study sports cohort
TBI, traumatic brain injury

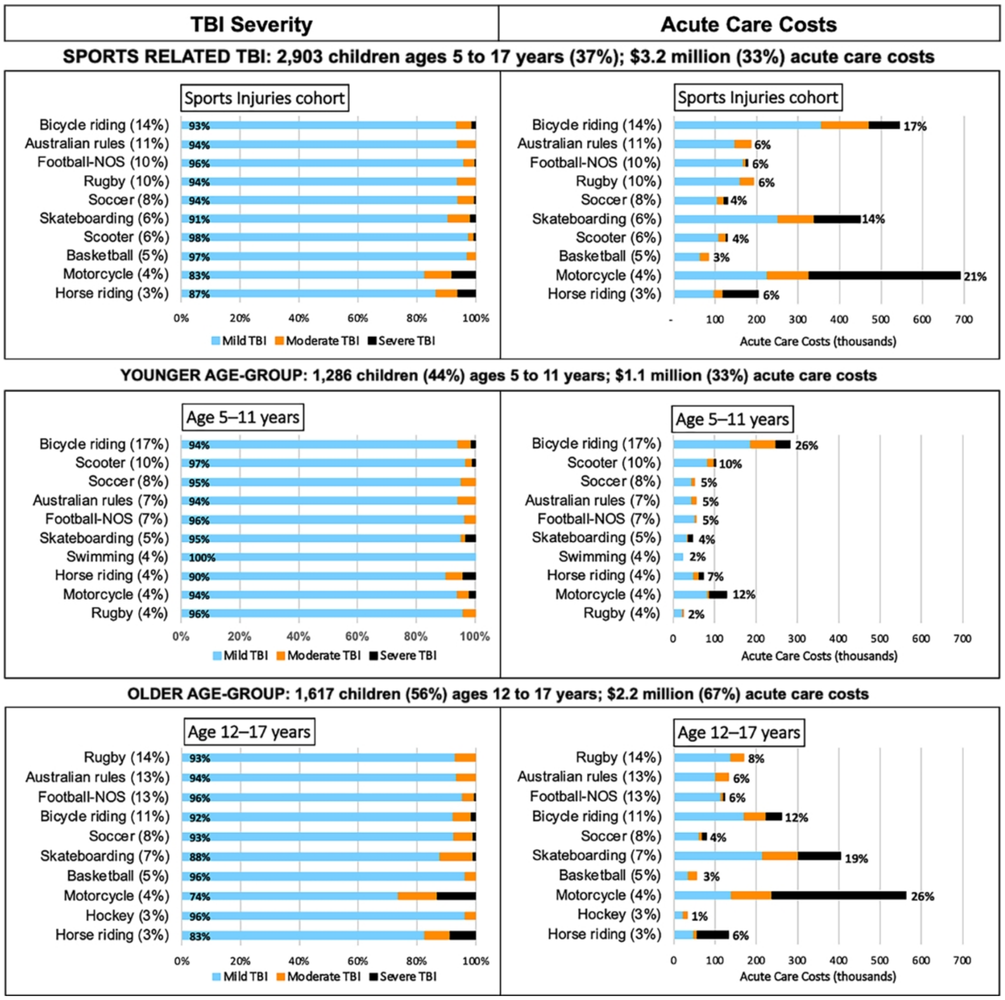

Figure 2. Sports-related TBI severity§ and acute care costs† by age groups
Top ten sports activities in decreasing order of injury frequency
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019
§TBI Severity: Mild TBI, 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

