Traumatic Brain Injuries for Different Road Users and Restraint Use: an overview using Indian in-depth crash data

Junaid Shaikh, Shiyang Meng

Abstract Traumatic brain injuries (TBIs) are commonly observed in road crashes. In India, TBIs are studied mainly with cross-sectional data, or among fatally injured road users. This study aims to compare the distribution of TBI types across different road users and restraint groups and across all severity levels observed in Indian road crashes. Road Accident Sampling System India (RASSI) data were queried from April 2014 to March 2024. The injuries were coded based on Abbreviated Injury Scale (AIS) 2005 with 2008 update, and were grouped based on road user types and restraint use. Vulnerable road users (powered two-wheeler riders, pedestrians, and bicyclists) had a higher occurrence of TBI in road crashes than all other road users. Most of the TBIs were of AIS2 and AIS3 severity, which indicates under-reporting of mild TBIs (AIS1) in India when compared with the data from Germany and USA. The most frequent TBI types observed were subdural haematoma, subarachnoid haemorrhage, vault fractures, contusion-laceration, and base fractures. Future regulations and consumer rating programs have the potential to address these most frequently occurring TBIs. Finally, the most frequent TBI types were not different across the road users.

Keywords head injuries, helmet, Indian crash database, Traumatic brain injury (TBI), VRU.

I. INTRODUCTION

Globally, 1.2 million people died in road traffic crashes in 2021 [1]. Though the fatalities have decreased by 5% compared to 2010, the numbers remain alarming. The World Health Organization (WHO) identified the South-East Asia region as having the highest share of fatalities (28%) among WHO member states. India alone accounted for an estimated 200,000 fatalities, representing 66% of the South-East Asia region's total [1]. The reported road traffic fatalities in India were 168,491 in 2022, a 9% increase on the previous year [2]. The estimated socio-economic cost of road traffic fatalities in India is around USD $34–39 billion, which represents 1.2–1.3% of the country's Gross Domestic Product (GDP) in 2019 [3].

Head is the most commonly injured body region among fatal road users in India [4-5]. Traumatic brain injuries (TBIs) are more frequently observed in road crashes compared to falls or other violence (communal or interpersonal violence, gunshots, blunt weapons, etc.) in India [6-7], contrasting with Europe, where falls are the leading cause of TBIs [8]. An autopsy study of 245 fatal cases in India, involving powered two-wheeler riders and pillion riders, highlighted that subdural haematoma and subarachnoid haemorrhage with skull fractures are the predominant TBI types in fatal motorcycle crashes for riders and pillion riders [9]. These TBI types, along with contusions and lacerations to the brain, are also common among pedestrians and four-wheeler occupants [10].

Existing studies on TBI in India have several limitations. They tend to focus on TBIs resulting from various causes, such as road crashes, falls, other violences [6], without providing detailed insights specific to road crashes, including the use of protective devices. Many of these studies are also outdated [6][10] and have small sample sizes collected from a single geographical location [6][9-10]. Additionally, TBIs are often studied for more common categories of road user in India, such as two-wheeler, four-wheeler and pedestrian, while neglecting specific road user groups, such as bicycles, heavy vehicles, etc. [10]. Furthermore, these studies considered only fatally injured people [9-10] and are cross-sectional studies that may have sampling bias – patients admitted based on the hospital's history of dealing with trauma; based on the status of the hospital; collaborations with emergency care, etc. – for which the true incidence of TBI occurrence in Indian road crashes is unknown. Finally, the quality of quantitative studies focusing on TBIs in India is low [7]. The current study aims to compare the distribution of TBI types between different road users, and between restraint and non-restraint groups, across all severity levels

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observed in Indian road crashes using an in-depth crash database. This will contribute to the selection of relevant brain injury criteria for future safety regulations and ratings in India.

II. METHODS

The Road Accident Sampling System India (RASSI) database was queried for crashes between April 2014 and March 2024, comprising 10 years of data. For these years, RASSI has data from eight locations (currently operates in five locations) and collects data based on the following inclusion criteria: (1) the crash must include at least one motorised vehicle; and (2) the crash location must be in a public area within the study region [4]. There were 7,118 crashes involving 20,299 people: 3,579 fatalities; 4,337 with serious injury; 4,709 with minor injury; and 7,674 with no injury. Injury records were available for 48% (n=6,117) of the fatal and injured people. Each person was classified into the road user groups based on the BODYTYPE variable that describes the road user (Table AI).

Traumatic Brain Injury Classification

TBI severity and type were classified and coded according to the Abbreviated Injury Scale (AIS) 2005 version with 2008 update. The TBI types were further categorised into 16 groups according to their pathological features and clinical presentations (i.e. concussion with or without consciousness) (Table BI) [11]. Out of the 20,299 available persons, the following were excluded: 1,636 were seated in an inappropriate seating position (sitting on a lap, cargo area, or any other location); 92 were farm-tractor, earth-moving equipment, mobile crane, or tricycle; and 7,148 were uninjured. This process led to the inclusion of a total of 11,423 fatal or injured people. People with injury records were further reduced to 5,582, of which 2,082 had at least one TBI of any type and severity, resulting in 5,649 TBIs (after excluding the “Exclude” group – refer Table BI; n=343 injuries). These 5,649 TBIs were studied across different AIS severities, road users, seat-belt use (for four or more wheeled vehicles: belted or unbelted; Table CI), and helmet use (for two-wheeled vehicles: helmeted or unhelmeted; Table CI). Kendall’s Tau statistical test [12] was performed to confirm the differences or similarities in the order of injury types between the groups.

