Title: Sports-related brain injury in the general population: an epidemiological study

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ABSTRACT

Objective: To determine the incidence, nature and severity of all sports-related brain injuries in the general population.

Design: Population-based epidemiological incidence study.

Methods: Data on all traumatic brain injury (TBI) events sustained during a sports-related activity were extracted from a dataset of all new TBI cases (both fatal and non-fatal), identified over a one-year period in the Hamilton and Waikato districts of New Zealand. Prospective and retrospective case ascertainment methods from multiple sources were used. All age groups and levels of TBI severity were included. Details of the registering injuries and recurrent injuries sustained over the subsequent year were obtained through medical/accident records and assessment interviews with participants.

Results: Of 1369 incident TBI cases, 291 were identified as being sustained during a sports-related activity (21% of all TBIs) equating to an incidence rate of 170 per 100,000 of the general population. Recurrent injuries occurred more frequently in adults (11%) than children (5%). Of the sports-related injuries 46% were classified as mild with a high risk of complications. Injuries were most frequently sustained during rugby, cycling and equestrian activities. It was revealed that up to 19% of TBIs were not recorded in medical notes.

Discussion: Given the high incidence of new and recurrent TBI and the high risk of complications following injury, further sport specific injury prevention strategies are urgently needed to reduce the impact of TBI and facilitate safer engagement in sports activities. The high levels of 'missed' TBIs, highlights the importance in raising awareness of TBI during sports-related activity in the general population.

INTRODUCTION

The physical, social and psychological benefits of engaging in sports-related activities are well documented[1], however, participation in sports-related activities can place individuals at increased risk of injury.[2] Injury to the brain as the result of a high acceleration, multiple or rotational impact to the head in the context of sport is common, with previous studies revealing that up to 15% of all traumatic brain injuries (TBIs) are sustained during sports-related activities.[3] In the USA, 1.6 to 2.3 million cases of sports-related head injury occur every year, with high associated direct and indirect costs (estimated to be US$56billion each year).[4]

The most recent consensus statement[5] on concussion in sport highlights that the term concussion specifically refers to a low velocity shaking of the head. Many injuries sustained during sport can involve severe injury or a direct blow to the head, in addition to injuries sustained through shaking of the brain. All injuries where there is an injury sustained to the brain will be referred to as TBIs in this article to encompass the full spectrum of injuries that may occur within the sports context, rather than just concussion.

Although early management has improved enormously with more people now surviving acute injury, those who do survive a significant brain injury frequently experience persistent difficulties in physical, social, cognitive and emotional functioning.[6-8] There is emerging evidence that there may also be long-term effects from sustaining even a mild TBI(s). For example, mild TBIs may pre-dispose individuals to early onset dementia and cognitive impairment,[9] depression[10] and neurogenerative disease.[11] Sustaining multiple impacts to the head (recurrent TBI) can result in cumulative effects as the surviving brain cells from the initial injury become more vulnerable to further damage.[12]

Previous studies on the epidemiology of brain injuries sustained during sport have revealed that males and those under 18 years of age are at increased risk of sports-related TBI.[3 13] Generally, the highest rates of TBIs occur in hockey, rugby, equestrian activities, cycling, winter sports and football.[3 13 14] However, the findings of previous studies are limited as recruitment has been restricted to particular populations (such as school children or professional athletes) or specific sporting activities (such as football players). Studies examining sports-related injuries in the general population have also been limited as they have focused on hospital or emergency department records to identify TBI cases. This approach to case ascertainment can result in cases of mild TBI being missed as people may not wish to go to hospital or an emergency department (particularly if it may affect return to play), may not realise they have experienced a brain injury, or the TBI can be overshadowed by more severe injuries, such as broken bones, that require immediate treatment. Population-based studies utilising a range of sources of case ascertainment sources are needed to accurately capture the extent of sports-related TBI in the general population. It is also unclear if the greater risk of TBI experienced by people of Maori and Pasifika ethnicity (indigenous populations of New Zealand, NZ) identified in TBI incidence studies[15] is also observed in sports-related TBIs.

