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Pedestrian injury risk and the effect of age

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ABSTRACT

Older adults and pedestrians both represent especially vulnerable groups in traffic. In the literature, hazards are usually described by the corresponding injury risks of a collision. This paper investigates the MAIS3 + F risk (the risk of sustaining at least one injury of AIS 3 severity or higher, or fatal injury) for pedestrians in full-frontal pedestrian-to-passenger car collisions.

Using some assumptions, a model-based approach to injury risk, allowing for the specification of individual injury risk parameters for individuals, is presented. To balance model accuracy and sample size, the GIDAS (German In-depth Accident Study) data set is divided into three age groups; children (0–14); adults (15–60); and older adults (older than 60). For each group, individual risk curves are computed. Afterwards, the curves are re-aggregated to the overall risk function.

The derived model addresses the influence of age on the outcome of pedestrian-to-car accidents. The results show that older people compared with younger people have a higher MAIS3 + F injury risk at all collision speeds. The injury risk for children behaves surprisingly. Compared to other age groups, their MAIS3 + F injury risk is lower at lower collision speeds, but substantially higher once a threshold has been exceeded. The resulting injury risk curve obtained by re-aggregation looks surprisingly similar to the frequently used logistic regression function computed for the overall injury risk. However, for homogenous subgroups – such as the three age groups – logistic regression describes the typical risk behavior less accurately than the introduced model-based approach.

Since the effect of demographic change on traffic safety is greater nowadays, there is a need to incorporate age into established models. Thus far, this is one of the first studies incorporating traffic participant age to an explicit risk function. The presented approach can be especially useful for the modeling and prediction of risks, and for the evaluation of advanced driver assistance systems.

1. Introduction

In most western countries, there is a pronounced shift toward an older population (ABS, 1999a,b; DESTATIS, 2009). These demographic changes open markets, and influence politics and road user behavior. While older adults are often seen as a special group of traffic participants, there has been little research on the effect of age on injury risk and the consequences of traffic accidents (Demetriades et al., 2004).

Among road users, pedestrians are already a group with a high injury risk. For a given crash severity, i.e. collision speed, pedestrian injury distribution tends to show more severe injuries than for any other traffic participants. Therefore, pedestrians are the most vulnerable group of road users (Stürtz et al., 1976), and people over 60 are even more likely to suffer fatal injuries than younger people (Loo and Tsui, 2009).

This study explores injury risk functions for pedestrians of different age groups. In detail, the risk for children up to age 14 is comparable to the risk for adults (ages 15–59) and for older adults (aged 60 and above). While pedestrian injury risk depends on a multitude of modifying factors, e.g. the front form of the striking vehicle (Ashton, 1978; Han et al., 2012), impact location of the pedestrian on the vehicle (Langwieder et al., 1980), the prime factor in injury/fatality risk is the collision speed of the vehicle (e.g. Walz et al., 1983). Therefore, this study is restricted to only one parameter, collision speed.

The aim of the present paper is the establishment of age group-specific injury risk curves for pedestrians in full-frontal pedestrian-to-passenger-car accidents. The results will extend the

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Table 1
Summary of work file.

	Exposed	MAIS3 + F injured
Children	329	30 (9.1%)
Adults	568	86 (15.1%)
Seniors	297	93 (31.3%)
All	1194	209 (17.5%)

model of Niebuhr et al. (2013). By introduction of the age group, more variability is incorporated into the injury risk model. Therefore, the injury risk for members of an age group is modeled in a more precise and realistic manner. These age group-specific risk functions can be re-aggregated into an overall risk function. The present results show that logistic regression approaches lead to suitable approximations for the overall risk function, but have limitations for subgroups (or individuals).

2. Material and methods

2.1. Data

The pedestrian-to-passenger-car accidents analyzed are part of the German In-Depth Accident Study (GIDAS). The GIDAS teams operate in two areas, namely the Greater Hanover and the Greater Dresden areas. The GIDAS sampling criterion is traffic accidents with at least one injured participant (Otte et al., 2003), which leads to bias toward an over-representation of severe and fatal accidents (Pfeiffer and Schmidt, 2006).

