Traumatic brain injury findings from Great Britain's in-depth RAIDS database relating to delta-V

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I. INTRODUCTION

Each year 1.35 million people die in road traffic collisions (RTCs) globally with at least a further 50 million casualties [1]. RTC injuries are the 8th leading global fatality cause and 10th leading cause of disability globally [2]. Traumatic brain injury (TBI) is frequently severe and leads to significant morbidity and reductions in quality of life [3-4]. One study estimated 34 million TBI (all severity) are sustained on the roads each year [5]. In GB, over half of patients requiring neuro-specialist care are not transferred directly to a hospital with appropriate provisions [6]. Direct transfer to a site with neuro-specialist provision reduces mortality from 36-19% [7]. A better understanding of how collision biomechanics relate to TBI outcome is therefore key to reducing death and disability by preventing primary injury and reducing the time to reach specialist treatment. Delta-V is an established collision severity metric for both overall and body-region specific injury severity [8-11]. While powerful, AIS is not used by emergency medical services (EMS) and cannot capture all TBI (e.g. when symptomatic presentation is used for diagnosis). We assess the ability of a delta-V-based metric to predict TBI severity and pathology using logistic regression and data from Great Britain's Road Accident In-Depth Studies (RAIDS) [12].

II. METHODS

Data Source and Inclusion Criteria

RAIDS is a UK Government Department for Transport initiative to collect in-depth RTC data across Great Britain (GB) aiming to prevent serious and fatal injuries in GB [12]. Data about the collision scene, environmental factors, vehicles and injuries sustained is collected and entered by trained collision investigators, ensuring high accuracy. Clinical information is from hospital notes, radiology reports and post-mortem reports where applicable. As accessed 4th April 2020, the RAIDS population (2013-20) captured 2,048 collisions involving 5,329 subjects (37% female). Of 3,034 casualties (39% female), 78% are 16-60 years, 14% are >60 years and 5.5% are <16 years old.

Table 1 – RAIDS database breakdown showing the main different road user types for all subjects and casualties in RAIDS.

Category	All Users	Car	LGV	HGV	Bus	Motorcycle	Pedal Cycle	Pedestrian
Subjects	5,329	3,960 *(74%)*	366 *(7%)*	259 *(5%)*	196 *(1%)*	265 *(5%)*	108 *(2%)*	143 *(3%)*
Casualties	3,034	2,180 (72%)	191 *(6%)*	82 *(3%)*	80 *(<1%)*	251 *(5%)*	105 *(2%)*	138 *(3%)*

Traumatic Brain Injury Classification

We classify the TBI severity of casualties within RAIDS using the Mayo Classification system [13] which combines TBI indicators with pathology presence, as previously outlined [14]. Solo TBI indicators (Glasgow Coma Score, loss of consciousness) are only known for 62% RAIDS casualties necessitating a combined system. Our free-text search algorithm finds TBI-related terms and treatments in clinical and post-mortem information. Terms were refined using 2013-19 RAIDS data and validated manually for 2019-20 data (507 subjects in 200 collisions), obtaining ≥99.4% agreement. Five severity groups were constructed (uninjured, injured without TBI, symptomatic-possible TBI, mild-probable TBI and moderate-severe TBI) and key pathologies were examined (skull fracture, subdural hematoma, subarachnoid hemorrhage and focal injury). Where possible, direct comparisons between AIS codes and free-text pathology groups (e.g. subarachnoid) were made, showing no AIS-coded injuries were missed.

Analysis using delta-V

Delta-V relates to injury severity [8-11]. For car occupants, we adopt the method previously outlined in detail [14]. The longitudinal, lateral and total delta-V is calculated using AiDamage (which applies CRASH) [15]. We include all single impacts with valid CRASH delta-V, in addition to multiphase impacts with one clear injury-causing event. For pedestrians, travel speed of the impacting vehicle relates to injury risk [16]. The majority of pedestrians in RAIDS are injured while crossing (69.4%) at low speeds, therefore pedestrian delta-V is approximated as vehicle impact speed. Cyclists travel at higher speeds, so their velocity component parallel to the direction of travel of the impacting vehicle can be influential and is taken into account. Those already lying in the road were excluded as they are not accelerated to the speed of the impacting vehicle. We produced single-variate logistic regression curves for car occupants (n=683) and a combined pedestrian-cyclist group (n=147) to determine the risk of TBI severity and specific pathologies. We also analyze the influence of delta-V direction (using 'N-1' χ^2)[17]).

