
Authors: McKinlay, A.,¹ Grace, R.C.,¹ Horwood, L.J.,² Fergusson, D.M.,² Ridder, E.M.,² MacFarlane, M.R.³

¹ Department of Psychology, University of Canterbury, Christchurch New Zealand.
² Christchurch Health and Development Study, University of Otago, Christchurch New Zealand.
³ Department of Neurosurgery, Christchurch Hospital, Christchurch, New Zealand.

Correspondence to:
Audrey McKinlay
University of Canterbury
Private Bag 4800
Christchurch
New Zealand
e-mail: aco24@student.canterbury.ac.nz
Abstract

Little is known about the incidence and prevalence of traumatic brain injury (TBI), particularly for infants, children and young adults.

**Primary objective:** The purpose of this study was to provide an accurate estimate of the incidence and prevalence of TBIs for individuals between 0-25 years of age.

**Method and Procedures:** We used a birth cohort of 1265 individuals for which information regarding TBI events, both hospitalised and non-hospitalised, had been recorded.

**Main Outcomes and Results:** The average incidence for this age group ranged from 1.10 per100 to 2.36 per 100 per year, with an overall prevalence of approximately 30%. The most common source of injury was falls for individuals 0-14 years of age and contact sports and motor vehicle accidents for 15-25 years olds. Approximately one third of the individuals who experienced a TBI went on to have one or more additional injuries.

**Conclusions:** The incidence rates reported here are much higher than those previously found. It is clear that TBIs constitute a major health issue and therefore it is important to have accurate information to enable planning for primary health care services and to inform prevention programmes.
Introduction:

Traumatic brain injury (TBI) is one of the most frequent accident types for both children and young adults, and a major cause of mortality and morbidity. Approximately 70-90% of TBIs are classified as mild, [1] but even these types of injuries can result in ongoing problems [2-3]. Although it is clear that TBIs represent a major health issue, little is known about their incidence and prevalence, particularly for the highest risk groups: Infants, children, and young adults. Indeed, a recent World Health Organisation task force review reported that more high-quality research on TBI was required to enable accurate planning for primary health care services and to inform prevention programmes [1].

Reported incidence of TBI varies between 100-to-300 per 100 000 per year for children and young adults [1] [4-6]. However, accurate information is difficult to obtain and varies depending on how TBI is defined and the age range that is included. Most previous studies have relied on hospital admission or discharge information, which may seriously underestimate the true extent of the problem because the majority of TBIs are mild and therefore not admitted to hospital. Data from the few population-based samples that are available suggest that the majority of individuals with TBIs will be seen by either their General Practitioner (GP) or at the Accident and Emergency department (A&E) and will be treated without being admitted [7-8].

Another drawback of previous research is that due to heavy reliance on cross-sectional designs, there is limited information regarding the incidence of multiple TBIs within individuals. The identification of multiple TBIs is important because it has previously been reported that a single TBI doubles the risk for future TBI, and that two such injuries increase the risk of a third injury by eightfold [9]. Moreover, it has been
suggested that multiple TBIs may have a cumulative impact on cognitive functioning [10-11].

Finally, there is virtually no information regarding the prevalence of TBI for the high-risk group of birth to 25 years. One exception is Segalowitz and Brown [12], who asked a group of 18 year olds’ (n = 616) to report whether they had experienced a mild head injury in their life time. Approximately 31% of the sample reported in the affirmative (36% males, 23% females). Body and Leathem [13] asked a group of high school students (n=135) aged between 14-15 years to report the number of head injuries that they had sustained in the last 3 years. Approximately 44% of the sample (47% males, 53% female) reported having sustained one or more head injuries in the last three years. However, both these studies relied exclusively on self-report rather than official records, and may have been subject to inaccurate recall.

