Single-Vehicle Powered Two-Wheeler Crashes in India: Guidance for Test Method Development

Junaid Shaikh, Jolyon Carroll

Abstract In India, 75,000 powered two-wheeler (PTW) riders lose their lives annually. PTWs impacting trucks, cars, and self-fall are the most frequent crash scenarios. The characteristics of PTW self-fall events and the later sequence of events are not well established. The current study queried the Indian crash database RASSI for PTW self-fall crashes between 2014 and 2024. PTW crashes where the first event was a self-fall and the riders were fatally injured were selected. The PTWs were smaller and lighter than in high-income countries. The medians were 110 cc for engine size and 35 km/h for the travel speed. The fatally injured PTW riders were mainly males (85%) with median height and weight of 165 cm and 65 kg, respectively. Riders who experienced self-fall as the first event subsequently impacted another vehicle (65%), mainly heavy vehicles, or had no secondary impact (35%), while 52% of the riders were run over. Abdomen, head, and thorax were the most frequently injured body regions when the rider impacted another vehicle after the self-fall. Head dominates when there is no secondary impact after the self-fall. The current work provides information to set relevant input conditions for future tests related to PTW self-fall events that could lead to improved rider protection in India.

Keywords Crash database, load case, motorcycle, PTW, self-fall.

I. INTRODUCTION

Road traffic fatalities are a major health concern: globally, around 1.2 million lives are lost annually [1]. For most road users the number of fatalities in 2022 was lower than the average fatalities in 2017–2019, except for powered two-wheelers (PTWs) [2]. The powered two- or three-wheeler rider fatalities are concerning, with nearly 46% occurring in the World Health Organization's South-East Asia Region [1]. In India, the reported PTW rider fatalities is around 75,000 per annum [3].

In India, for riders who are killed or seriously injured, PTW impacting trucks and cars are the most frequent crash scenarios, and self-fall is among the top five [4], while for fatal pillion riders self-fall is the most common [5]. Self-fall is also a common crash scenario in Germany [4]. Previous research established those rankings, but the situation, particularly for riders who are killed, is unknown. Furthermore, available data on the crash characteristics during self-fall in India are limited [4].

Globally, for PTW and motorcycle safety, only the ISO 13232 standard and its sub-parts require full-scale vehicle crash evaluations. These tests have been established with around 200 impact configurations evaluated virtually, and seven requiring physical testing due to their frequent occurrence in the real world [6]. Based on the ISO 13232 standard, the Automotive Research Association of India (ARAI) has recently built the capability to perform crash tests on motorcycles [7]. However, none of the impact configurations focuses on self-fall crashes because the standard is written around motorcycle and car crashes. This study aims to supplement the information on motorcycle-to-car crashes with complementary information on the crash characteristics and sequence of events for PTW self-fall crashes. By using real-world, in-depth crash data for this purpose, we provide evidence that could support future development of test methods with a view to accomplishing the Sustainable Development Goals (SDG) target 3.6 of the United Nations, which is to halve the number of global deaths and injuries from road traffic crashes by 2030.

II. METHODS

Road Accident Sampling System - India (RASSI), an Indian in-depth crash database, was used for this study. RASSI currently operates in five locations and collects road crashes that occur in its sampling locations based on

J. Shaikh (tel: +91-9821617552; e-mail: junaid.shaikh@autoliv.com) is a Project Lead Traffic Safety Research Engineer with Autoliv India Pvt. Ltd, Bangalore, India. Dr J. A. Carroll is a Senior Research Specialist in Biomechanics at Autoliv, Vårgårda, Sweden.

the inclusion criteria, of which the two basic criteria are: (1) the crash must include at least one motorised vehicle and (2) the crash spot must be in a public area within the study location [8]. The RASSI data from April 2014 to March 2024 were used for the analysis. During this period, 7,118 crashes and 3,579 fatalities were investigated. Of these fatalities, riders and pillion riders of PTW (excluding mopeds) were the most frequent (45%), followed by pedestrians (22%), and car occupants (15%). Cases with a fatal PTW rider outcome where the first event was a self-fall were analysed. The complete data extraction process is shown in the Appendix, Fig. A1. Self-fall is defined where the object contacted by the PTW in its first event was coded in the database as one of the following: non-collision injury; other or unknown non-collision; ditch or culvert; ground; embankment; or not applicable.