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III. INITIAL FINDINGS

Of 3,034 casualties, 561 (18.5%) sustained a TBI of which 316 (56.5%) were estimated to be moderate-severe, 116 (20.8%) were mild-probable and 127 (22.7%) were symptomatic-possible. The TBI population contained 342 car, 161 LGV and 77 HGV occupants, 67 motorcyclists, 41 cyclists and 66 pedestrians. Key pathologies were subarachnoid hemorrhage (165, 29.5%), focal brain injury (154, 27.5%), skull fracture (129, 23.1%) and subdural hematoma (96, 17.2%). In RAIDS overall, injury prevalence was higher for women [$\chi^2_{(1)}$=15.8, p<0.001], but TBI was more common among men [$\chi^2_{(1)}$=5.9, p=0. 015]. Vulnerable road users had greatest risk of moderate-severe TBI [$\chi^2_{(1)}$=290.6, p<0.001] with pedestrians worst affected particularly by skull fracture [$\chi^2_{(1)}$=233.5, p<0.001]. Delta-V was known for 147 cyclists/pedestrians and 683 car occupants. In all instances increasing delta-V lead to increased risk of moderate-severe TBI (Fig. 1a). When accounting for delta-V, pedestrians/cyclists had a 6x higher likelihood of sustaining moderate-severe TBI [OR($CI_{95\%}$): 6.33 (3.76-10.66)]. Likelihood for different road users varied with pathology (10x higher for skull fracture [OR($CI_{95\%}$): 10.56 (5.15-21.67)] (Fig. 1b). Directional delta-V analysis was done for car occupants with higher longitudinal (n=562), higher lateral (n=113), longitudinal-only (n=374) and lateral-only (n=62) delta-V. Car occupants exposed to greater lateral than longitudinal delta-V had increased risk of moderate-severe TBI, despite the vector sum of delta-V being lower in lateral-dominant cases (Fig. 1c). When exposed to lateral delta-V only, relative risk of subarachnoid hemorrhage was 3.44x higher ($CI_{95\%}$: 1.04-11.43). Case analysis showed subarachnoid hemorrhage commonly occurred head contact due to intrusion.

Fig. 1a - TBI Risk by Road User

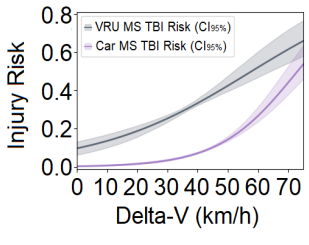

Fig. 1b - Skull Fracture Risk

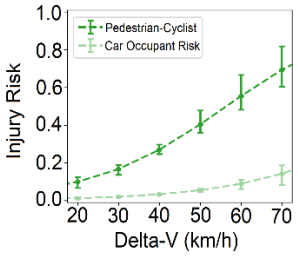

Fig. 1c - Delta-V distributions

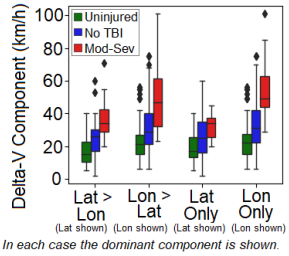

Fig. 1d –TBI prevalence in lateral-dominant impacts

	ΔV_{LAT} greater* only**	ΔV_{LON} greater* only**	'N-1' χ^2
MS TBI*	11	27	4.3 p=0.04
No MS TBI*	102	535	
SAH**	4	7	4.5 p=0.03
No SAH**	58	367	

Fig. 1. Traumatic brain injury risk increases with increasing delta-V. Risk varies by (a) road user type and (b) pathology. Car occupants exposed to higher lateral delta-V had higher TBI risk (c) despite lower distributions.

IV. DISCUSSION

Our overall TBI prevalence results support findings from similar studies [18-19]. The difference between road user groups is unsurprising, as occupants are protected by restraint systems. Biomechanically skull fracture is caused by high linear accelerations and direct impact [20-21] with risk related to impact velocity, a key component of pedestrian-cyclist delta-V metric [17]. In car occupants, we observed higher moderate-severe TBI risk in lateral-dominant collisions supports previous work linking side impacts/rollover collisions (which often have high lateral delta-V components) to serious head injury [11,22]. The directional differences observed in this current GB dataset highlight areas where car occupant head injury risk can be further mitigated. Further data and investigation are required to understand the effect of near- and far-side impacts and whether subarachnoid hemorrhage in car occupants exposed to only lateral delta-V is primarily due to intrusion as observed in this small number of cases. As more data becomes available, further work is ongoing to investigate pathology-specific and other risk factors (e.g. age, gender, belt use, rollover). This study improves our understanding of the relationship between RTC biomechanics and pathology outcomes while reporting on novel in-depth data from Great Britain.

V. ACKNOWLEDGEMENTS

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