Road Traffic Accident-Related Traumatic Brain Injuries in China: influence of seatbelt, helmet use and crash configuration among different road users

Guorong Li, Shiyang Meng

Abstract Traumatic Brain Injury is a leading cause of deaths and disabilities in road traffic accidents. Leveraging the China In-depth Accident Study database, this study analyses Traumatic Brain Injury patterns among different road users and discusses prevention strategies. Pedestrians were identified as the most vulnerable road user. On their behalf, there are recommendations to reduce closing velocity through automated emergency braking and to promote the use of pedestrian protection airbags. Helmets showed limited effectiveness in preventing Traumatic Brain Injury, indicating the need to improve the helmet standard GB 811–2022 for China and to avoid non-standard helmet use.

Keywords Helmet performance, pedestrian protection, road traffic accident, traumatic brain injury, vulnerable road user

I. INTRODUCTION

Globally, 34 million people sustain Traumatic Brain Injuries (TBIs) in road crashes every year, making it a primary cause of fatalities and disabilities [1]. Given the high incidence and severity of TBIs, extensive knowledge has been developed in the field of injury biomechanics to understand the mechanical response of the head [2]. Insights derived from real-world data can provide valuable inputs in prioritising TBI prevention and developing injury criteria for specific type of TBI.

Several studies have presented TBI patterns from real-life data. Older bicyclists in The Netherlands were found to have a higher risk of sustaining TBIs among patients with moderate and severe TBIs [3]. A study in China, using data from 56 neurosurgical centres across the country, found that half of the patients sustained TBIs from road crashes [4]. These studies generally present TBI distributions from the clinical perspective, including patients sustained TBIs by various trauma mechanism. By analysing relationship between road crash dynamics (e.g. delta-V) and TBI pathology, a study from Great Britain found that Vulnerable Road Users (VRUs) had a much higher likelihood of sustaining TBIs than car occupants under similar delta V [5]. Cycle helmets were found protective particularly against skull fracture and subdural haematoma. Based on road crash data in a Chinese city, another study found that the risk of a pedestrian suffering severe TBI is 100 times higher at an impact speed exceeding 70 km/h compared to an impact speed below 40 km/h [6].

Given the frequency of road crashes involving VRUs in China [7], many victims with TBIs can be expected. This study, based on data from China In-depth Accident Study (CIDAS), provides an overview of TBI occurrence patterns among different road users. The content covers the distributions of TBI occurrence, severities, specific TBI types, and implications for TBI prevention. Further in-depth studies are anticipated based on this study.

II. METHODS

Real-life crash data from the China In-depth Accident Study (CIDAS, version 202406) database were used for this study. To ensure the data were representative of China, the CIDAS team investigated crashes occurring since 2011 in at least six cities with different traffic conditions. The inclusion criteria for CIDAS require that at least one person is known to have been injured and that at least one four-wheeled vehicle is involved [7]. VRU-only crashes are therefore not within the scope of their investigation. Although the inclusion criteria do not specify the severity of injury to be included, the database faces underreporting issues for low-severity crashes. Underreporting of low-severity crashes is common in all crash databases, as these incidents are often not reported to the police.

This study included occupants from passenger cars and VRUs, including pedestrians, cyclists and powered two-

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/three-wheeler (PTW) riders. Participants with multiple collisions and occupants of cars colliding with VRUs were excluded. A total of 9,112 crashes involving the targeted road users were selected for this study, including 12,287 road users (3,685 sustained TBIs), and 42,629 injuries. The final data included information about road-user type, protection status (i.e. belted/unbelted, helmeted/unhelmeted), injury severity, specific TBI type, closing velocity, and impact type. 'Belted' was coded if occupants used seatbelts, regardless of the type. Three-point seatbelts are most common. 'Helmeted' was coded if riders used helmet before the crashes happened, regardless of the status after crashes.