Thus the aim of the present study was to obtain accurate information regarding the incidence and prevalence of TBI for children, adolescence and young adults. We used data from a prospective longitudinal study of a large birth cohort of 1265 children born in Christchurch, New Zealand. The use of a birth cohort provides a unique opportunity to accurately identify TBIs that occurred over a 25 year period that required any medical intervention. A secondary aim of the study was to identify the incidence of multiple TBIs for this age group.
Methods:

Participants

The data were gathered as part of the Christchurch Health and Development Study (CHDS), a 25-year longitudinal study of a birth cohort of 1265 children born in the Christchurch (New Zealand) urban region in mid-1977. These children represented 97% of all births occurring in Christchurch during the recruitment period for the study. Cohort members have been studied at birth, four months, one year and annual intervals to age 16 years, and again at ages 18, 21 and 25 years. Data have been gathered using information from a combination of sources including: parental interview, self report, psychometric assessments, teacher questionnaire, medical records and other official record data [14-15]. All data gathered as part of the study have been subject to the signed consent of research participants. Ethical approval for this aspect of the study was granted by the Canterbury Ethics Committee.

While the initial cohort comprised 1265 children, through the normal processes of sample attrition in longitudinal research (death, refusal, loss to follow-up), by age 25 the number of participants assessed had reduced to 1003 (79.3% of the initial cohort). Thus not all participants were assessed on all occasions. The ways in which the issue of varying sample numbers over time has been treated in the analysis are described in the Statistical Analysis section below and in footnotes to the tables.

Traumatic Brain Injury

Information on TBI was collected in the following ways. At each assessment from age 4 months to 16 years comprehensive information was obtained on the child’s history of medical attendances (GP, specialist, hospital) since the previous assessment. As part of this information, details were obtained on all injury events that resulted in medical attendance. Information on GP and private specialist attendances was based on parental
recall. In cases where parental recall was considered suspect, the reported history of medical attendance was cross-checked with the medical practitioner’s records. All hospital attendances (both inpatient and outpatient) were verified against hospital records. On the basis of these prospectively collected data it was possible to construct the child’s history of medical attendance for head injury events for each year from birth to age 16 years.

For the period from 16-25 years information on head injury events was obtained on the basis of participant self reports of medical attendances for head injury, supplemented by hospital record data. At ages 18, 21 and 25 years, participants were questioned about their history of medical contacts including visits to the GP in the past 12 months and all hospital contacts since the previous assessment. Since the questioning concerning GP contacts did not cover the full assessment period, this information was further supplemented by explicit questioning at age 25 concerning head injury events. Specifically, participants were asked to recall whether they had ever attended a doctor or hospital as a result of a head injury event, and for each incident reported to describe the nature/source of the injury, the age at which the injury happened, medical diagnosis (if any) and nature/source of treatment. All reported hospital attendances were again verified against hospital records. This information was used to construct the participant’s history of medical attendance for head injury events for each year from age 16- 25 years.

Injuries to the head were extremely common in the cohort and by the age of 10 years nearly half of the cohort (n= 525) had sustained an injury to the head. Therefore, all cases that were included in the analysis had to meet a minimum criterion of a blow to the head for which medical treatment was sought and a diagnosis of concussion or suspected concussion was given. Individuals who had experienced a non-specific injury to the head, with no diagnosis of concussion, were not included in the TBI group.
Individuals were considered to have sustained a mild TBI if they did not exceed one or more of the following criteria: (1) Loss of consciousness of more than 20 minutes, if present; (2) Hospitalization of equal to or less than two days for brain injury, if this occurred; (3) Post-traumatic amnesia of less than 2 hours, if present; (4) No neurological signs; and (5) No evidence of skull fracture, (6) GCS on admission <14. If symptoms of the injury exceeded these criteria the individual was considered to have sustained a moderate/severe TBI.

During the course of the study there were a total of nine injury deaths, including one child who drowned in infancy and eight participants (7 male, 1 female) who died from injuries received in motor vehicle accidents. Detailed information was not available on the extent/nature of injuries sustained by those who died in MVAs. However, it seems likely that the majority of these individuals would have sustained a TBI as a result of the accident. These individuals have not been included in this analysis.