The GIDAS database was queried for frontal car-to-pedestrian accidents for the years 1999–2013, resulting in a number of 1426 cases. Passenger cars and vans with a reconstructed impact speed were included. Pedestrians of known age, and not lying on the ground prior to impact, were included. Accidents not containing injury levels for the pedestrian (90 cases), age of the pedestrian (11 cases) or reconstructed collision speed (160 cases) were removed from the dataset. Some cases are lacking in more than one property. All pedestrians included had at least one injury. The individual injuries were validated against the AIS codebook, and the AIS codes aggregated to the maximum AIS (MAIS) for the ISS body regions as well as for the individual (AAAM, 2005). The pedestrians with at least one documented AIS3+ injury, and all fatalities, were coded as severely injured (MAIS3 + F), $N = 209$. All survivors without an AIS3+ injury were coded as slightly injured, $N = 985$. For some survivors, there were no documented AIS3+ injuries, but the GIDAS assessed MAIS was coded as unknown. These cases were omitted from the analysis to suppress coding errors. The final work file then comprised 1194 pedestrians, of which 209 (17.5%), had at least one AIS3+ or fatal injury. The pedestrians were separated into three age groups: “children,” 0–14 years (Loo and Tsui, 2009; Öman et al., 2015), “adults,” 15–59 years, and “seniors,” 60 years and older (Horberry et al., 2006). See Table 1.

The AIS-98 coded injuries and the separately coded localizer information of each pedestrian were used to generate AIS-2008 codes. This procedure underestimates the number of AIS-2008 injuries but due to the aggregation function used has no crucial influence on the results.

2.2. Injury scaling

In accident research, the use of the Abbreviated Injury Scale (AIS) is quite common. It has been established for many years (States, 1969; States and Huelke, 1980; Petrucelli et al., 1981), and has been updated and improved over time (AAAM, 1998, 2005). Furthermore, the AIS is the basis of the well-accepted Injury Severity Score (ISS) (Baker et al., 1974; Somers, 1983; Osler et al., 1997) and the recently introduced ISSx (Niebuhr et al., 2013). The definitions of both the ISS and the ISSx are shortly reviewed for better understanding. The six ISS body regions are treated as a sorted set, descending from the most severely injured body region; the index i refers to the i-th most severely injured body region. This is in line with the concept of order statistics. Then, the ISS is defined as

$$\text{ISS} := \sum_{i=1}^{3} \text{AIS}_{[i]}^2 \qquad (1)$$

By definition the ISS maxes out at 75. The ordinal AIS-scale is rescaled to an interval scale (Stevens, 1946) using an exponential transformation in order to improve the linear correlation between injury severity and lethality:

$$\text{AISx}_{[i]} := 25 * \frac{(e^{\text{AIS}_{[i]}} - 1)}{(e^5 - 1)} \qquad (2)$$

The scaling factor in Eq. (2) is set to fit the ISS scale from 0 to 75. As for the ISS, the ISSx value maxes out at 75. Furthermore, linear scaling was used to maximize the similarities between the defining equations for ISS and ISSx:

$$\text{ISSx} := \sum_{i=1}^{3} \text{AISx}_{[i]} \qquad (3)$$

The present study focuses on MAIS3 + F injuries. This injury severity corresponds to an ISSx value of about 3. Due to the later introduced tuning parameters a_j there was no need for exact determination of the ISSx value, and the choice of 3 for the ISSx value is suitable, cf. (4).

2.3. Procedure

The theoretical foundation of the present study is the family of pedestrian injury risk functions as established by Niebuhr et al. (2013). This family of risk functions is based on some general assumptions. For the current study, these assumptions have been weakened, and play a pivotal role in all further results. The assumptions are as follows:

(B1). A relative speed of 0 km/h cannot cause injuries, and thus contains no injury risk.
(B2). In equivalent accident scenarios, a higher relative speed is associated with an equal or higher injury risk.
(B3). The probability of a more severe injury is always lower than the risk of a less severe injury.
(B4). For each homogeneous group j there exists a critical speed $v_{crit,j}$, i.e. a technical accident severity, at which all pedestrians of group j are injured for a given injury severity.

In general, the critical speed $v_{crit,j}$ may depend on the injury severity class under scrutiny. The relative speed describes the closing speed of the pedestrian and the passenger car on impact.

Based on these assumptions (B1)–(B4) and in accordance to Niebuhr et al. (2013), the risk function for the group j ($j = 1, \ldots, J$) and a given injury severity, say ISSx, depending on the relative speed v is then modeled by:

$$r_{\text{ISSx}+,j}(v) = \min_{v \geq 0} \left\{ \left(\frac{v}{v_{crit,j}(\text{ISSx})} \right)^{\text{ISSx}/a_j}, 1 \right\}, \qquad (4)$$

where a_j is a real-valued, positive parameter.

As only one injury severity class (MAIS3 + F) is considered in this paper, the possible dependence of $v_{crit,j}$ on the injury severity (ISSx) will not be explicitly stated in all formulae, i.e. the notation $v_{crit,j}$ is used instead of the more precise $v_{crit,j}(\text{ISSx})$.