TBI severities and types were identified by the Abbreviated Injury Scale (AIS) issued by the Association for the Advancement of Automotive Medicine (AAAM). CIDAS team coded injuries recorded in medical or autopsy report using AIS 2005. To align with the latest changes, we manually mapped the AIS codes of TBIs to the 2015 version [8]. One notable change was that severity codes of concussion without Loss of Consciousness (LOC) were upgraded from minor (AIS1) to moderate (AIS2). We further categorised the injuries or injury subtypes according to their pathological features and clinical presentations (i.e. with or without LOC). Information on velocity and impact type was selected from the worst injury event; in-depth crash data may record several events for each crash. In addition, closing velocity was calculated based on the collision angle and collision velocities of both participants. Collision angle and velocities are estimated based on evidence from surveillance video (if available), on-site investigations, and vehicle damage. Impact type was defined based on Principal Direction of Force (PDOF), which was coded according to o'clock direction from 1 to 12. Damage location was also considered to define impact type of passenger cars. For example, the impact type of a passenger car is frontal if the PDOF is 11, 12 or 1 and the damage location is to the front of the vehicle.

TBI risk curves and odds ratios for different TBI types were by logistic regression models [5]. To compare the vulnerability of different road users, we created two models for MAIS2+ and MAIS3+, with closing velocity, age (as a continuous variable), and road user type as independent variables. Additionally, four separate models for helmeted and unhelmeted PTW riders focused on MAIS2+ and MAIS3+ were developed to highlight the differences with changing closing velocities, using only closing velocity and age as independent variables. To understand the differences in TBI occurrence by seatbelt or helmet use, the odds ratios for most frequent six TBI types were evaluated using 12 univariate models (i.e. six models each road user). The dependent variables are the specific TBI types, with the independent variable being protection status (i.e. seatbelt for car occupants and helmet for riders).

Data processing and statistical analysis were carried out using R 4.4.1 [9].

III. INITIAL FINDINGS

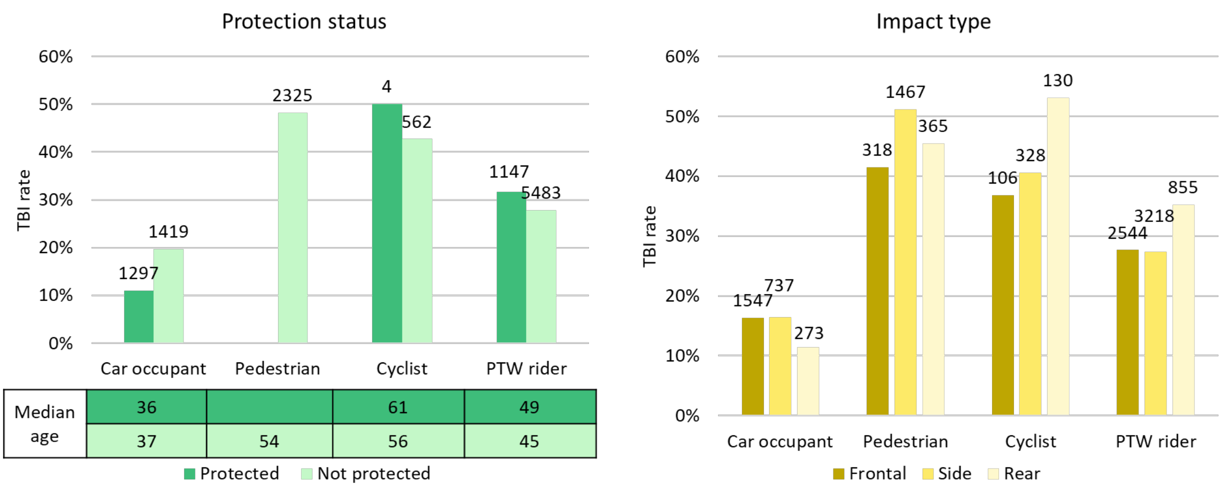

Fig. 1. TBI rate for different road users.

Fig. 1 illustrates the TBI rates for different road users, categorised by their protection status and impact type. The TBI rate is the number of road users diagnosed with TBIs divided by the total number of road users in each group. 'Protected' refers to belted car occupants and helmeted riders; 'Unprotected' refers to unbelted and unhelmeted car occupants and riders. The data included 6,630 PTW riders but only 566 cyclists. Only four helmeted cyclists were found, making it not meaningful to compare with other groups. In general, pedestrians had the highest rate of sustaining TBIs while car occupants had the lowest. Further, belted car occupants had a lower TBI rate than unbelted ones while helmeted PTW riders had a slightly higher rate than unhelmeted riders (31% compared to 28%). The median age of each group is provided in Fig. 1 (left). Among all road users, cyclists and PTW riders had the highest TBI rates in rear impacts, while car occupants had the lowest, as shown in Fig. 1 (right). Pedestrians had the highest rate in side impacts.