A population-based TBI incidence study using prospective and retrospective methods to identify cases via multiple sources in NZ revealed that the TBI incidence rate was higher than previous estimates (overall incidence rate of 790 per 100,000 of the general population).[16] The sequence of injury prevention model[17] emphasises that describing the nature and extent of the injury problem is a critical component to design, implement and evaluate injury prevention strategies. Given the drive to encourage adults and children to engage in sport as part of maintaining a healthy lifestyle, it is important that general population are able to do so in the safest way possible. To provide an evidence base for the design and implementation of sports-related injury prevention strategies, a population-based incidence study of sports-related TBIs in the general population is needed.[16] Therefore the purpose of this study is to report on the incidence, nature and severity of sports-related brain injury from a population-based TBI incidence dataset using multiple case ascertainment approaches.

METHODS

Ethical approval was obtained from the Northern Y Regional Ethics Committee of NZ (NTY/09/09/095). This study formed a component of a population-based incidence study that identified all TBI events that occurred in a one-year period (1st March 2010 to 28th February 2011) in the Hamilton and Waikato districts in the central North Island of New Zealand (Total Population 173,214, including 20% Maori and 2% Pasifika).[18] To be eligible for inclusion, identified TBI cases were required to have been primarily resident in the study area for the past 12–months. Cases included people across all ages and encompassed the full spectrum of injury severity (including fatal and non-fatal injuries). The methodology of the parent epidemiological study[19] (and full incidence findings[16]) are described elsewhere. In brief, all new cases of TBI that occurred in the study region were identified using a capture-recapture approach. Prospective and retrospective searches of hospital, coroners, ambulance, general practitioner (GP) or other clinical records (e.g., physiotherapy) were conducted. Searches also included school and sports club accident records, national health-care databases (Accident Compensation Corporation and New Zealand Health Information Service) and local prison records. Self-referrals and referrals from community services were also accepted. As many cases of TBI go unrecognised, all people who experienced an accident resulting in an injury to the upper half of their body were contacted and screened to identify if a TBI had been sustained.

A TBI was defined in accordance with the World Health Organization (WHO) criteria as *an acute brain injury resulting from mechanical energy to the head from external physical forces*.[20] Symptoms needed to be related to the TBI and not be due to drugs/alcohol or medications, nor caused by other injuries/treatments (e.g., systemic injuries, facial injuries), or other problems (e.g., psychological trauma, co-existing medical conditions). TBI severity was classified using the Glasgow Coma Scale (GCS): mild TBI as GCS 13-15 and/or Post Traumatic Amnesia (PTA) <24 hours; moderate TBI –GCS 9-12 and/or PTA 1-6 days; and severe TBI –GCS 8 or less and/or PTA 7 or more days.[21 22] If GCS and PTA severities differed, the more severe category was assigned. If no information on PTA was available, severity was based on the worst GCS score.

Details of the injury were obtained from medical records and through an interview assessment with the participant (where possible) to ascertain if the injury met the study criteria for TBI (reviewed by a panel of clinicians). If it was unclear if the case met the inclusion criteria they were excluded. Information on recurrent TBIs was collected from interviews with participants over 12 months following the initial injury and via medical/accident records. As the majority (over 95%) of injuries were mild, they were sub-classified using Servadei et al's[23] criteria. This criteria classifies mild TBI into three categories according to their risk of intracranial lesions; low-risk, medium-risk and high-risk mild TBI based on the presence of clinical signs (e.g., vomiting), risk factors (e.g., pre-trauma epilepsy) and neurological deficits (e.g., impaired vision/speech). These criteria aim to identify patients who require neuroimaging and further medical treatment to prevent onset of subsequent complications.

Based on the incidence data from the parent study of 1369 cases,[16] data were extracted on all TBI events that were reported to have been sustained during a sports-related activity. For the purposes of this study, sports-related activities were defined as 'participation in a specified activity for the purpose of competition or pleasure involving physical exertion and skill,[24] that may follow rules or require the use of specific equipment (such as a ball) to complete'. Physical activities that were not deemed to meet this definition included walking, gardening or playing on playground equipment. Additionally, injuries sustained whilst cycling to a destination (cycling as a means of transportation) were also not included as the primary purpose was for transportation rather than competition or pleasure.

Incidence rates were calculated per 100,000 of the general population using NZ census data for the study region. The profile of TBIs is presented by age, gender, nature and severity of injury and type of sports-related activity. Frequencies of attendance at health care services following injury, recurrent injuries and identification of the TBI in the medical notes are reported. To enable comparison of the frequency of injury and level of participation in sport, the percentage of people participating in each sport were gathered from data from the "Sport and Recreation Participation Levels in New Zealand report".[25 26] These reports classify participation as partaking in each sport at least once per year with separate profiles for children and adults. As participation levels were published separately for boys and girls under 16 years of age in the young new zealander's report, the average participation rate was calculated for use in this analysis.