The distributions of PTW travel speed, PTW specifications – length, weight, engine size – the role of the rider (rider or pillion), rider anthropometric measurements, helmet usage status, runover status – the rider being run over by the wheels of another vehicle, and collision partners for the second event are summarised in the Results section. For injury data, the Abbreviated Injury Scale (AIS) 2005 version with the 2008 update [9] was used. Further, only moderate or more serious (AIS2+) injuries were selected, while minor or unknown severity (AIS1 or AIS9) injuries were removed, which was approximately 55% of all injuries. The complete analysis and visualisation were done in the programming language R [10].

III. RESULTS

There were 1,613 PTW fatalities within the data sample, of which one-quarter were pillion riders. The most frequent first events were PTW impacting trucks (22%), followed by self-fall (21%), and then PTW impacting cars (15%), which is in line with earlier work [4]. However, the earlier work [4] focused on killed or seriously injured riders, for which the frequency order is different from the current work (Appendix, Fig. B1). Within the new sample, 336 fatalities resulted from PTW self-fall. Motorcycles were more frequently involved (67%) than scooters. The median engine size of the PTW was 110 cc (interquartile range [IQR]: 47 cc, two unknowns excluded). The cumulative distribution of travel speed is shown in Fig. 1, with a median of 35 km/h (IQR: 18 km/h; 77 unknowns excluded). The overall median length (motorcycle and scooter) was 198 cm (IQR: 20 cm; two unknowns excluded), and the kerb weight was 112 kg (IQR: 28 kg; 13 unknowns excluded). When the length and weight are visualised together with the PTW category (motorcycles or scooters), two distinct clusters are highlighted, varying mainly across their length (Appendix, Fig. C1), with scooters being shorter than motorcycles.

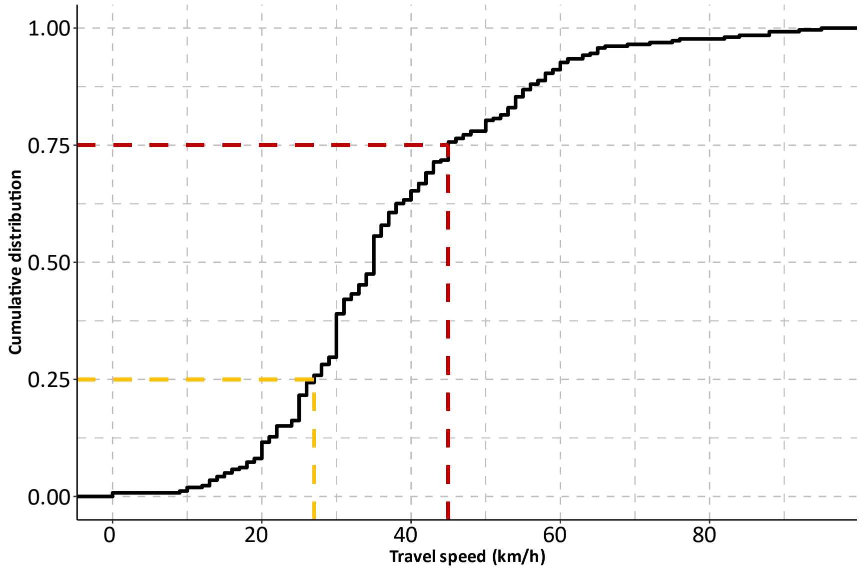

Fig. 1. Cumulative travel speed distribution of powered two-wheelers (PTWs) with fatal riders involved in self-fall crashes (n=259). Dashed lines illustrate 25th and 75th percentile speeds at 27 km/h and 45 km/h.