According to the prediction of logistic regression models, we presented TBI risks of different road users at the age of 46 years (median age of the sample), as shown in Fig. 2. The model results for injury risk curves can be found in the Appendix, where risk curves of any ages can be generated. At the same age and same level of closing velocity, the TBI risk from high to low was: pedestrian, cyclist, PTW rider, car occupant. This is true for both moderate-to-severe TBIs (AIS2+) and for severe TBIs (AIS3+). The closing velocity of pedestrians under 50% TBI risk (AIS2+) was about 40 km/h and it was 125 km/h for car occupants.

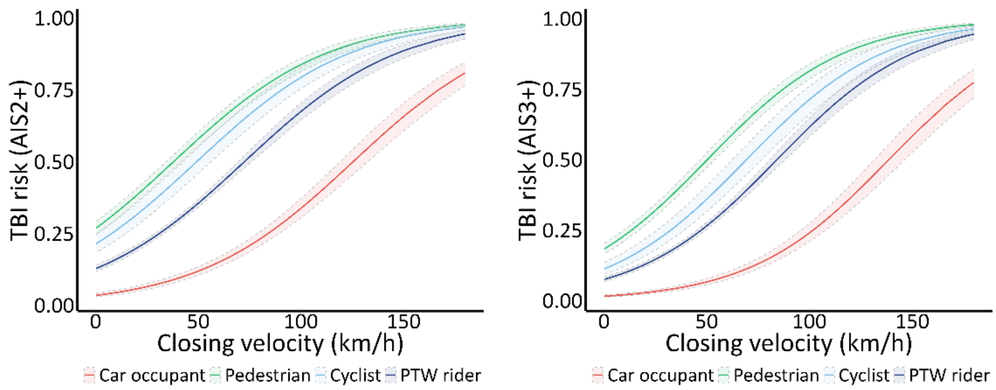

Fig. 2. TBI risk curves for 46-year-old road users. The shaded areas refer to 95% confidence interval.

Injury severity distributions for different road users sustained TBIs are shown in Fig. 3, considering only the most severe TBI for each person. The total number of protected and unprotected occupants in the right figure does not match the number in the left figure due to some occupants having unknown protection status. Among all road users sustained TBIs, 84% of pedestrians sustained severe TBIs and 68% of car occupants. When comparing different protection statuses, unbelted car occupants had a 7% higher proportion of severe TBIs than those who were belted. Helmeted PTW riders had a 2% higher proportion of severe TBIs compared to unhelmeted riders.

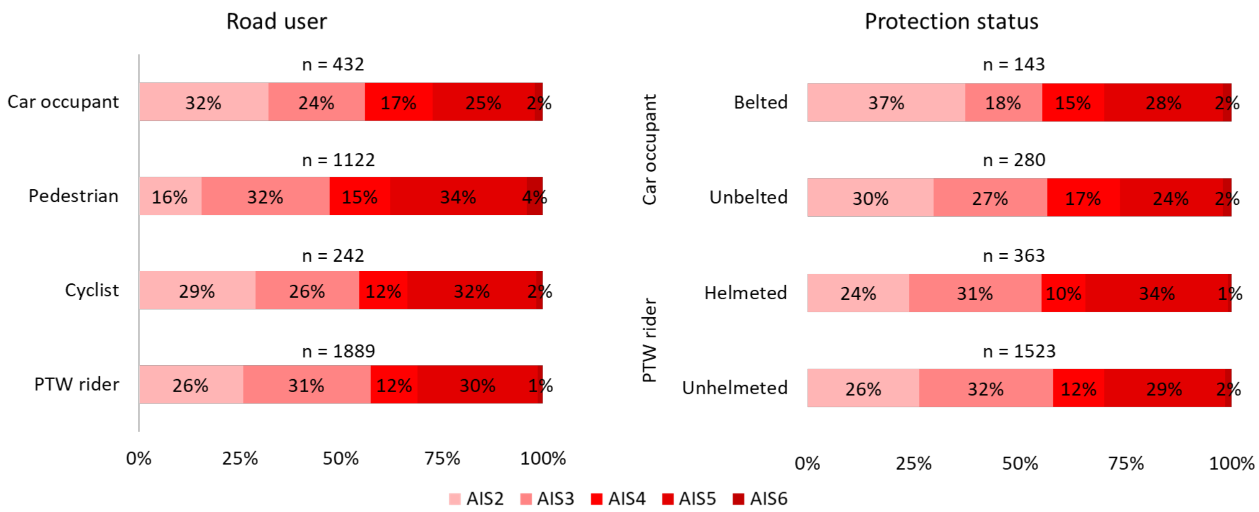

Fig. 3. Injury severity distribution for road users sustained TBIs. n represents the number of persons.

