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Detailed assessment of pedestrian ground contact injuries observed from in-depth accident data

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ABSTRACT

Most pedestrians struck by vehicles receive injuries from contact with the vehicle and also from the subsequent ground contact. However, ground related pedestrian injuries have received little focus. This paper uses 1221 German pedestrian collision cases occurring between 2000 and 2015 to assess the distribution and risk factors for pedestrian ground related injuries. Results show that for MAIS 2, the ground accounted for 24% of cases, for MAIS 3 the ground accounted for 20% of cases and for MAIS 4–5, the ground accounted for 14% of cases. There were no AIS 6 ground related injuries, though there were several fatal cases where the ground was coded as the most serious injury. The head, thorax and spine dominate AIS 4–5 ground contact injuries. Vehicle impact speeds were higher for ground related AIS 4–5 compared to AIS 2 injury cases and the average impact speed for ground related injuries to the upper and lower extremities was lower than for body regions like head, thorax and spine. There was a significant age effect on pedestrian ground related injury outcome, with older pedestrians suffering more severe injuries and the median age for thorax injuries was higher than for all other body regions. There was no significant difference in the proportions of AIS 2+ head injuries produced by ground contact for more recent vehicles (model year since 2005) compared to older vehicles (model year before 2005). However, logistic regression analysis showed that the normalised bonnet leading-edge height is a risk factor for adult pedestrian AIS2+ ground related head injuries, and this provides empirical support for recent computational modelling predictions which implied a relationship between vehicle shape and pedestrian ground contact injuries. Considering the potential benefits of preventing pedestrian ground contact, for collisions below 40 km/h two thirds of the injury costs would be eliminated if ground contact could be prevented, and even higher benefits are likely at lower speeds (20 and 30 km/h). These data demonstrate the importance of ground related pedestrian injuries and show that vehicle shape influences pedestrian injury outcome in ground contact. The data therefore provides significant motivation for countermeasures to prevent or moderate pedestrian ground related injuries.

1. Introduction

The World Health Organization estimates about 270,000 pedestrian fatalities occur annually following road traffic collisions (Who, 2013). There is now a good understanding of the relationship between vehicle speed, front-end design and pedestrian injury outcome (Simms, 2005; Simms and Wood, 2009; Rosén et al., 2011; Niebuhr et al., 2016; Li et al., 2017a; Li et al., 2017b) and this is reflected in legislative tests and consumer test protocols for pedestrian protection in the European Union. Many modern vehicles have improved front-end designs and some have external airbags and pop-up bonnets for pedestrian protection.

However, although most pedestrians struck by vehicles subsequently impact the ground, there has been much less focus on pedestrian ground contact injuries, and the opportunities for their prevention. Pedestrian ground contact is mostly less severe than vehicle contact (Ashton and Mackay, 1983), but the potential benefit of eliminating pedestrian ground contact injuries remains very high, though technically challenging to achieve. Distinguishing between pedestrian injuries from the vehicle versus the ground generally presents a challenge for collision investigators (Otte and Pohlemann, 2001; Neal-Sturgess et al., 2007) and the distribution and risk factors for pedestrian ground contact injuries remains poorly understood. Otte and Pohlemann (Otte and Pohlemann, 2001) analysed the 1985–1999 German in-depth Accident Study (GIDAS) data and found that 65 percent of pedestrians had injuries from ground contact. However, the severity and