III. RESULTS

Vulnerable road users (VRUs) such as powered two-wheelers (p-2w; 21%), pedestrians (30%), and bicyclists (36%) had a higher share of TBIs than other road users (Fig. 1). Car occupants had the highest share (11%) of TBI injuries among the four or more wheeled vehicles. From here on, the paper will focus on these four categories of road user; the details of the other road users can be found in the Appendix.

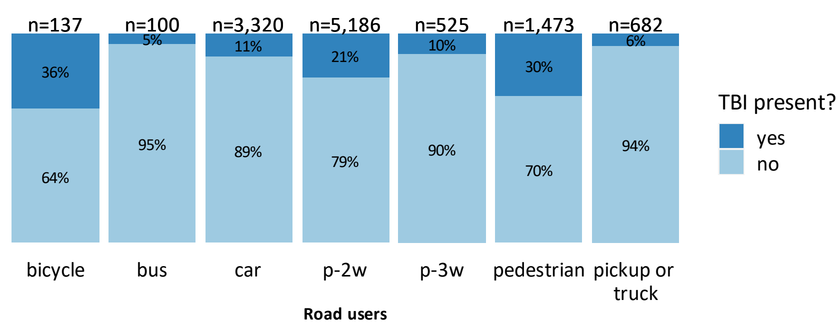
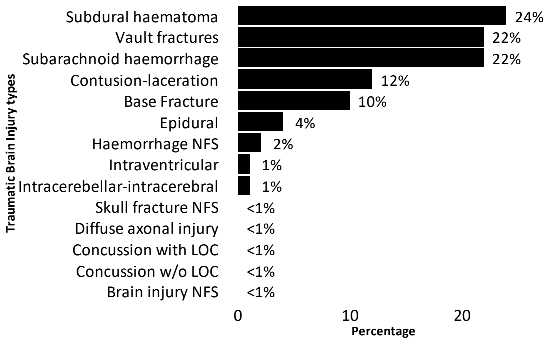


Fig. 1. TBI presence across different road users for people who were fatal or injured (n=11,423).

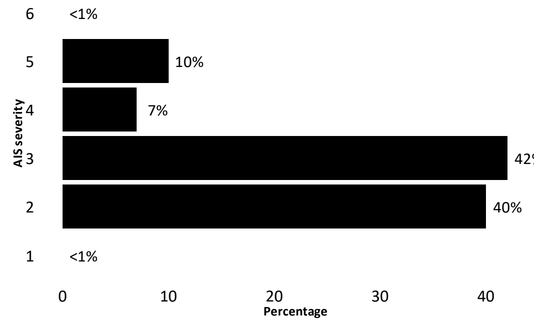
Subdural haematoma (24%), subarachnoid haemorrhage (22%), vault fractures (22%), contusion-laceration (12%), and base fractures (10%) were the most frequent TBI types (Fig. 2(a)). Furthermore, most of the TBIs were of AIS severity “2-moderate” (40%) and “3-serious” (42%) (Fig. 2(b)).

Overview of Traumatic Brain Injury

This section will provide an overview of TBI types across four categories of road user – p-2w, pedestrians, bicyclists, and cars – as they have a higher share of TBIs. The overview for other road users is presented in the Appendix, Fig. D1.



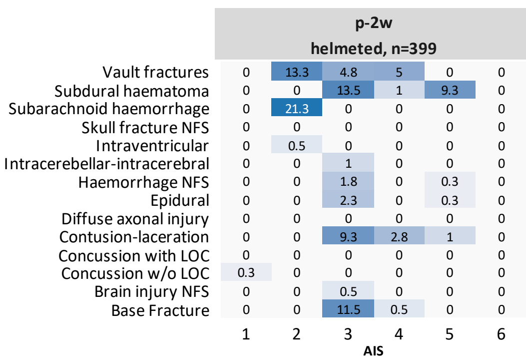
(a)



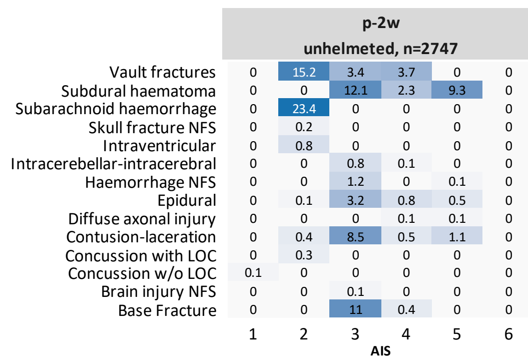
(b)

Fig. 2. (a) Distribution of TBI types observed in RASSI (n=5,649); (b) distribution of TBIs across AIS severity levels (n=5,649).