Of all fatal riders, 84% (including pillions) did not wear a helmet, 11% wore a helmet (full-face, three-quarter shell, or half shell), 4% had improper helmet use, and for 1% helmet use was unknown. Most of the fatal riders were male (85%). Nearly 52% of the fatal riders were run over. The median height and weight of the riders was 165 cm (IQR: 9 cm; 207 unknowns excluded) and 65 kg (IQR: 15 kg; 274 unknowns excluded), respectively. Figure 2 illustrates the distribution of fatal PTW riders across the role of the rider, their second event, and the occurrence of a runover. Post-self-fall, most (57%) of the PTWs impacted another vehicle, leading to a runover, while most of the remaining group had no secondary impact. The other vehicles in the "Another vehicle" category during the second event were mainly trucks and buses (87%), followed by cars (5%), pickups (4%), powered two-wheelers (3%), and powered three-wheelers.

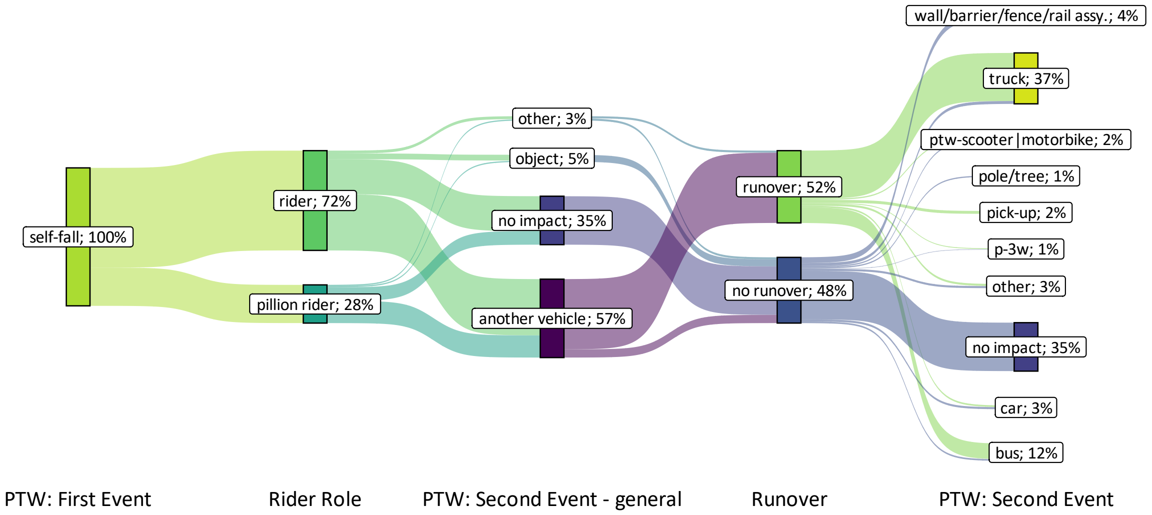

Fig. 2. Sankey plot for fatal powered two-wheeler (PTW) riders having a self-fall followed by their second event details and runover outcome (n=336).

Injury details were extracted for the two major scenarios: secondary impact with another vehicle, and no secondary impact. Riders with an unknown helmet use status were excluded. The first scenario, the PTW having a secondary impact with another vehicle, highlights that the abdomen has more frequent injuries, which are relatable to runovers, followed by the head and the thorax. For the second scenario, the PTW did not have a secondary impact. In that case, the riders mainly sustained head injuries (68%), followed by thorax (16%) from the first event, which was a self-fall (Fig. 3). It can be noted that the share of thorax injuries was the same in both scenarios.