**Statistical analysis**

As noted above, because of the longitudinal nature of the data, the number of individuals for whom TBI data were available varied somewhat over the 25 year period. To account for this, standard life table methods were used to calculate the cumulative prevalence of TBI over time. Differences in cumulative prevalence between males and females were tested for statistical significance using Gehan’s Wilcoxon test. Incidence rates for given five year age intervals were calculated using the person-years method (total number of events occurring during the interval divided by the total number of person years of observation).
Results:

Incidence and Prevalence

Four hundred and fifty eight qualified head injury events were recorded in the cohort from birth to 25 years. Of these, 307 (67.03%) were dealt with in the outpatient setting, i.e. seen by the GP or at A&E and sent home without any further intervention, and 151 (32.97%) were admitted to hospital for observation or inpatient care. The average incidence of TBIs over this age range was 1.75% per year. A total of 318 individuals accounted for the 458 injury events recorded, giving an overall prevalence for TBIs of 31.59% to age 25 years. The prevalence of injuries of sufficient severity to warrant an inpatient stay of at least one night was 12.39%.

Age

As is shown in Figure 1 and Table 1, incidence varied depending on the age of the individual. The lowest incidence rates occurred between five and ten years of age, and the highest rates between fifteen to twenty years of age.

(Skip the insertion of Figure 1 and Table 1 here)

Sex difference

The number of males and females in the cohort was comparable, but considerably more of the 318 individuals who experienced a TBI were male (65.72%). Males sustained over 63.19% of the outpatient injuries and 70.86% of the inpatient injuries. As displayed in Figure 2, males were consistently more likely to have TBIs after 5 years of age. The cumulative portion of males versus female who experienced a TBI injury is shown in Figure 3. Prevalence of TBIs sustained by males over the 25 year period was 38.47% compared to 24.4% for females (P<0.001 by Gehan’s Wilcoxon test). Figure 3 shows a steeper slope for ages 0-5 for both males and females, and over 15-25 years for males which is consistent with the peak incidence rates shown on Table 1.
Source of Injuries

Because there was a marked change in the source of the injuries at approximately 14 years of age, results for 0-14 years and 15-25 years are displayed separately in Tables 2 and 3, respectively. Table 2 shows that falls (66.96%) and being hit by an object (10.13%) accounted for most of the injuries for children under 15 years of age, with all other injury types accounting for less than 25%. However, when the cohort reached 15 years of age, rugby, assaults and motor vehicle accidents were the most common source of injury, together accounting for over 64% of the injury events for this age group.

Multiple Injuries

The number of multiple TBIs is shown on Table 4. Overall 28.9% of individuals had two or more TBIs. As reported above, the prevalence of TBIs in the cohort was 31.59%. From this group a further 28.93% of these went on to have a second TBI and 22.83% of these went on to have a third TBI, with 33.30% of these children having four or more TBIs.

Severity

Approximately 10% of all individuals who experienced a TBI met the criteria of a moderate-severe injury (n=32; one individual experienced 2 severe injuries). For these cases the duration of hospitalization varied from 1-100 nights. Motor Vehicle accidents accounted for 37.5% (n=12/32) of the moderate to severe injuries, while falls accounted for 34.4% (n=11/32). Sports related injuries and hits to the head by an object and fights accounted for 18.8% (n=6/32) and 9.4% (n=3/34) respectively.
Discussion:

Over 30% of the individuals in this study were reported to have sustained a TBI by the time they had reached 25 years of age. This figure is lower than the prevalence rates of 31% (retrospective recall for just mild head injuries the first 18 years of life) and 44% (retrospective recall of the previous three years) suggested by Segalowitz and Brown [12] and by Body and Leathem [13]. However, as both of those studies relied solely on self report methodologies, they were vulnerable to inaccurate recall and reporting.

Another aspect of this study that may have resulted in a lower prevalence rate was that we used the minimum inclusion criterion of a diagnosis of concussion or suspected concussion given by a medical professional. This criterion excluded cases where there was an injury to the head, but no evidence of brain injury, or cases in which the individual did not seek medical attention.