RESULTS

There were 291 injuries sustained during sports-related activities (21% of all TBIs) equating to an incidence rate of 170 per 100,000 of the general population. The characteristics of the sample are described in Table 1. From the overall sample children <16 years of age accounted for 39% of all injuries (51% <18 years). The frequency of sports-related injuries peaked between 10 and 35 years of age (Figure 1) with males (<16 years of age; 73%) and adults (69%) experiencing a higher frequency of TBI. As shown in Table 1, just under half of all injuries (46%) were classified as having a high-risk of further complications from the injury. Only half of the sample (51%) reported experiencing loss of consciousness immediately following injury. Less than 1% (N = 1) of injuries resulted in mortality.

For adults, TBIs were most commonly sustained during rugby (union and league), equestrian activities and motorcross/trail riding (Table 2). For children (under 16 years of age), TBIs were most commonly sustained whilst cycling, playing rugby, football and swimming (Table 3). Cycling resulted in the highest number of moderate and severe injuries for those under 16 years of age. Participation in cycling is high (23% in adults and 68% in children) which may account for the higher number of injuries observed. Rugby, motor-cross and equestrian activities had lower participation levels (<6%).

For the injuries sustained while playing rugby (for both adults and children), 42 injuries (62%) were sustained during a tackle or a collision with another player, 4 (6%) were sustained during a scrum/ruck, 2 (3%) through contact with a moving ball or hitting a post and 1 (2%) due to a slip on the field. The actual mechanism of injury could not be determined for 19 of the injuries sustained whilst playing rugby (28%). For equestrian injuries, 19 injuries (73%) were sustained due to falling from the horse while riding, 6 (23%) due to being knocked or kicked by the horse in the head and 1 (4%) due to a fall whilst leading a horse. All cycling injuries were sustained through falling off the bicycle (or being hit by an object causing a fall). Of the 198 cases where information on alcohol use was available for adults, 7 cases (4%) were found to be under the influence of alcohol at the time of injury.

Attendance to a health care service (GP or hospital) following injury was higher for children (83%) than adults (74%). Thirty-one participants (11%) were hospitalised following initial consultation, 11 (4%) received a referral to another service and 73% were discharged. There were 27 (15%) adults and 7 (6%) children who received a CT scan following injury. Over half of the sample (57% children, 63% adults) sustained other injuries in addition to their TBI, including broken bones, fractures, sprains and lacerations. On reviewing the notes of participants who sought medical attention, the TBI had not been recorded in 19% of adults and 11% of child cases. Of the 194 cases (67% of the total) who were able to confirm if they had experienced a TBI prior to entry into the study, 89 (46%) has experienced at least one prior TBI.

During the year following the initial injury, 26 of the 291 sports-related injury cases (9%) reported experiencing a recurrent TBI, with 16 (6%) participants reporting a subsequent injury whilst participating in the same sport as their initial injury (4 recurrent injuries each were reported for rugby and cycling, 3 from horse-riding falls, 2 from boxing and 1 further injury sustained when snowboarding, playing softball or motorcross). Recurrent injuries were more frequent in adults (11%) than children (5%).

DISCUSSION

The incidence of sports-related TBIs in New Zealand is high in relation to other activities and other countries, particularly for rugby, equestrian activities, cycling and football. The proportion of cases where the TBI was not recorded in medical notes is of concern. Adolescents and young adults were at highest risk of injury, which may reflect the higher participation in sports activities in these age groups. The overall frequency of sports-related injuries for children <18 years of age was found to be lower (51%) than reported in a previous study (61%) that identified TBI cases through hospital and emergency department records . These disparate findings may reflect different participation levels in sports activities between countries (US and NZ) and the influence of using different case identification methods (hospital records vs multiple sources of case ascertainment). It is also possible that, as previous studies identified TBI cases based on hospital records alone, the proportion of adults who did not seek medical treatment revealed in this study may have been missed in previous research. Males were found to be at an increased risk of injury in comparison to females, supporting the findings of previous studies of concussion in sport[27 28] People of Maori and Pasifika ethnicity were over-represented in this sports-related TBI sample indicating an increased risk of sports-related TBI, reflecting the trends observed in overall TBI epidemiological findings.[15]