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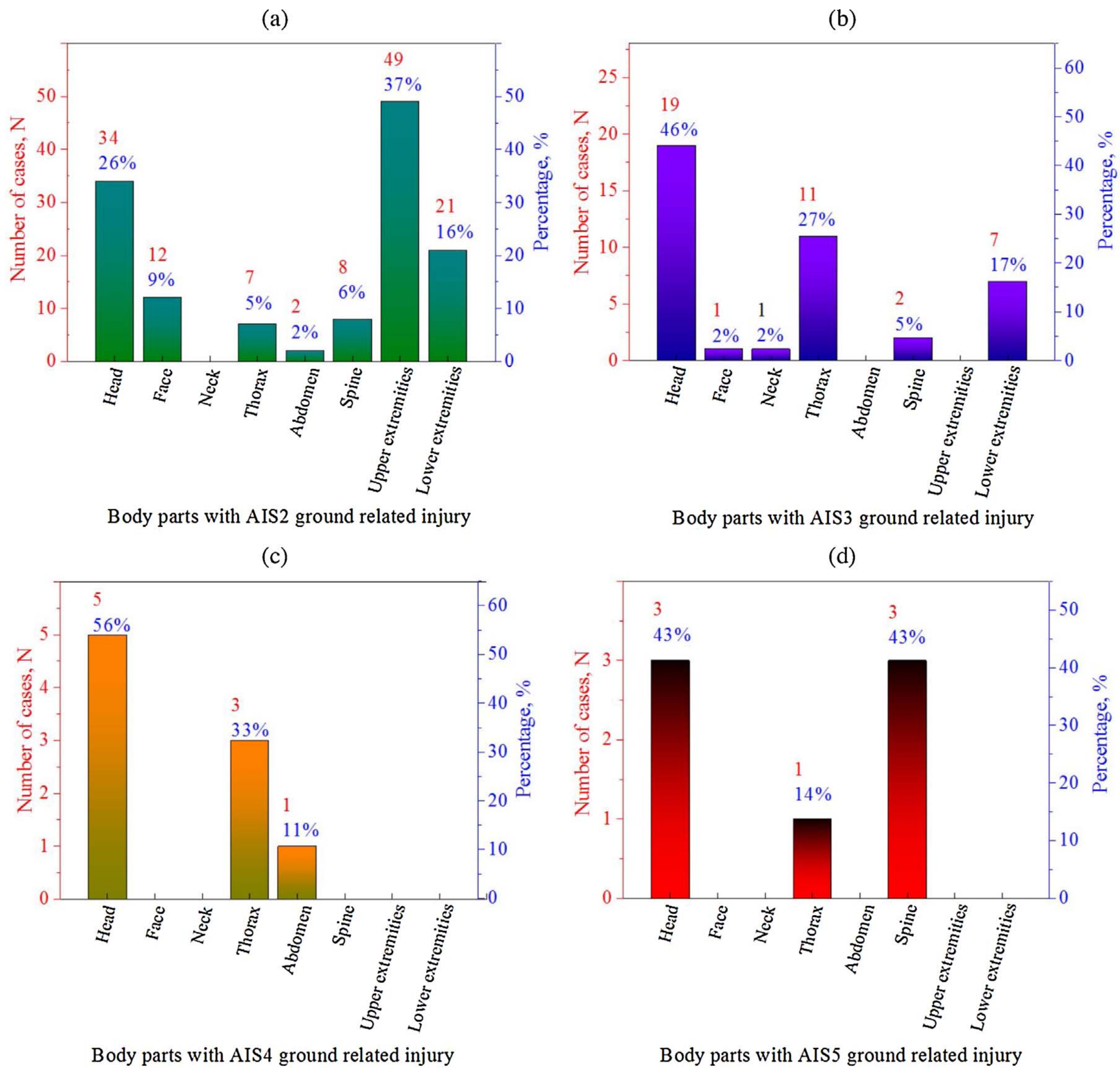

Fig. 1. Number of cases and percentage distribution of body regions injured by pedestrian ground contact for different AIS levels: (a) AIS 2, (b) AIS 3, (c) AIS 4, and (d) AIS 5.

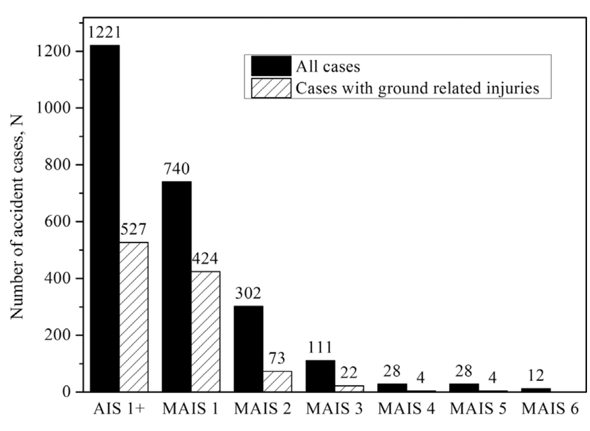

Fig. 2. GIDAS cases with and without ground related injuries. At each MAIS level, the black columns show the total number of cases and striped columns show the number of cases where the highest AIS injury is associated with ground contact.

distribution of injuries were not clearly reported and the front-end shape of the vehicle fleet has since changed significantly. An analysis of the US Pedestrian Crash Data Study (PCDS) found 17% of pedestrian injuries were ground related (Zhang et al., 2008). The PCDS data also showed that head injuries from ground contact were significantly increased following collisions with Light Trucks and Vans (LTVs) compared to passenger cars, and this was attributed to their higher bonnet leading edge heights (Roudsari et al., 2005). A recent analysis of 150 pedestrian collision cases in the UK found almost half the head injuries were ground related, but vehicle contact injuries were more severe (Badea-Romero and Lenard, 2013). Analysis of 100 French pedestrian collisions (Guillaume et al., 2015) indicated that more than half of AIS 2+ injuries were ground related for vehicle speeds below 30 km/h. Overall, the literature provides some detail on pedestrian head injuries from ground contact, but the whole body distribution of ground contact injuries is not reported and risk factors for ground injuries remain poorly understood from collision data.

Computational studies have addressed pedestrian ground contact (Kendall et al., 2006; Tamura and Duma, 2011; Tamura et al., 2014; Crocetta et al., 2015; Yin et al., 2017) and these studies observed a strong influence of the initial crash configuration on the pedestrian ground contact interaction. However, several also identified patterns governing the kinematics of ground contact (Kendall et al., 2006; Tamura and Duma, 2011; Tamura et al., 2014; Crocetta et al., 2015; Yin et al., 2017), determined by the inertial and geometric interaction of the pedestrian and vehicle front and also the collision speed. The bonnet leading-edge height influences ground contact kinematics (Simms et al., 2011; Hamacher et al., 2012; Crocetta et al., 2015; Yin