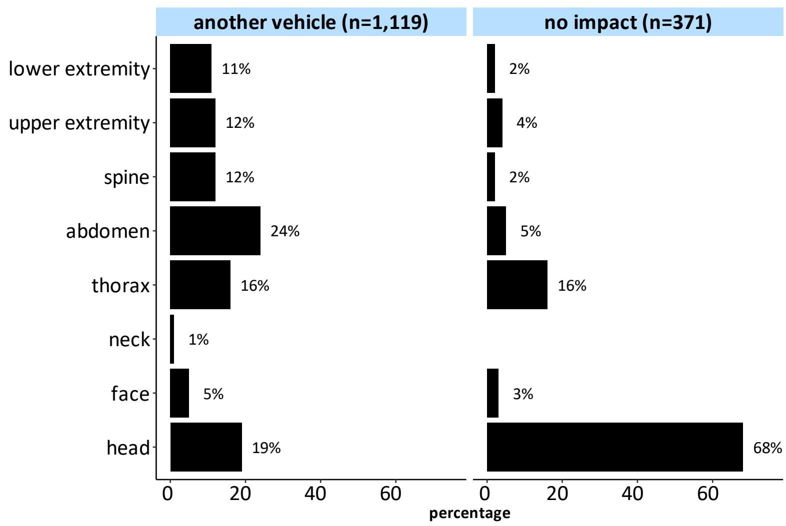

Fig. 3. Distribution of AIS2+ injuries across different body regions for fatal powered two-wheeler (PTW) riders having self-fall and then either impacting another vehicle (left) or having no secondary impact (right).

IV. DISCUSSION

PTW self-fall is among the top two crash scenarios experienced in events leading to a fatality in this sample of RASSI cases from India. From this sample, information about the crash characteristics has been extracted to help guide further investigation and research, potentially leading to the development of a test procedure that could represent such events. The self-fall of PTW typically occurs at a travelling speed of about 35 km/h, leading to two major scenarios: either impacting another vehicle, or having no secondary impacts and continuing to roll or slide.

Impacting another vehicle increases the probability of a runover, often with heavy vehicles (trucks or buses). The abdomen, head, and thorax are the frequently injured body regions in these events. Injuries to the extremities and the spine are also common in this scenario. However, when there is no secondary impact after the self-fall of the PTW, the head is the dominant injured body region in the event, followed by the thorax. The average PTW (based on the median points from this sample) is a motorcycle with general specifications: engine size of around 110 cc, length of 198 cm, and weight of 112 kg, much smaller than that observed in Germany [11]. The riders' general details were: male, with a height of around 165 cm, and weight of around 65 kg, which is shorter and lighter than the 50th percentile male Anthropometric Test Device (ATD).

The study used unweighted data because the objective was to understand the crash characteristics in the PTW self-fall crashes. However, even when the data were weighted – which is not included in the current results – self-fall was still among the top two crash scenarios. Thus, addressing the PTW self-fall crashes will be important to meet SDG target 3.6.

Nearly 50% of the riders with a self-fall were run over, mainly by heavy vehicles. Underrun protection devices are meant to address the contact of heavy vehicles with cars and provide a barrier from vehicular intrusion under the load bed or the front bumper [12]. Extended runover protection devices and wheel protection would be potential countermeasures to mitigate the runover situations of PTW riders [13]. Alternatively, there is also potential for on-bike countermeasures, such as motorcycles with a roof [14] that could withstand forces from heavy vehicles during runover or, better still, prevent underrun altogether. Such structures would also provide additional opportunities to restrain the rider within a frame, preventing secondary contacts or at least cushioning the ground contact during the self-fall. However, the suitability of countermeasures like these should be evaluated for Indian roads and the local traffic conditions.

The remaining 50% of riders who were not run over were mostly involved in pure self-fall events and had no secondary impacts. The self-fall was initiated mainly due to traffic-calming speed bumps, uneven road surfaces, and inappropriate manoeuvres during overtaking, leading to a hard contact with the ground. Speed-bump-installing authorities or representatives should realise that inappropriate installations can lead to fatalities and should install speed bumps that adhere to standards. In theory, there appears to be potential for wearable protection on the rider, such as helmets or inflatable airbag garments, to help cushion the contact with the ground.

The injury overview showed a high frequency of head injuries, even when the helmet was used (Appendix, Fig. D1). The current helmet standards in India consider linear accelerations during the evaluation [15], but do not account for rotational motion, as adopted by the equivalent UN Regulation [16]. Importantly, a test procedure looking into ground impacts from these cases should represent the relative speed of the rider to the ground (from the travelling speed of about 35 km/h), as well as the contribution coming from the fall from the riding posture to the ground. This tangential speed to the road surface is close to the likely transition in helmet rolling and sliding behaviour [17] and therefore could be critical in evaluating improved helmet designs.