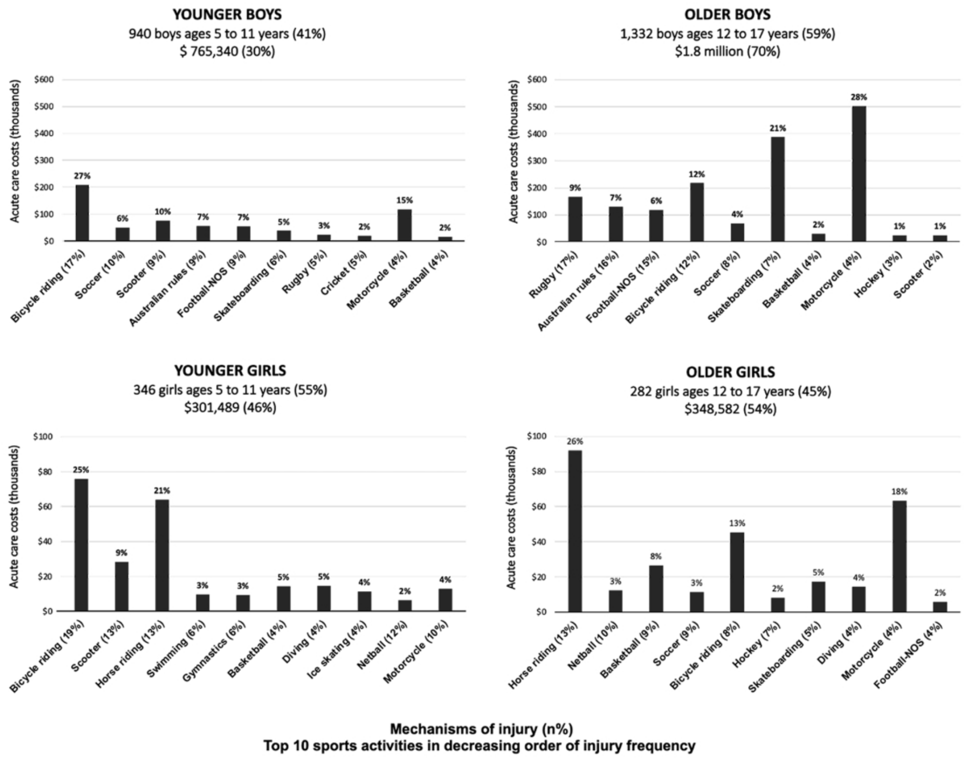

Figure 3. Acute care costs† of sports-related TBIs stratified by age and sex
†Costs inflated to 2018 Australian dollars using the Reserve Bank of Australia general consumer price index rates from 13 September 2019

Supplementary material of:

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

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

	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; bungy 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)
U50: Team ball sports	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)
U50.01-05: Football	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)
U50.1-50.3: Basketball and Netball	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)
U51: Team bat sports	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)
U53: Boating sports			
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)
Sports activities						
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–£1,031)	£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–£895)	£5,133 (0.47)
Martial Arts	8 (0.85)	£534 (£0–£1,178)	£4,271 (0.92)	5 (0.38)	£188 (£188–£188)	£942 (0.09)
Dancing	5 (0.53)	£196 (£174–£219)	£982 (0.21)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
Athletics	5 (0.53)	£455 (£0–£1,040)	£2,274 (0.49)	7 (0.53)	£258 (£136–£379)	£1,803 (0.17)
Snow sports	1 (0.11)	£474	£474 (0.10)	2 (0.15)	£369 (£0–£2,674)	£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–£621)	£810 (0.08)
Cheerleading	0			0		
Dodgeball	2 (0.21)	£188 (£188–£188)	£377 (0.08)	3 (0.23)	£365 (£0–£749)	£1,096 (0.10)
Lacrosse	0			3 (0.23)	£404 (£0–£1,031)	£1,212 (0.11)
Rollerblading	0			0		
Boxing	2 (0.21)	£369 (£0–£2,674)	£740 (0.16)	2 (0.15)	£188 (£188–£188)	£377 (0.04)
Handball	0			3 (0.23)	£188 (£188–£188)	£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–£1,631)	£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–£971)	£210,439 (54)
Sports activities						
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–£345)	£1,997 (0.95)
Football-NOS	3 (0.87)	£284 (£0–£610)	£851 (0.47)	10 (3.5)	£331 (£221–£440)	£3,305 (1.6)
Rollerblading	3 (0.87)	£188 (£188–£188)	£565 (0.31)	2 (0.71)	£2,612 (£0–£33,402)	£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–£397)	£2,675 (1.3)
Basketball	15 (4.3)	£563 (£93–£1,033)	£8,445 (4.6)	25 (8.9)	£634 (£0–£1,369)	£15,867 (7.5)
Motorcycle	10 (2.9)	£761 (£8–£1,515)	£7,614 (4.2)	11 (3.9)	£3,463 (£0–£7,653)	£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–£303)	£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–£901)	£2,788 (1.3)
Netball	12 (3.5)	£309 (£132–£486)	£3,710 (2.0)	29 (10)	£249 (£210–£289)	£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–£2,144)	£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–£1,273)	£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