1) Powered two-wheeler: of all fatal and injured riders, there were 3,239 TBIs (399–helmeted, 2,747–unhelmeted, and 93–other-unknown). Subarachnoid haemorrhage, vault fractures, and subdural haematoma were the most frequent TBI types in both the helmeted (68.2%) and unhelmeted (69.4%) groups (Fig. 3(a) and (b)).



(a)

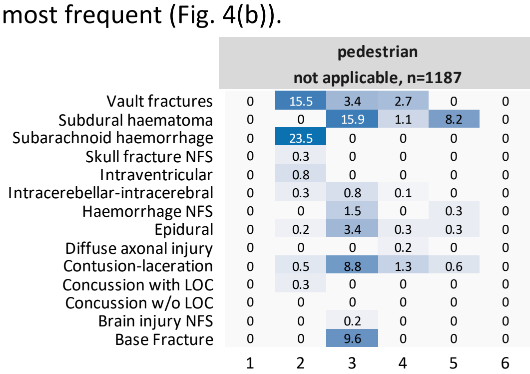


(b)

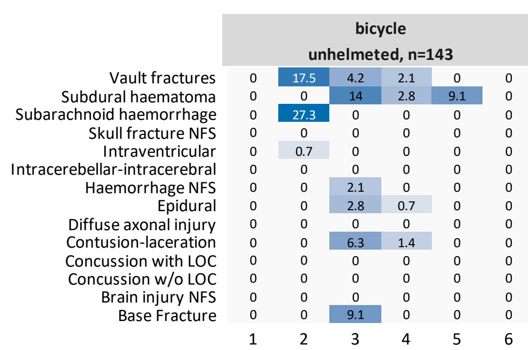
Fig. 3. Distribution of all TBIs across different types and severities for powered two-wheeler riders: (a) helmeted group; (b) unhelmeted group.

2) Pedestrian: there were 1,187 TBIs observed for pedestrians. The most frequent TBI types among pedestrians were subarachnoid haemorrhage (24%) and vault fractures (16%) of AIS2, and subdural haematoma (16%) of AIS3 (Fig. 4(a)).

3) Bicycle: there were no bicyclists in the database wearing a helmet. Of all TBIs (n=143) in unhelmeted bicyclists, subarachnoid haemorrhage (27%) and vault fractures (18%) of AIS2, and subdural haematoma (14%) of AIS3 were the most frequent (Fig. 4(b)).



(a)



(b)

Fig. 4. Distribution of all TBIs across different types and severities for: (a) pedestrians; and (b) bicyclists.

4) Car: there were 849 overall TBIs (73–belted, 670–unbelted, and 106–other-unknown; other-unknown were excluded). Figure 5(a) and (b) highlight that in cars the order of the most frequent TBI type is different. For the belted group, vault fractures, subdural haematoma, and contusion-laceration were more frequent, while for the unbelted group, subarachnoid haemorrhage was more frequent than contusion-laceration.

car belted, n=73	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
Vault fractures	0	19.2	1.4	2.7	0	0
Subdural haematoma	0	0	19.2	0	2.7	0
Subarachnoid haemorrhage	0	11	0	0	0	0
Skull fracture NFS	0	0	0	0	0	0
Intraventricular	0	2.7	0	0	0	0
Intracerebellar-intracerebral	0	0	1.4	0	0	0
Haemorrhage NFS	0	0	8.2	0	0	0
Epidural	0	0	0	0	0	0
Diffuse axonal injury	0	0	0	1.4	0	0
Contusion-laceration	0	0	13.7	0	4.1	0
Concussion with LOC	0	0	0	0	0	0
Concussion w/o LOC	1.4	0	0	0	0	0
Brain injury NFS	0	0	1.4	0	0	0
Base Fracture	0	0	9.6	0	0	0

(a)

car unbelted, n=670	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
Vault fractures	0	18.2	3.7	3.4	0	0
Subdural haematoma	0	0	16.9	1.8	5.4	0
Subarachnoid haemorrhage	0	16	0	0	0	0
Skull fracture NFS	0	1.6	0	0	0	0
Intraventricular	0	0.9	0	0	0	0
Intracerebellar-intracerebral	0	0	1.2	0	0	0
Haemorrhage NFS	0	0	4	0	0	0
Epidural	0	0.1	2.4	0.4	0.4	0
Diffuse axonal injury	0	0	0	0	0.1	0
Contusion-laceration	0	0.1	11.5	0.4	1.3	0
Concussion with LOC	0	0.9	0.1	0	0	0
Concussion w/o LOC	0.6	0	0	0	0	0
Brain injury NFS	0	0	0.3	0	0.4	0
Base Fracture	0	0	7.3	0.1	0	0

(b)

Fig. 5. Distribution of all TBIs across different types and severities for car occupants: (a) belted group; (b) unbelted group.

Overall, the distribution of TBI types across the four road users and restraint use are statistically similar (Table EI), particularly for the most frequent injury types (Fig. 6). The top five TBI types observed in RASSI across car occupants, p-2w riders, pedestrians, and bicyclists are subdural haematoma, vault fracture, subarachnoid haemorrhage, contusion and laceration, and base fracture. A detailed distribution of other road users is presented in the Appendix, Fig. E1.