Evaluating complete system-level performance of inflatable or deployable solutions rather than relying on component tests would be possible (and could support complementary countermeasures) if a test procedure could realistically recreate the fall event. This analysis has shown two critical aspects for such future test considerations: (1) in the description of typical attributes for the events, the two-wheelers involved and their riders, and (2) in the knowledge that there is an even split in cases involving runover outcomes or not. This limits the relevance of test procedures that focus on either the runover or no-runover cases and encourages countermeasures for both self-fall and self-fall with a consequent runover. Protection from being runover may be assessed in a simplified, component-level or quasi-static test, but that would not remove the need for some self-fall test procedure to assess vehicle-based or wearable countermeasures in events as described in the results.

This study has limitations. There was no information on whether the rider was separated during or after the self-fall phase. European data have shown that most of the riders did not separate after the self-fall and were in the upright position [18]. However, further evidence, such as CCTV, is required to confirm the findings in the Indian context. Further, the micro details, such as impact angle, throw distance, the body region of riders who impact with another vehicle, and the sequence of impacts of the rider and not the PTW, are unclear in the coded retrospective data and require further investigation. Given the complexity of possibilities, a general recommendation could be to split any physical test procedure representing these events into two temporal steps: (1) a simple self-fall scenario – vehicle rolling due to gravity; (2) to instigate an impact of the PTW along with rider to a barrier representing an object or a vehicle. If the test purpose needs both elements, then the combined sequence could be easier to simulate in a virtual setting than a physical one.

Regardless of the final application, this is a first step in understanding the crash characteristics during PTW self-fall crashes involving fatal riders in India. Further research with other data sources will be needed to define the micro details of the rider's behaviour and contacts. That should help to refine self-fall test conditions and to lend additional confidence to the potential effectiveness of PTW rider safety countermeasures.

V. CONCLUSION

PTW crash after self-fall generally ends in one of two situations: impact with another vehicle, mainly heavy vehicles; or no secondary impact. This study provides information to set relevant input conditions for future tests related to self-fall events in India. Depending on the intended application, further research may be needed to understand the feasibility of performing PTW self-fall scenarios in crash test facilities and to evaluate rider protection systems. Based on the current work, some recommendations can be made to increase safety around these self-fall events. One is to include appropriate tangential and normal velocities in protective helmets and other equipment requirements. Rider protection also needs to address runover situations. Effective rider protection in those events should contribute substantially to reducing the burden of road traffic fatalities.

VI. ACKNOWLEDGEMENTS

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VIII. APPENDIX

A. Data extraction process

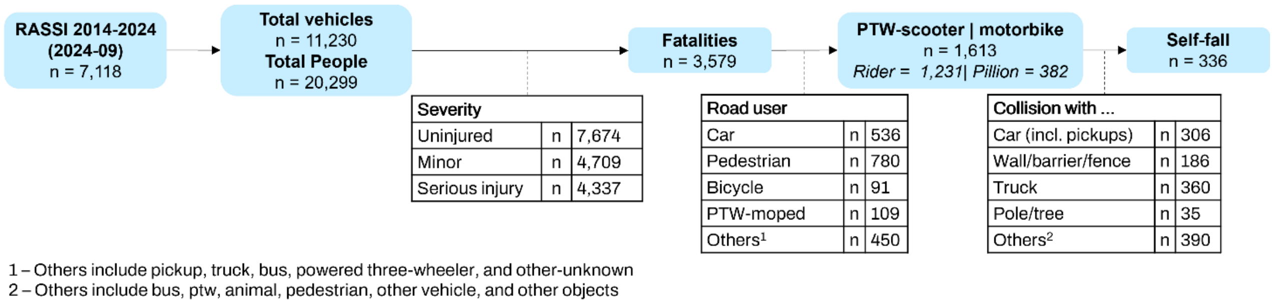

Fig. A1. Filters applied to extract self-fall crashes in RASSI.