TBIs were most frequently sustained during rugby and cycling sports for both children and adults, with a high number of TBIs sustained in equestrian activities in adults, and soccer/ football in children. Equestrian activities were of particular interest as the frequency of injuries was high in comparison to the participation levels in New Zealand. Falls were a common mechanism of injury across sports-related activities through tripping or slipping over or through horse-riding or cycling. Whilst TBI prevention strategies have been implemented in NZ, the findings of this study emphasise the need for continued efforts to prevent sports-related TBI. Sport specific strategies may be needed to ensure policies/promotion activities and use of protective gear responds to the unique requirements of each sport.[5 29]

Despite 98% of injuries being classified as 'mild' in this sample, a high proportion of injuries (46%) were identified as having a high risk of further complications (such as intracranial lesions) and symptoms. This suggests that greater emphasis is needed to both identify and seek treatment for what appears to be a relatively minor head injury. The early identification and proper treatment of the head injury will help prevent exacerbation of symptoms and reduce the risk of complications. The lack of recording of TBI in the medical notes, supports previous evidence, that the knowledge of TBI and effective management in community sport is low[28] and suggests that medical personnel may need to routinely screen for TBI following an accident sustained during a sports-related activity.

The high number of recurrent injuries sustained within the year following injury and proportion of people who did not seek medical treatment following injury or where the TBI injury was missed, highlights the need for greater awareness of TBI in the sports context, both within the community and medical care. The high rates of prior injuries in the current sample supports the proposal by Guskiewicz et al[30] who stated that those with previous brain injuries are at a high risk of further injury. The high rates of recurrent injury indicate that people may well be returning to activity too soon or without the necessary precautions/assessment and placing themselves at higher risk of re-injury suggesting implications for concussion management and return to play protocols.[30]

Currently, most scales for assessing TBI following sport primarily focus on whether there was a loss of consciousness and post-traumatic amnesia immediately following injury.[30] The current findings question the dependence on these criteria alone in the identification of TBI. Despite medical confirmation of having experienced a TBI, just over half of the participants reported experiencing loss of consciousness. This suggests that TBI may have been missed unless other symptoms were taken into account and greater emphasis needs to be placed on other common symptoms of TBI, such as blurred vision (seeing 'stars'), headaches, dizziness, confusion as well as amnesia and loss of consciousness in screening for TBI. Increased public awareness of these symptoms may also help people to decide whether they need to seek medical treatment following an injury to the head.

This study provides details of all sports-related TBI from a large population based community sample, across all ages and injury severity during a one-year period to support the identification of the main mechanisms of injury and help to inform prevention strategies as proposed by the sequence of injury prevention model.[17] In addition to the most complete case ascertainment on a population level, standardised diagnostic criteria were used, thus enhancing the methodological robustness and comparability of the study findings. However, despite the comprehensive case ascertainment approach, the findings may still be an underestimate of sports-related TBI as it was not possible to identify the exact mechanism of injury for some cases which were excluded from the analysis. The results of the study are also limited due to a lack of precise information on participation levels across all sports in New Zealand, which precluded the calculation of risk ratios or rates per exposure.

There is a wealth of evidence that participating in sports and physical activity is beneficial for both physical and mental health for both adults and children.[1] However, the findings of this study reveal that more action is needed to be taken to make engagement in these activities as safe as possible and to reduce the incidence of TBI.

CONCLUSIONS

There is a high rate of sports-related TBIs in New Zealand, with the highest levels of injury observed for rugby, equestrian activities, cycling and football. Occurrences of TBI sustained during sports-related activities may be missed in medical records due to lack of identification or nonattendance to medical services following injury. The high levels of mild high-risk TBIs highlights the importance in raising awareness of TBI and the provision of appropriate treatment to all severities of TBI sustained during sports-related activity.

Practical Implications

- Epidemiological studies on the incidence and nature of injury at the community level can assist in the effective implementation of injury prevention programmes and management.

- Based on the diversity of mechanism of injury between sports-related activities, sports organisations need to investigate sport specific ways to modify training, techniques and use of equipment to prevent injury and reduce incidence to encourage safer engagement in sport.
- Given the high proportion of injuries where the TBI was missed, increased awareness of TBI and the full spectrum of associated symptoms is needed by coaches, parents, teachers and sports club personal to facilitate the identification and response to TBI.
- Based on the findings that falls were a common cause of injury (particularly for cycling and equestrian activities), strategies to prevent and reduce the risk of injury from falls should be considered.