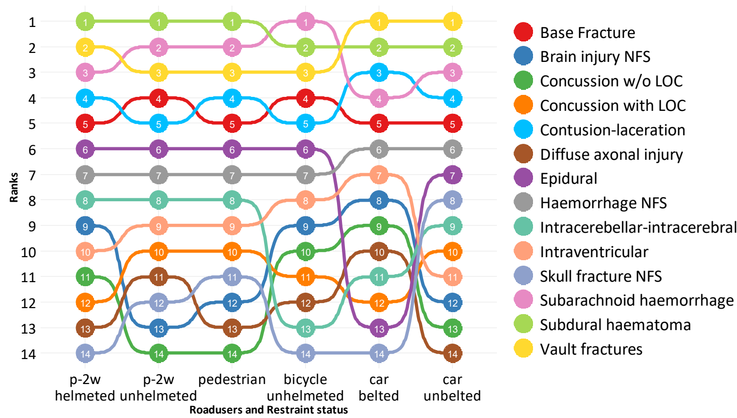


Fig. 6. The rank order of TBI types across p-2w riders, pedestrians, bicyclists, and car occupants for different restraint usage (n=5,219).

IV. DISCUSSION

This study found that road users, including p-2w rider, bicyclist, pedestrian, and car occupant, shared a similar injury pattern with regard to the most common types of TBI. The top five most common TBI types identified were subdural haematoma, subarachnoid haemorrhage, vault fractures, contusion-laceration, and base fractures. In terms of severity, AIS2 and AIS3 were predominant, accounting for 40% and 42% of all TBIs, respectively. This injury severity distribution shows a very different picture from Germany and the USA, where AIS2 injuries are disproportionately more common than AIS3+ injuries [11][13], and where concussion is the most frequent TBI type for all VRU types [11]. In RASSI, however, concussion is observed for less than 1%. This finding suggests a potential under-recognition or under-reporting of mild TBIs in India.

Further, the current work highlights the incidence of TBI in real-world road crashes. Previous literature has analysed data from particular hospitals [6][9-10], which are prone to sampling biases [14]. In the current work, however, all severities were considered and not restricted to the more severely injured persons. In addition, the current data are based on a stratified sampling scheme with a comparatively better sampling design and frame. The findings highlight that bicyclists and pedestrians have a higher occurrence of TBIs than p-2w and cars as, in general, these road users are also at much higher risks than p-2w or cars, even at lower speeds [15]. The most frequent TBIs identified in the current work among VRUs, particularly pedestrians and bicyclists, should be considered in future car regulations and consumer rating programs to reduce their occurrence in the real world.

One of the limitations of this study is the under-reporting of injuries in the database due to incomplete medical records available from hospitals. The under-reporting could be due to a lack of diagnosis of the lower severity injuries or failure to report high severity injuries when multiple high-severity injuries are available. On the other hand, as per AIS, there is a 0.8% probability of death for an occupant when the maximum severity injury is AIS2 [16]. But in RASSI, the probability of death for occupants with maximum injury severity of AIS2 is 11.2%. This suggests that in RASSI, injuries of higher severity might be under-represented. The depth of single injury information available in RASSI is decent, mainly covering the type and sub-type of the lesion (level-2 and level-3). The injury data can be further improved by focusing on level-4 information, i.e. lesion size (Appendix F).

Differences between helmeted and unhelmeted p-2w riders, and between belted and unbelted car occupants, were expected. It was found, however, that the distribution of TBI types across different road users and restraint use were not statistically different (Figs 3, 5 and 6). These findings need further research to understand why there were no differences. The current work did not analyse the influencing factors for each TBI type; factors such as age, gender, and speed could be studied to better understand their effect on different TBI types.

V. CONCLUSION

The top five TBI types common across road users in RASSI are subarachnoid haemorrhage, subdural haematoma, vault fractures, base fractures, and contusion-laceration. These injuries must be prioritised in future regulations and consumer rating programs in India. The most frequent TBI types across the road users were not different, irrespective of the restraint use.

VI. ACKNOWLEDGEMENTS

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VIII. APPENDIX

A. Road user groups

TABLE AI
ROAD USER GROUPS

Road users	Values from BODYTYPE variable
Car	1-9
Bus	11-19
Pickup or truck	21-29
P-2W	31-33
P-3W	41-42
Bicycle	51
Pedestrian	VEHNO=101
Other	71, 81-83, 777777