Incidence of TBI based on hospital admissions has previously been reported at between 100-to-300 per 100 000 per year for children and young adults [1] [4-6]. By contrast, incidence rates in our study were much higher, 1000-3000 per 100 000 per year, depending on the age of the individual. The average incidence rate was 1,750 per 100 000 per year. The difference between this and previous studies on incidence rates was that we were able to identify all individuals who had experienced a TBI, not just those who were admitted to hospital and for whom hospital records could be located. Only 30% of brain injuries in this study were admitted to hospital, with over two times as many being seen by their general practitioner or at the Accident and Emergency department and sent home. Because so many TBIs are in the mild range, particularly for children under 14 years of age, it is likely that incidence rates based solely on hospital admissions will seriously underestimate the extent of any problem.
There were a number of findings that were consistent with previous studies. Firstly, the majority (approximately 90%) of the TBIs were of mild severity [5] [16]. Also, males were more likely than females to experience a TBI event [6], sustaining over 63.19% of the outpatient injuries and 70.86% of the inpatient injuries. Further, the cause of TBI changed with the age of the child (see Pelsoso, von Holst et al., [6] for review). For children 14 years of age and under, falls and being hit by an object accounted for most the injuries, whereas for individuals over 14 years of age rugby, assaults and motor vehicle accidents were the most common source of injury. The source of injuries was consistent whether or not the injuries required hospital treatment or not. The only exception to this was motor vehicle accidents, with the majority of these resulting in hospitalization. Moreover, the most frequent cause of moderate-severe TBIs experienced by young adults in the 15-25 year period was motor vehicle accidents. Only nine moderate–severe injuries occurred in the 0-14 year period.

A major strength of this study was that much of the information regarding TBIs events was collected prospectively from a longitudinal birth cohort, providing an accurate estimate of the incidence and prevalence of TBIs for individuals aged 0-25 years. Retrospective memory is likely to be less accurate, relying not only on the individual remembering the event, but also understanding what constitutes a TBI. Nor do these data rely solely on hospital records where diverse admission criteria will result in a variability of incidence rates. As Thurman and Guerrero [16] noted, even in the same region, hospital admission practices change over time and figures that rely on these may give the incorrect appearance of declining rates of TBI.

However, it is also important to be aware of the disadvantages of this study design. It is possible that the incidence rates in this study may not reflect current rates as the information used relied on accident events that occurred up to 30 years ago, and safety
regulations imposed in the intervening period could have reduced the current incidence of certain types of accidents. Further, recall of outpatient injuries across the 16-25 year age group required retrospective recall at age 25 years and therefore may be less accurate. However, these disadvantages are balanced by the fact that we had multiple sources through which to check these injury events (parent, self-report and hospital records). Further, all data on TBIs up to 16 years of age were collected prospectively.

This study provided a unique opportunity to examine incidence, prevalence and source of TBIs across a high risk age group, 0-25 years. Data regarding all TBIs was collected across this period; much of the data was prospectively gathered. Further, information was available from a single group of individuals enabling us to examine the rate of repeated TBIs. Our findings demonstrate that the incidence and prevalence of TBIs for this age group are much higher than previously reported. Accurate information of this type is important in order to identify high risk populations and risk factors for these individuals. Given the general lack of information regarding incidence and prevalence for this age group, it is important that these findings are replicated using other groups.
References:


Acknowledgements:
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Table 1: Incidence of head injury for individuals aged between 0-25 years

<table>
<thead>
<tr>
<th>Age</th>
<th>No. of Incidents</th>
<th>Average yearly rate per 100</th>
<th>No. of Incidents</th>
<th>Average yearly rate per 100</th>
<th>Total average yearly Rate per 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 years</td>
<td>81</td>
<td>1.41</td>
<td>27</td>
<td>0.47</td>
<td>1.85</td>
</tr>
<tr>
<td>5-10 years</td>
<td>39</td>
<td>0.71</td>
<td>21</td>
<td>0.38</td>
<td>1.10</td>
</tr>
<tr>
<td>10-15 years</td>
<td>33</td>
<td>0.66</td>
<td>26</td>
<td>0.52</td>
<td>1.17</td>
</tr>
<tr>
<td>15-20 years</td>
<td>74</td>
<td>1.48</td>
<td>44</td>
<td>0.88</td>
<td>2.36</td>
</tr>
<tr>
<td>20-25 years</td>
<td>80</td>
<td>1.60</td>
<td>33</td>
<td>0.66</td>
<td>2.25</td>
</tr>
</tbody>
</table>

1 Actual numbers of children for whom head injury information was available varied slightly over the years. Therefore, 5 yearly rates calculated by total incidence/total observed persons are presented. 2 Outpatient refers to all cases where the individual was seen by the GP or an A&E without being admitted to hospital; 3 Inpatient refers to a TBI event which resulted in admission to hospital.
Table 2: Source of TBIs for individuals aged between 0-14 years of age.