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REFERENCES

1. Penedo FJ, Dahn JR. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current Opinion Psychiatry* 2005;18(2):189-193.
2. Kolt GS. The risky side of sports participation. *J Sci Med Sport.* 2013;16(2):87-88.
3. Beck AJ, Kerr J. The epidemiology of sports head injuries in a rural population. *Br J Sports Med* 2011;45(A20).
4. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil* 2006;21(5):375-378.
5. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport--the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Pm R* 2013;5(4):255-279.
6. Bazarian JJ, Cernak I, Noble-Haeusslein L, et al. Long-term neurologic outcomes after traumatic brain injury. *Journal of Head Trauma Rehabilitation* 2009;24:439-451.
7. Dikmen SS, Corrigan JD, Levin HS, et al. Cognitive outcome following traumatic brain injury. *Journal of Head Trauma Rehabilitation* 2009;24:430-438.
8. Safaz I, Alaca R, Yasar E, et al. Medical complications, physical function and communication skills in patients with traumatic brain injury: a single centre 5-year experience. *Brain injury : [BI]* 2008;22(10):733-739.
9. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery* 2005;57(4):719-26; discussion 19-26.
10. Holsinger T, Steffens DC, Phillips C, et al. Head injury in early adulthood and the lifetime risk of depression. *Archives of General Psychiatry* 2002;59(1):17-22.
11. Lehman EJ, Hein MJ, Baron SL, et al. Neurodegenerative causes of death among retired National Football League players. *Neurology* 2012;79(19):1970–1974.
12. Cantu RC. Posttraumatic Retrograde and Anterograde Amnesia: Pathophysiology and Implications in Grading and Safe Return to Play. *Journal of Athletic Training* 2001;36(3):244-248.
13. Harris AW, Jones CA, Rowe BH, et al. A population-based study of sport and recreation-related head injuries treated in a Canadian health region. *J Sci Med Sport* 2012;15(4):298-304.
14. Selassie AW, Wilson DA, Pickelsimer EE, et al. Incidence of sport-related traumatic brain injury and risk factors of severity: a population-based epidemiologic study. *Ann Epidemiol* 2013;23(12):750-756.
15. Barker-Collo S, Wilder NJ, Feigin VL. Trends in Head Injury Incidence in New Zealand: A Hospital-based study 1997/1998 to 2003/2004. *Neuroepidemiology* 2009;32(1):32-39.
16. Feigin VF, Theadom A, Barker-Collo SL, et al. Incidence of traumatic brain injury in New Zealand: a population-based study. *The Lancet Neurology* 2013;12(1):53-64.
17. Van Mechelen W, Hlobil H, Kemper HCG. Incidence, severity, etiology and prevention of sports injuries - a review of concepts. *Sports Med* 1992;14(2):82-99.
18. Statistics New Zealand. New Zealand Census 2006: Statistics New Zealand, 2006.
19. Theadom A, Barker-Collo S, Feigin V, et al. The spectrum captured: a methodological approach to studying incidence and outcomes of traumatic brain injury on a population level. *Neuroepidemiology* 2012;38(1):18-29.
20. Carroll LJ, Cassidy JD, Holm,L, et al. Methodological issues and research recommendations for mild traumatic brain injury: the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabil Med* 2004;43 Suppl:113-125.
21. Teasdale G, Jennett B. Assessment of coma and impaired consciousness: a practical scale. *Lancet* 1974;2:81-84.
22. Ponsford J, Willmott C, Rothwell A, et al. Use of the Westmead PTA scale to monitor recovery of memory after mild head injury.[erratum appears in Brain Inj. 2004 Oct;18(10):1065]. *Brain Injury* 2004;18(6):603-614.
23. Servadei F, Teasdale G, Merry G. Defining acute mild head injury in adults: a proposal based on prognostic factors, diagnosis and management *Journal of Neurotrauma* 2001;18(7):657-664.
24. Burt CW, Overpeck MD. Emergency visits for sports-related injuries. *Ann Emerg Med* 2001;37(3):301-308.
25. Sport and Recreation New Zealand. Sport and recreation participation levels: findings from the 2007/08 Active NZ Survey. Wellington, New Zealand, 2009.
26. Sport New Zealand. Sport and recreation of young new zealanders. Wellington, New Zealand, 2012.