B. Traumatic Brain Injury types based on AIS codes

TABLE BI [11]
TRAUMATIC BRAIN INJURY TYPES BASED ON AIS CODES

TBI types	AIS codes
Skull fracture NFS	150000.2
Base fracture	150200.3, 150204.3, 150206.4
Brain injury NFS	140299.5, 140499.3, 140699.3
Brain stem transection	140218.6
Vault fractures	150400.2, 150402.2, 150404.3, 150406.4, 150408.4
Concussion w/o LOC	161000.1, 161001.1
Concussion with LOC	161002.2, 161003.2, 161004.2, 161005.2, 161006.3
Diffuse axonal injury	161007.4, 161008.4, 161011.5, 161012.5, 161013.5, 140628.4, 140625.4, 140627.5
Contusion-laceration	140204.5, 140212.6, 140402.3, 140407.2, 140403.3, 140404.4, 140405.5, 140474.3, 140473.3, 140472.4, 140602.3, 140604.3, 140605.2, 140606.3, 140608.4, 140610.5, 140611.3, 140612.3, 140613.2, 140614.3, 140616.4, 140618.5, 140620.3, 140621.2, 140622.3, 140624.4, 140626.5, 140688.3, 140687.3, 140686.4
Epidural	140414.3, 140416.2, 140418.4, 140422.5, 140630.3, 140631.2, 140632.4, 140634.5, 140636.5
Subdural haematoma	140438.3, 140440.2, 140442.4, 140446.5, 140650.3, 140651.3, 140652.4, 140654.4, 140656.5, 140655.5
Subarachnoid haemorrhage	140466.2, 140693.2, 140694.2, 140695.3
Subpial	140470.2, 140696.2, 140697.2, 140698.3
Intracerebellar-intracerebral	140426.3, 140428.2, 140430.4, 140434.5, 140638.3, 140639.2, 140642.2, 140643.2, 140645.4, 140640.4, 140647.3, 140649.4, 140646.5, 140648.5, 140641.5
Intraventricular	140678.2, 140675.2, 140677.4
Haemorrhage NFS	140210.5, 140410.3, 140629.3
Excluded	140202.5, 140208.5, 140214.6, 140216.6, 140478.3, 140477.3, 140476.5, 140450.3, 140458.3, 140462.3, 140690.3, 140691.3, 140692.5, 140660.3, 140662.3, 140664.4, 140666.5, 140668.3, 140670.3, 140672.4, 140674.5, 140701.9, 140702.9, 140703.9, 140676.3, 140680.3, 140681.3, 140683.5, 140682.3, 140799.3

C. Restraint types across different road users

TABLE CI

RESTRAINT TYPES ACROSS DIFFERENT ROAD USERS

Road users	**Variables**	**Values**
Car, Truck, Bus	MANUSE	‘Unbelted’ = [0]
		‘Belted’ = [4-Lap and shoulder belt]
		‘Other-unknown’: = [1,2,3,5–18,999999]
P-2W	HELM_USE	‘Unhelmeted’: = [0]
		‘Helmeted’: = [1-Motorcycle helmet used - Full face, 2-Motorcycle helmet used – Three-quarter shell, 3-Motorcycle helmet used - Half shell, 5-Unknown Helmet type, 6-Helmet used improperly - Full face, 7-Helmet used improperly – Three-quarter shell, 8-Helmet used improperly - Half Shell, 9-Helmet used improperly - Unknown helmet]
Bicycle	HELM_USE	‘Unhelmeted’: = [0]
		‘Helmeted’: = [4-Bicycle helmet, 10-Helmet used improperly - Bicycle helmet]

D. Traumatic Brain Injury types distributed across different severity levels for different road users

bicycle — unhelmeted, n=143

AIS	1	2	3	4	5	6
Vault fractures	0	17.5	4.2	2.1	0	0
Subdural haematoma	0	0	14	2.8	9.1	0
Subarachnoid haemorrhage	0	27.3	0	0	0	0
Skull fracture NFS	0	0	0	0	0	0
Intraventricular	0	0.7	0	0	0	0
Intracerebellar-intracerebral	0	0	0	0	0	0
Haemorrhage NFS	0	0	2.1	0	0	0
Epidural	0	0	2.8	0.7	0	0
Diffuse axonal injury	0	0	0	0	0	0
Contusion-laceration	0	0	6.3	1.4	0	0
Concussion with LOC	0	0	0	0	0	0
Concussion w/o LOC	0	0	0	0	0	0
Brain injury NFS	0	0	0	0	0	0
Base Fracture	0	0	9.1	0	0	0

car — belted, n=73

AIS	1	2	3	4	5	6
Vault fractures	0	19.2	1.4	2.7	0	0
Subdural haematoma	0	0	19.2	0	2.7	0
Subarachnoid haemorrhage	0	11	0	0	0	0
Skull fracture NFS	0	0	0	0	0	0
Intraventricular	0	2.7	0	0	0	0
Intracerebellar-intracerebral	0	0	1.4	0	0	0
Haemorrhage NFS	0	0	8.2	0	0	0
Epidural	0	0	0	0	0	0
Diffuse axonal injury	0	0	0	1.4	0	0
Contusion-laceration	0	0	13.7	0	4.1	0
Concussion with LOC	0	0	0	0	0	0
Concussion w/o LOC	1.4	0	0	0	0	0
Brain injury NFS	0	0	1.4	0	0	0
Base Fracture	0	0	9.6	0	0	0

car — unbelted, n=670

AIS	1	2	3	4	5	6
Vault fractures	0	18.2	3.7	3.4	0	0
Subdural haematoma	0	0	16.9	1.8	5.4	0
Subarachnoid haemorrhage	0	16	0	0	0	0
Skull fracture NFS	0	1.6	0	0	0	0
Intraventricular	0	0.9	0	0	0	0
Intracerebellar-intracerebral	0	0	1.2	0	0	0
Haemorrhage NFS	0	0	4	0	0	0
Epidural	0	0.1	2.4	0.4	0.4	0
Diffuse axonal injury	0	0	0	0	0.1	0
Contusion-laceration	0	0.1	11.5	0.4	1.3	0
Concussion with LOC	0	0.9	0.1	0	0	0
Concussion w/o LOC	0.6	0	0	0	0	0
Brain injury NFS	0	0	0.3	0	0.4	0
Base Fracture	0	0	7.3	0.1	0	0