To determine if closing velocity is a dominant factor leading to more severe TBIs in helmeted PTW riders, Fig. 4 (left) provides the TBI risk curves for helmeted and unhelmeted PTW riders separately. Likelihood ratio tests were conducted to determine if the helmeted and unhelmeted curves are significantly different. The p-value is 0.03 for MAIS2+ and 0.08 for MAIS3+, indicating a significant difference for MAIS2+ curves. The results show a slightly lower TBI risk for helmeted PTW riders when the closing velocity is below 25 km/h. However, the TBI risk becomes higher for helmeted PTW riders when closing velocity exceeds 25 km/h. Additionally, we present a cumulative distribution of closing velocities of PTW riders in Fig. 4 (right). Only 35% of all riders had closing velocities below 25 km/h, and this percentage is lower for riders with severe TBIs (20%). To identify the most frequent TBI types, Fig. 5 lists percentages of the top five TBI types for each road user. Note that blanked bars do not mean the percentages are zero; only information for the top five TBI types of each road user were plotted. Contusion-laceration was found to be the most frequent TBI for all road users, followed by subarachnoid haemorrhage for VRUs, and base fracture for car occupants. For severe TBIs, base fracture was the second most frequent TBI type for VRUs. Other common TBI types included vault fracture, subdural haematoma, concussion without LOC, epidural haematoma, and some Not Further Specified (NFS) brain injuries.

To understand the influence of seatbelt and helmet on specific TBI types, odds ratios of protection status on frequently occurring TBI types were calculated separately based on TBI records from car occupant (676) and PTW rider (3,950), as shown in Fig. AI. Upper and lower boundaries were the 95% confidence intervals of the odds ratios. No significant differences in TBI patterns were observed between protected and unprotected road users.

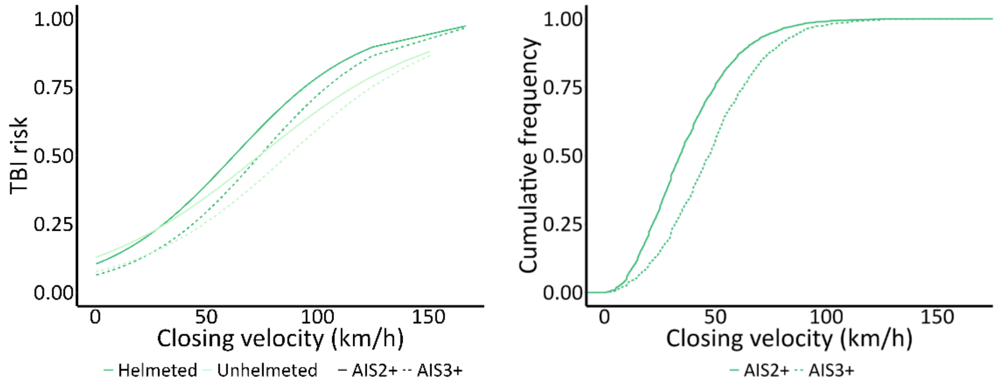

Fig. 4. TBI risk curves (age 46 years) and cumulative distribution for PTW riders.