27. Pakzad-Vaezi K, Singhal A. Trends in paediatric sport- and recreation-related injuries: An injury surveillance study at the British Columbia Children's Hospital (Vancouver, British Columbia) from 1992 to 2005. *Paediatr Child Health* 2011;16(4):217-221.
28. King D, Hume PA, Clark T. First-aid concussion knowledge of rugby league team management, administrators and officials in New Zealand. *New Zealand Journal of Sports Medicine* 2010;37(2):56-68.
29. Sahler CS, Greenwald BD. Traumatic brain injury in sports: a review. *Rehabil Res Pract* 2012;2012:659652.
30. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *Jama* 2003;290(19):2549-2555.

Table 1: Characteristics of study participants

	Sample Population (N=291)
Mean age in years (SD)	22.5 years (14.3)
Male gender	205 (70%)
Ethnicity	
European	187 (64%)
Maori	79 (27%)
Pasifika	16 (6%)
Other	9 (3%)
Primary source of case identification	
Hospital	160 (55%)
GP/Accident or medical clinic	65 (22%)
Self-referral	4 (1%)
Coroner/death certificate	1 (<1%)
National health databases	43 (15%)
Other (Patient support organisations, sports clubs, schools, allied health professionals)	18 (6%)
TBI severity	
Mild Low-risk	59 (20%)

Mild Moderate-risk	98 (34%)
Mild High-risk	127 (44%)
Moderate	3 (1%)
Severe	4 (1%)

Table 2. Frequency of brain injuries by sports-related activity for adults (>16 years)

			Percentage of injuries by TBI severity classification			
Sports Activity	Number of Injuries (%) (N=177)	Participation (%)	Mild Low Risk (%)	Mild Medium Risk (%)	Mild High Risk (%)	Moderate or Severe (%)
Rugby	53 (30)	6%	17 (32)	18 (34)	18 (34)	-
Equestrian	22 (12)	3%	6 (27)	6 (27)	10 (45)	-
Motorcross/Trail-biking	21 (12)	<1%	3 (14)	7 (33)	10 (48)	-
Cycling	15 (9)	23%	2 (13)	5 (33)	8 (36)	-
Surfing/Wakeboarding	9 (5)	5%	3 (33)	-	5 (56)	-
Skateboarding	8 (5)	2%	3 (38)	3 (38)	1 (13)	1 (13)
Football	6 (3)	7%	1 (17)	2 (33)	3 (50)	-
Skiing/Snowboarding	6 (3)	6%	1 (17)	2 (33)	3 (50)	-
Other sports	13 (7)	-	3 (23)	3 (23)	7 (54)	
Unspecified sporting activity	16 (9)	-	3 (19)	4 (25)	8 (50)	1 (6)

*Other sports (where less than 5 injuries occurred in the one year period) included; Boxing, Fishing/boating, hockey, cheerleading, basketball, trampolining, cricket, squash, netball, judo and ice-skating.

Table 3. Frequency of brain injuries by sports-related activity for under 16s

			Percentage of injuries by TBI severity classification			
Sports Activity	Number of Injuries (%) (N=114)	Average Participation %	Mild Low Risk	Mild Medium Risk	Mild High Risk	Moderate or Severe
Cycling	31 (27)	68%	5 (1.6)	11 (35)	13 (42)	2 (6)
Rugby	15 (13)	41%	1 (7)	9 (60)	5 (33)	-
Football	9 (8)	61%	1 (11)	5 (56)	3 (33)	-
Swimming	9 (8)	82%	-	3 (33)	6 (67)	-
Skateboarding	7 (6)	36%	1 (14)	3 (43)	3 (43)	-
Trampolining	7 (6)	-	2 (29)	3 (43)	1 (14)	1 (14)
Hockey	5 (4)	30%	2 (40)	1 (20)	2 (40)	-
Other sports	12 (11)	-	4 (33)	4 (33(	4 (33)	
Unspecified sports activity	11 (10)	-	1 (9)	5 (45)	5 (45)	-

*Other sports (where less than 5 injuries occurred in the one year period) included; Equestrian, motorcross/trail-biking, basketball, cricket, softball, volleyball, badminton, skiing/snowboarding, boxing, water-polo and high jump.

Figure 1. Frequency of sports-related injuries by age and gender