p-2w — helmeted, n=399

AIS	1	2	3	4	5	6
Vault fractures	0	13.3	4.8	5	0	0
Subdural haematoma	0	0	13.5	1	9.3	0
Subarachnoid haemorrhage	0	21.3	0	0	0	0
Skull fracture NFS	0	0	0	0	0	0
Intraventricular	0	0.5	0	0	0	0
Intracerebellar-intracerebral	0	0	1	0	0	0
Haemorrhage NFS	0	0	1.8	0	0.3	0
Epidural	0	0	2.3	0	0.3	0
Diffuse axonal injury	0	0	0	0	0	0
Contusion-laceration	0	0	9.3	2.8	1	0
Concussion with LOC	0	0	0	0	0	0
Concussion w/o LOC	0.3	0	0	0	0	0
Brain injury NFS	0	0	0.5	0	0	0
Base Fracture	0	0	11.5	0.5	0	0

p-2w — unhelmeted, n=2747

AIS	1	2	3	4	5	6
Vault fractures	0	15.2	3.4	3.7	0	0
Subdural haematoma	0	0	12.1	2.3	9.3	0
Subarachnoid haemorrhage	0	23.4	0	0	0	0
Skull fracture NFS	0	0.2	0	0	0	0
Intraventricular	0	0.8	0	0	0	0
Intracerebellar-intracerebral	0	0	0.8	0.1	0	0
Haemorrhage NFS	0	0	1.2	0	0.1	0
Epidural	0	0.1	3.2	0.8	0.5	0
Diffuse axonal injury	0	0	0	0.1	0.1	0
Contusion-laceration	0	0.4	8.5	0.5	1.1	0
Concussion with LOC	0	0.3	0	0	0	0
Concussion w/o LOC	0.1	0	0	0	0	0
Brain injury NFS	0	0	0.1	0	0	0
Base Fracture	0	0	11	0.4	0	0

p-3w — not applicable, n=118

AIS	1	2	3	4	5	6
Vault fractures	0	14.4	1.7	1.7	0	0
Subdural haematoma	0	0	14.4	1.7	3.4	0
Subarachnoid haemorrhage	0	24.6	0.8	0	0	0
Skull fracture NFS	0	0	0	0	0	0
Intraventricular	0	2.5	0	0	0	0
Intracerebellar-intracerebral	0	0	0.8	0.8	0	0
Haemorrhage NFS	0	0	0.8	0	0	0
Epidural	0	0	8.5	0	0.8	0
Diffuse axonal injury	0	0	0	0	0	0
Contusion-laceration	0	0	10.2	1.7	4.2	0
Concussion with LOC	0	0.8	0	0	0	0
Concussion w/o LOC	0	0	0	0	0	0
Brain injury NFS	0	0	0	0	0	0
Base Fracture	0	0	5.9	0	0	0

pedestrian — not applicable, n=1187

AIS	1	2	3	4	5	6
Vault fractures	0	15.5	3.4	2.7	0	0
Subdural haematoma	0	0	15.9	1.1	8.2	0
Subarachnoid haemorrhage	0	23.5	0	0	0	0
Skull fracture NFS	0	0.3	0	0	0	0
Intraventricular	0	0.8	0	0	0	0
Intracerebellar-intracerebral	0	0.3	0.8	0.1	0	0
Haemorrhage NFS	0	0	1.5	0	0.3	0
Epidural	0	0.2	3.4	0.3	0.3	0
Diffuse axonal injury	0	0	0	0.2	0	0
Contusion-laceration	0	0.5	8.8	1.3	0.6	0
Concussion with LOC	0	0.3	0	0	0	0
Concussion w/o LOC	0	0	0	0	0	0
Brain injury NFS	0	0	0.2	0	0	0
Base Fracture	0	0	9.6	0	0	0

pickup or truck — unbelted, n=84

AIS	1	2	3	4	5	6
Vault fractures	0	13.1	3.6	3.6	0	0
Subdural haematoma	0	0	9.5	4.8	7.1	0
Subarachnoid haemorrhage	0	23.8	0	0	0	0
Skull fracture NFS	0	1.2	0	0	0	0
Intraventricular	0	1.2	0	0	0	0
Intracerebellar-intracerebral	0	0	3.6	0	0	0
Haemorrhage NFS	0	0	4.8	0	0	0
Epidural	0	0	0	0	1.2	0
Diffuse axonal injury	0	0	0	0	0	0
Contusion-laceration	0	0	8.3	4.8	0	0
Concussion with LOC	0	0	0	0	0	0
Concussion w/o LOC	0	0	0	0	0	0
Brain injury NFS	0	0	0	0	0	0
Base Fracture	0	0	8.3	1.2	0	0

Fig. D1. TBI types (n=5,421) were distributed across different injury severities for different road users; excluded = 228 TBI injuries due to other-unknown restraint groups or outlier road users such as farm-tractors, buses, and tricycles (other).