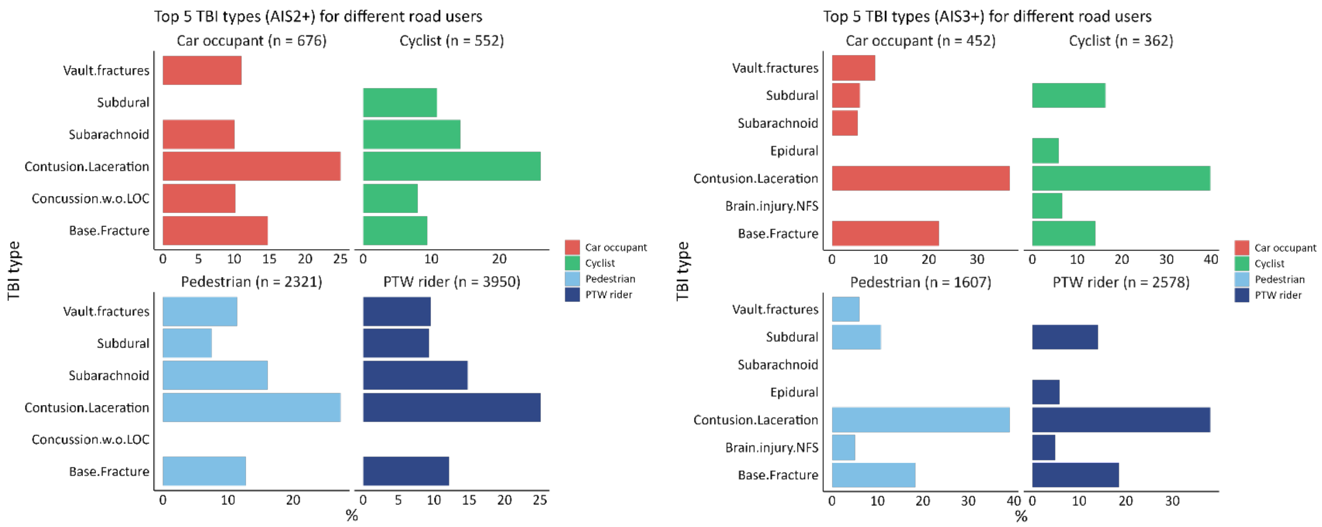

Fig. 5. The top five TBI types for different road users. n represents the number of injury.

IV. DISCUSSION

To understand TBI patterns in road traffic accidents in China, we analysed the influence of seatbelt and helmet use, along with crash configurations, among different road users using CIDAS data. Pedestrians were identified as the most vulnerable road user, consistent with previous studies [5-6], likely due to lack of protective equipment and their direct exposure to impact forces. Vehicles equipped with automated emergency braking systems have the potential to reduce closing velocity and lower the injury risk for pedestrians [10]. Promoting pedestrian protection airbags is also helpful in preventing pedestrians from sustaining TBIs [11].

According to statistics in Fig. 1, the percentage of belted passengers who sustained TBI is approximately half that of unbelted passengers, demonstrating the effectiveness of seatbelts in mitigating TBIs during a crash.

Furthermore, Fig. 3 (right) illustrates the shift in injury severity distribution between belted and unbelted occupants that sustained TBIs. The percentage of severe TBIs is 7% lower for belted occupants, indicating that seatbelts are more effective in mitigating severe TBIs (especially AIS3) compared to mild TBIs.

While helmets are specifically designed to protect the head, our results indicate that they do not perform very well in preventing TBIs for PTW riders. Helmets only show effective protection when the closing velocity is below 25 km/h, yet about 70% of PTW riders were exposed in crashes with closing velocities higher than 25km/h. Although PTW with a design maximum speed of 25 km/h accounts for a high proportion in China, the high velocity of the crash opponent is the main reason riders get injured. According to GB 811–2022, which is the helmet standard for motorcycle and electric bicycle users in China, the testing speed for the energy absorption test is 6 m/s (i.e. 21.6 km/h) for motorcycle and only 5.6 m/s (i.e. 20.16 km/h) for electric two-wheelers [12]. Furthermore, a survey-based study on the use of uncertified motorcycle helmets showed that in China, 72.9% of the helmets cost less than US$5 and only 34.6% had a certification mark [13]. Those uncertified helmets are expected to bottom out in crashes at speeds below the testing standards, worsening the situation for riders. Improving the helmet standard and avoiding the use of non-standard helmets are vitally important for effectively protecting PTW riders from sustaining TBIs in real-world crashes.

The TBI risk curves in this study are mainly for comparing the vulnerability of different road users. The possibilities of involving more relevant factors other than velocity and age will be investigated for prediction of TBI risks in the future.