B. Collision partner distribution for fatal powered two-wheeler riders

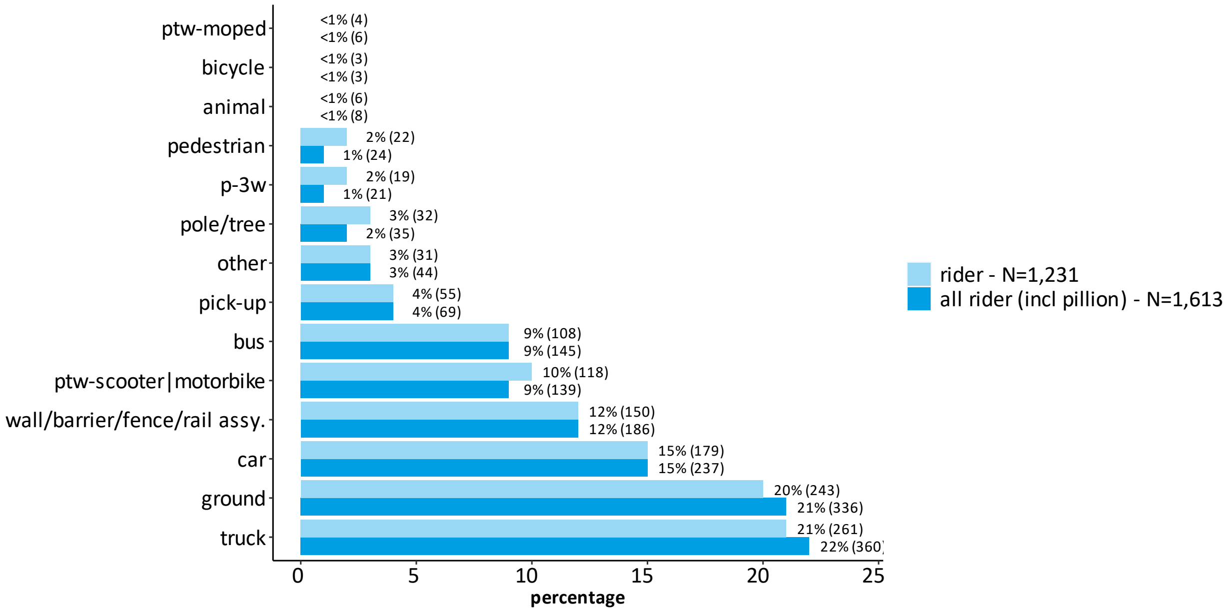

Fig. B1. Distribution of collision partners of fatal powered two-wheeler (PTW) riders during the first event (n=1,613).