E. Kendall's Tau Test and Ranking of TBI types

TABLE EI

KENDALL'S TAU TEST FOR COMBINATIONS OF ROAD USER TYPES AND RESTRAINT USE

Road User and Restraint Type Combinations	**Kendall's Tau (τ)**	**p-value**
bicycle unhelmeted and bus belted	-0.08	0.747
bicycle unhelmeted and bus unbelted	0.63	**0.001***
bicycle unhelmeted and car belted	0.69	**0.000***
bicycle unhelmeted and car unbelted	0.58	**0.003***
bicycle unhelmeted and p-2w helmeted	0.80	**0.000***
bicycle unhelmeted and p-2w unhelmeted	0.74	**0.000***
bicycle unhelmeted and p-3w	0.76	**0.000***
bicycle unhelmeted and pedestrian	0.71	**0.000***
bicycle unhelmeted and pickup or truck unbelted	0.74	**0.000***
bus belted and bus unbelted	0.25	0.233
bus belted and car belted	0.01	1.000
bus belted and car unbelted	-0.14	0.518
bus belted and p-2w helmeted	0.03	0.914
bus belted and p-2w unhelmeted	-0.12	0.591
bus belted and p-3w	-0.05	0.830
bus belted and pedestrian	-0.14	0.518
bus belted and pickup or truck unbelted	-0.08	0.747
bus unbelted and car belted	0.49	**0.014***
bus unbelted and car unbelted	0.30	0.157
bus unbelted and p-2w helmeted	0.52	**0.010***
bus unbelted and p-2w unhelmeted	0.41	**0.047***
bus unbelted and p-3w	0.43	**0.036***
bus unbelted and pedestrian	0.38	0.062
bus unbelted and pickup or truck unbelted	0.41	**0.047***
car belted and car unbelted	0.54	**0.007***
car belted and p-2w helmeted	0.67	**0.000***
car belted and p-2w unhelmeted	0.52	**0.010***
car belted and p-3w	0.54	**0.007***
car belted and pedestrian	0.54	**0.007***
car belted and pickup or truck unbelted	0.60	**0.002***
car unbelted and p-2w helmeted	0.74	**0.000***
car unbelted and p-2w unhelmeted	0.76	**0.000***
car unbelted and p-3w	0.65	**0.001***
car unbelted and pedestrian	0.82	**0.000***
car unbelted and pickup or truck unbelted	0.80	**0.000***
p-2w helmeted and p-2w unhelmeted	0.80	**0.000***
p-2w helmeted and p-3w	0.78	**0.000***
p-2w helmeted and pedestrian	0.82	**0.000***
p-2w helmeted and pickup or truck unbelted	0.80	**0.000***
p-2w unhelmeted and p-3w	0.76	**0.000***
p-2w unhelmeted and pedestrian	0.93	**0.000***
p-2w unhelmeted and pickup or truck unbelted	0.78	**0.000***
p-3w and pedestrian	0.78	**0.000***
p-3w and pickup or truck unbelted	0.71	**0.000***
pedestrian and pickup or truck unbelted	0.85	**0.000***