V. ACKNOWLEDGEMENTS

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VII. APPENDIX

TABLE AI

MODEL RESULTS OF TBI RISK FOR DIFFERENT ROAD USERS

Variable	MAIS2+		MAIS3+	
	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	-4.092 (0.017) ***	(0.013,0.021)	-5.085 (0.006) ***	(0.005,0.008)
Closing velocity	0.026 (1.027) ***	(1.025,1.029)	0.030 (1.030) ***	(1.028,1.033)
Road user: cyclist	2.018 (7.527) ***	(5.923,9.577)	2.061 (7.857) ***	(5.973,10.348)
Road user: pedestrian	2.317 (10.145) ***	(8.432,12.243)	2.629 (13.859) ***	(11.183,17.262)
Road user: PTW rider	1.403 (4.067) ***	(3.467,4.787)	1.620 (5.054) ***	(4.177,6.151)
Age	0.017 (1.017) ***	(1.014,1.019)	0.021 (1.021) ***	(1.018,1.024)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; reference group for road user is car occupant

TABLE AII

MODEL RESULTS OF TBI RISK FOR HELMETED PTW RIDERS

Variable	MAIS2+		MAIS3+	
	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	-3.498 (0.030) ***	(0.016,0.056)	-4.353 (0.013) ***	(0.006,0.026)
Closing velocity	0.034 (1.035) ***	(1.028,1.042)	0.036 (1.037) ***	(1.030,1.045)
Age	0.029 (1.029) ***	(1.019,1.041)	0.036 (1.037) ***	(1.024,1.049)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001

TABLE AIII

MODEL RESULTS OF TBI RISK FOR UNHELMETED PTW RIDERS

Variable	MAIS2+		MAIS3+	
	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	-2.866 (0.057) ***	(0.046,0.071)	-3.820 (0.013) ***	(0.006,0.026)
Closing velocity	0.026 (1.026) ***	(1.023,1.030)	0.029 (1.037) ***	(1.030,1.045)
Age	0.020 (1.021) ***	(1.017,1.025)	0.028 (1.037) ***	(1.024,1.049)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001

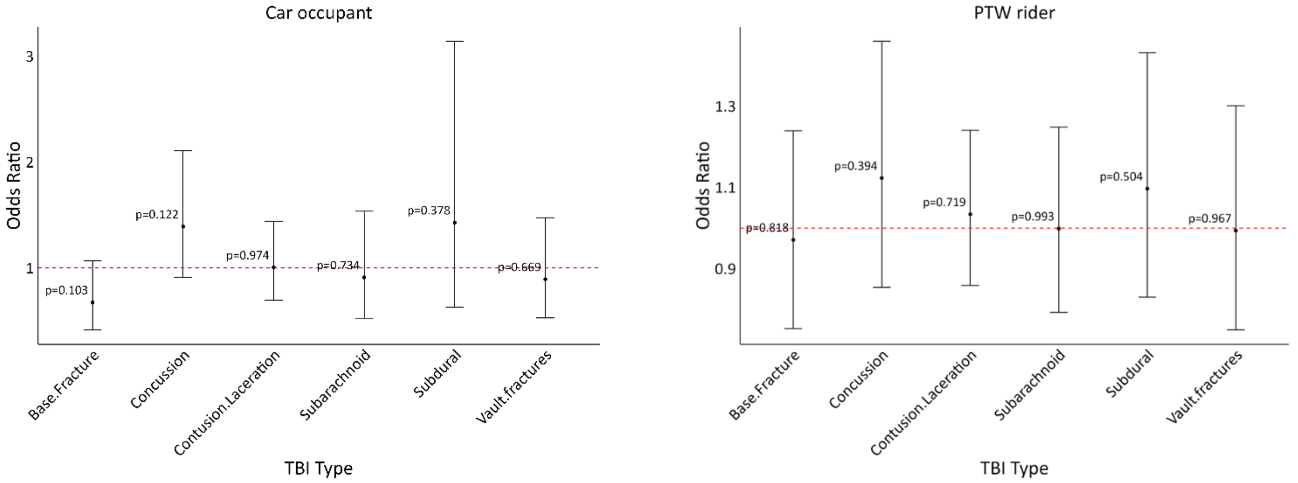

Fig. AI. Odds ratios of protection status on frequently occurring TBI types. The odds ratio over 1 indicate higher odds of sustaining TBIs for the road user under protection and vice versa.