C. *Distribution of powered two-wheeler length against kerb weight*

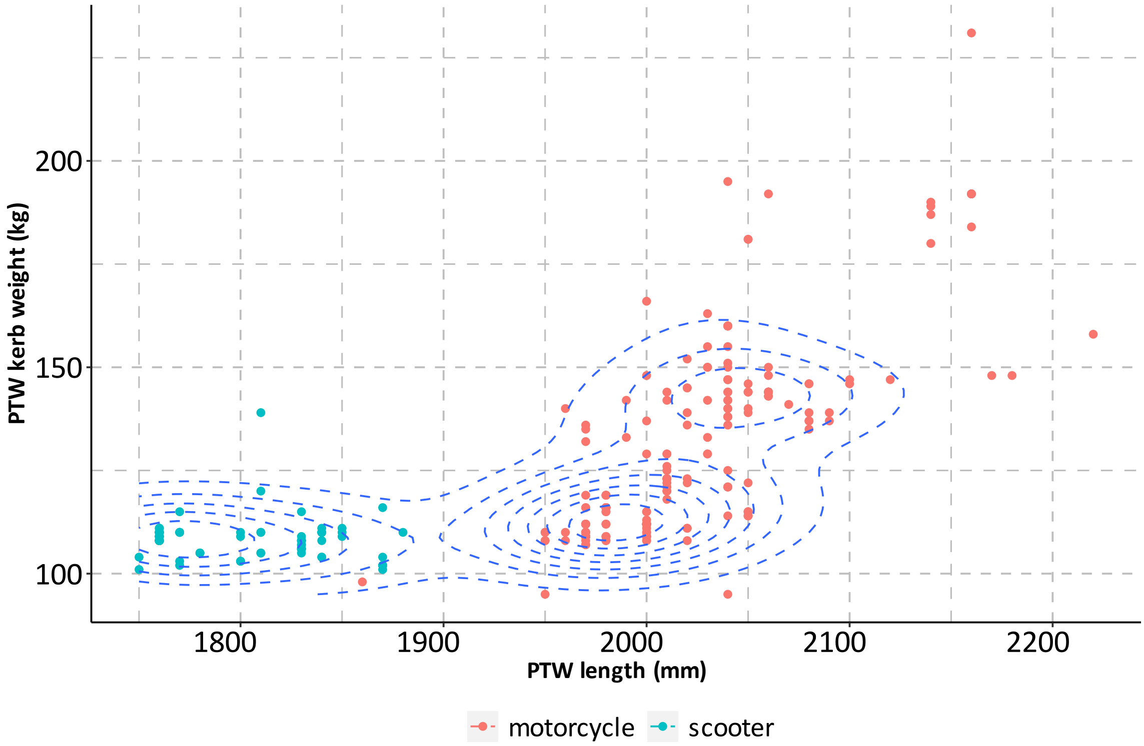

Fig. C1. Scatter plot for powered two-wheeler (PTW) length versus kerb weight for motorcycle and scooter (n=323; 13 unknowns excluded).

D. *Distribution of the injured body region of riders with different restraint use*

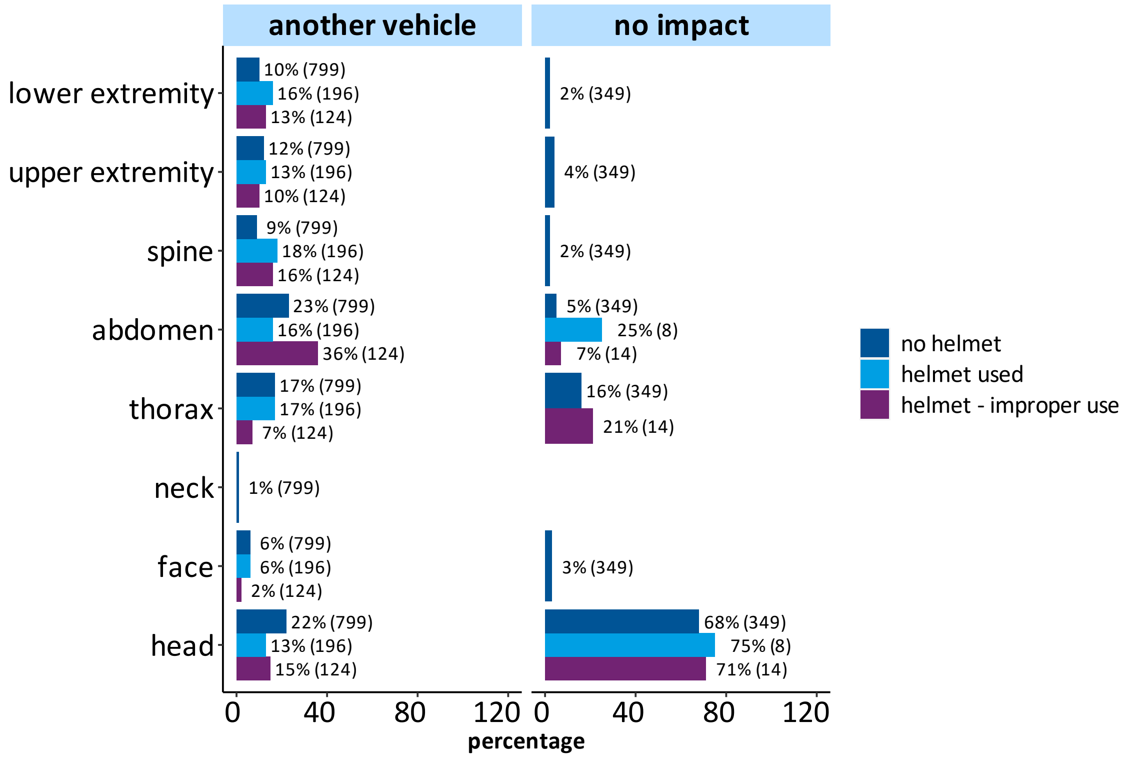

Fig. D1. Distribution of AIS2+ injuries across different body regions and restraint use for fatal powered two-wheeler (PTW) riders having self-fall and then either impacting another vehicle (left) or having no secondary impact (right).