** indicates p-value less than 0.05.*

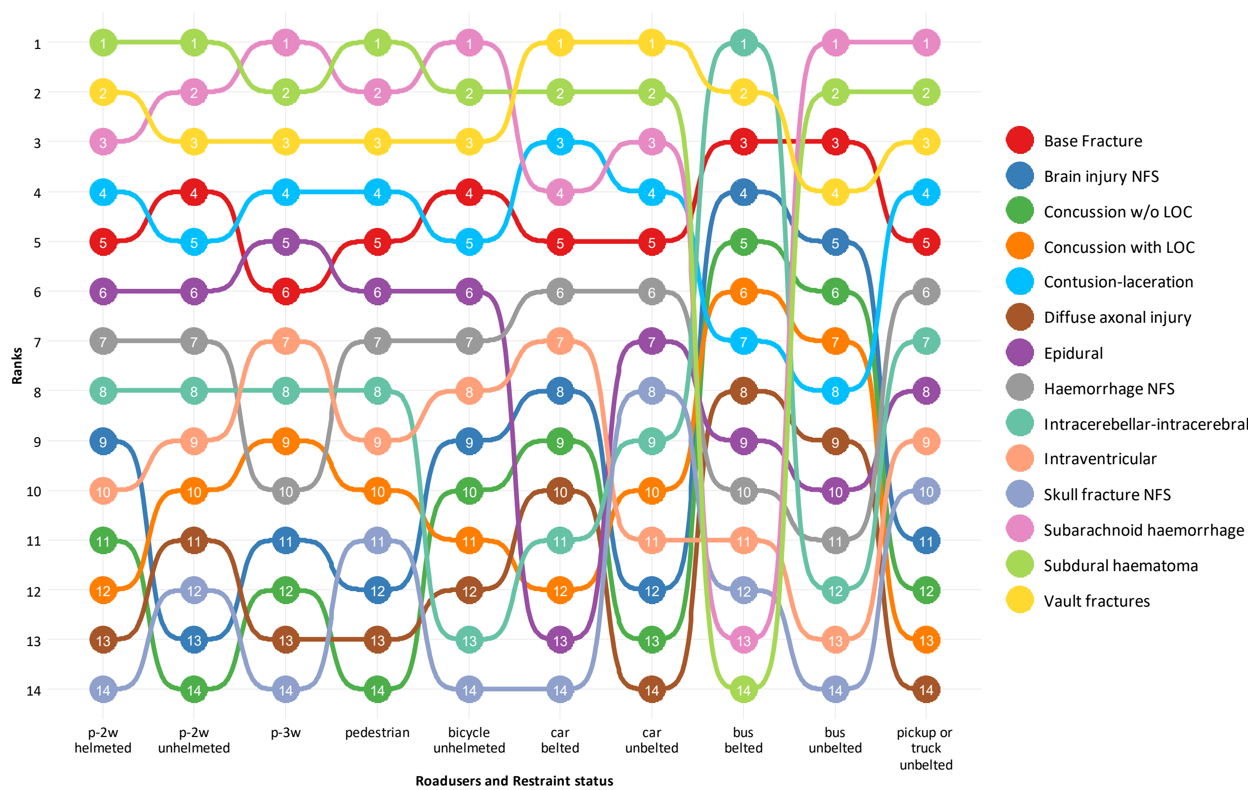

Fig. E1. The rank order of TBI types across different road users and restraint use (n=5,429; excluded=220 TBI injuries due to restraint use "unknown" and "only shoulder belt").

F. Injury Information

The first step of the current work was to check the completeness of injury information in the database. Single injury codes in the AIS manual have four levels of information: level-1: anatomical location; level-2: type of lesion; level-3: sub-type of the lesion; and level-4: the lesion size [11]. For example, level-1: "head whole area scalp (NFS) – 110099.1", level-2: "head whole area scalp abrasion – 110202.1", level-3: "head whole area scalp contusion; subgaleal haematoma if >6 months old – 110402.1", and level-4: "head whole area scalp contusion; subgaleal haematoma if >6 months old, subgaleal haematoma in infants ≤6 months old, blood loss >20% by volume in infants ≤6 months old – 110404.3". Of all injuries recorded in RASSI (after excluding 28 injuries due to coding error), most of the injuries had level-2 (64%) and level-3 (21%) information. Level-4 information was available only for 2% of injuries (Fig. F1). The trend was consistent across different body regions except for the head and spine. Head injuries have more (9%) level-4 information, and the spine has less (20%) level-2 information compared to other body regions (Fig. F2). A good level of injury information, particularly related to head injuries, was available in the RASSI database.

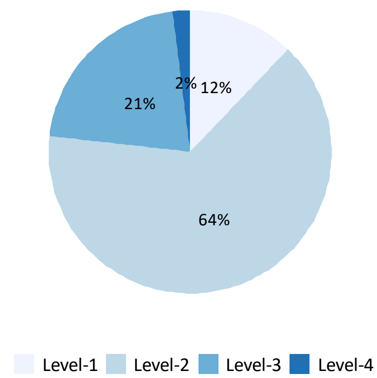

Fig. F1. Distribution of injury level information for all injuries in RASSI (n=46,978).

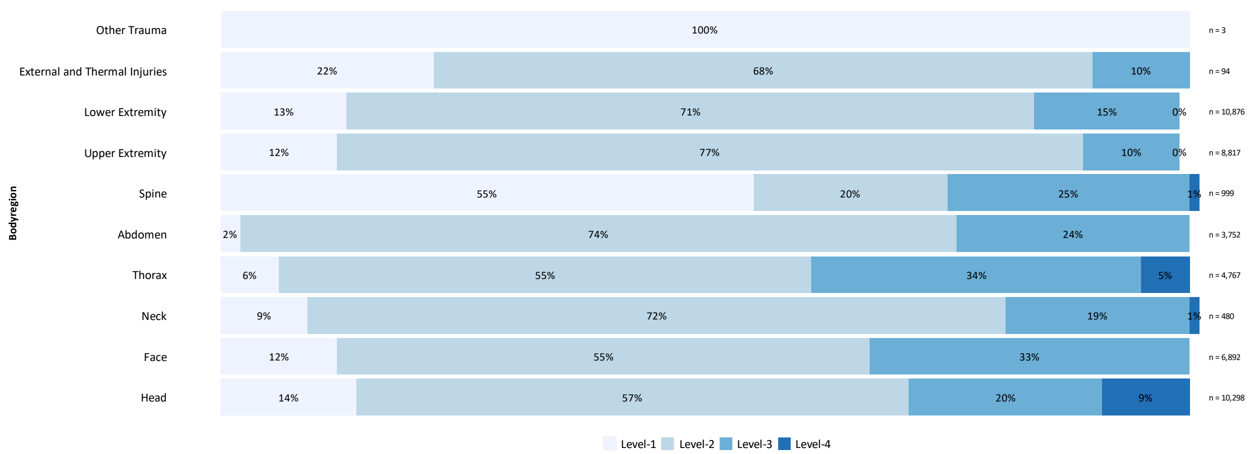

Fig. F2. Distribution of injury level information for all injuries across different body regions in RASSI (n=46,978).