<table>
<thead>
<tr>
<th>Source</th>
<th>Outpatient Treatment¹</th>
<th>Inpatient Treatment²</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Incidents</td>
<td>% of Injuries</td>
<td>No. of Incidents</td>
</tr>
<tr>
<td>Falls</td>
<td>102</td>
<td>66.7%</td>
<td>50</td>
</tr>
<tr>
<td>Hit with object</td>
<td>16</td>
<td>10.5%</td>
<td>7</td>
</tr>
<tr>
<td>Rugby</td>
<td>6</td>
<td>3.9%</td>
<td>4</td>
</tr>
<tr>
<td>Cycle, scooter etc</td>
<td>5</td>
<td>3.3%</td>
<td>0</td>
</tr>
<tr>
<td>Motor Vehicle</td>
<td>5</td>
<td>3.3%</td>
<td>10</td>
</tr>
<tr>
<td>Assault</td>
<td>1</td>
<td>0.7%</td>
<td>0</td>
</tr>
<tr>
<td>Sports</td>
<td>7</td>
<td>4.6%</td>
<td>2</td>
</tr>
<tr>
<td>Other/ Source not specified</td>
<td>11</td>
<td>7.2%</td>
<td>3</td>
</tr>
</tbody>
</table>

¹Outpatient refers to all cases where the individual was seen by the GP and/or A&E without being admitted to hospital; ²Inpatient refers to a TBI event which resulted in admission to hospital.
Table 3: Source of head injuries for Individuals aged between 15-25 years of age.

<table>
<thead>
<tr>
<th>Source</th>
<th>Outpatient Treatment¹</th>
<th>Inpatient Treatment²</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Incidents</td>
<td>% of Injuries</td>
<td>No. of Incidents</td>
</tr>
<tr>
<td>Rugby</td>
<td>42</td>
<td>27.3%</td>
<td>7</td>
</tr>
<tr>
<td>Assault</td>
<td>31</td>
<td>20.1%</td>
<td>15</td>
</tr>
<tr>
<td>Motor Vehicle</td>
<td>22</td>
<td>14.3%</td>
<td>32</td>
</tr>
<tr>
<td>Hit with object</td>
<td>22</td>
<td>14.3%</td>
<td>4</td>
</tr>
<tr>
<td>Sports</td>
<td>10</td>
<td>6.5%</td>
<td>5</td>
</tr>
<tr>
<td>Falls</td>
<td>13</td>
<td>8.4%</td>
<td>9</td>
</tr>
<tr>
<td>Cycle, scooter etc</td>
<td>12</td>
<td>7.8%</td>
<td>3</td>
</tr>
<tr>
<td>Other/ Source not specified</td>
<td>2</td>
<td>1.3%</td>
<td>2</td>
</tr>
</tbody>
</table>

¹Outpatient refers to all cases where the individual was seen by the GP and/or A&E without being admitted to hospital; ²Inpatient refers to a TBI event that resulted in admission to hospital.
Table 4: The number of individuals who experienced one or more TBIs over 0-25 years of age.

<table>
<thead>
<tr>
<th>Number TBIs</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>&gt;4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>226</td>
<td>71</td>
<td>14</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 1: Average rate of injuries per 100 children for each five year period.
Figure 2: Number of injury events sustained by the cohort members displayed separately for males (closed dots) and females (open dots) over the 25 year period.
Figure 3: Cumulative proportion of males (closed dots) versus females (open dots) who did not experience a traumatic brain injury over the 25 year period.