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Is 30 km/h a 'safe' speed? Injury severity of pedestrians struck by a vehicle and the relation to travel speed and age

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ABSTRACT

This study uses Swedish accident data for the years 2004–2008 to analyze the relationship between injury severity for pedestrians struck by a vehicle and the speed environment at accident locations. It also makes use of a multinomial logit model and other statistical methods. Speed measurements have been performed at accident sites, and the results show that there was a relationship between the (1) mean travel speed and (2) the age of the pedestrian struck and the injury severity and risk of fatality. The data also shows that even though fatal accidents (excluding run-over accidents) are rare in speed environments where the mean travel speed is below 40 km/h and severe injuries are rare below 25 km/h, over 30% of severe injury accidents occur in speed environments below 35 km/h. This indicates that 30 km/h speed limits might not be as safe as previously believed. The current speed policy needs to address this issue. To the author's best knowledge this is the first study that analyzes the relation between mean travel speed and injury severity for pedestrians struck by vehicles.

1. Introduction

When a pedestrian is struck by a motorized vehicle, then there is a considerable risk of injuries. The severity of those injuries and the probability of survival are highly dependent on several factors such as the age of the pedestrian [1–3], the vehicle type [4–6] and the impact speed [7–10]. The impact speed is the most direct way to measure the force of the impact and to obtain a statistically significant relation with the injury severity (see [11] for example). However, since it is hard to use that relation to formulate speed management strategies, speed limits and travel speeds remain more 'relevant'. The aim of this study is to analyze how the injury severity and fatality risk in pedestrian–vehicle accidents are related to the mean travel speed and the age of the pedestrian, and thereby improve the scientific basis for speed policies.

2. Literature review

When a pedestrian is struck by a motorized vehicle there is a complex chain of events. Each impact (with the vehicle and the ground) on the pedestrian's body and the resulting acceleration/deceleration has the potential to cause injuries. The location of the impact and its force are important since different parts of the body can sustain injuries differently and have different thresholds for injuries [12]. This means that the injury outcome is dependent on, for example, (i) the properties of the pedestrian [13,14] (height, direction vis-á-vis the vehicle and initial position) that will affect where the impacts will be, (ii) properties of the vehicle [5,14,15]: the shape of the vehicle will affect where the impacts will be and the stiffness of the vehicle can affect how blunt the impact will be and (iii) the impact speed [12,16] will affect both the chain of events and the bluntness of the impact.

The literature review shows that the risk of severe injuries is higher for Sport Utility Vehicles (SUVs), Light Truck Vehicles (LTVs) and trucks compared to passenger vehicles [4,17–19]. The fatality risk is also higher for LTVs and SUVs compared to passenger vehicles [4–6,18,20]. Three design factors where the SUV and LTV differ from the passenger vehicle affect the mechanisms of the collision: they are stiffer, have higher bumpers and are heavier [5]. Other studies have pointed out that it is not the weight, but rather the front structure that affects the injury severity [21]. Since the weight of any vehicle is so much greater than the weight of a pedestrian, the resulting acceleration for the human body in an impact can hardly make a significant difference.

The impact speed can influence the impacts between the pedestrian and vehicle and between the pedestrian and ground [12]. It is also the most direct variable with which to analyze the size of the forces involved in those impacts. Several studies have shown that the risk of severe injuries [7,10,18,22–24] and the risk of fatality [8–10,25,26] are dependent on the impact speed. Even though the resulting fatality risk values vary among the studies [27,28], they uniformly show that the fatality risk increases rapidly with higher impact speed, and that a

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10 km/h increase in impact speed will result in doubling of the fatality risk at urban speed levels [27].

Those two factors combined (chain of events and the force of impact) affect where on the body the sustained injuries will be and how blunt the impact will be. However, the severity of the resulting injuries will also be influenced by the pedestrian's individual properties and injury threshold. This injury threshold may vary between individuals; for example a light collision or light impact might not cause any injuries to a young pedestrian, while the same impact might cause severe injuries to an older and less physically strong pedestrian. Previous research shows that the risk of severe injuries is higher for seniors compared to younger adults [1,7,17,19]. The prognosis of those injuries is also highly individual and dependent on, among other things, the time to medical treatment and the quality of it [29,30]. This individual difference is often studied according to age, i.e. the survivability is highly related to the age of the victim. Previous studies have found that seniors have a higher risk of fatality compared to younger adults [1–3,19,20]. This difference becomes even higher if the data is weighted with regard to vehicle type, impact speed and other individual factors [1].

This study applies mean travel speed instead of impact speed (which has been applied in earlier studies). Even though this will weaken the relation between the force of the impact and injury severity, it is of interest due to the fact that the travel speed is more practical for design and policy purposes. The relation between those variables requires some discussion. It stands to reason that there should be a relation between the travel speed and the impact speed; therefore it is logical to expect a relation between the travel speed and the severity outcome of an accident. Two studies are identified as analyzing the relation between the travel speed of the vehicle involved in an accident and the injury outcome. Leaf and Preusser [31] analyzed data material from FARS (Fatality Analysis Reporting System) and GES (NHTSAs General Estimates System) and accident data material from Florida, and Pasanen and Rosén [32] analyzed the data material from GIDAS (German Indepth Accident Study). Both studies showed that the fatality risk increased rapidly with higher travel speed of the vehicle involved in the accident. Still, it is problematic that the travel speed of the vehicle is often not known or known with poor precision [31]. Studies often use speed limits as a proxy for the travel speed, and several found a relation between the fatality risk and the speed limit [4,29,31,33]. The literature review has revealed only one study that did not find a relation between the frequency of injuries and the speed limit [34]. This study [34] only referred to fatal accidents, but ascertaining the influence of different speed limits on injury severity requires including non-fatal accidents, otherwise the data material will be biased that can result in biased frequencies of severe injuries and misleading conclusions. It can therefore be concluded that the literature indicates a relation between speed limits and the fatality risk of struck pedestrians. This would also indicate that a relation can be expected between the speed level (expressed as mean travel speed) and the injury severity of an accident. To our knowledge no study has tried to analyze this relationship in terms of pedestrians struck by vehicles. It is certainly important to get a more 'complete' picture of the influence of speed level on injury outcome in order to compensate for the limitations of studies based on speed limits. Compared to the speed limit, the mean travel speed has the advantage that it often differs considerably from the speed limit, for example at intersections.

3. Data

The study is based on two separate datasets that were acquired from the STRADA database (Swedish Traffic Accident Data Acquisition). The aim of STRADA is to collect police and hospital reports for all accidents that occur in Sweden (currently STRADA does not get data from all regions of Sweden). This accident data is not as detailed, though, as in-depth accident databases, and therefore cannot be used to estimate impact or travel speed in accidents.

Dataset 1 includes all injury accidents where a pedestrian was struck by a motorized vehicle (collisions with motorbikes were excluded) in Sweden between 2004 and 2008 and the age of the pedestrian was known. The aim of dataset 1 is to have extensive data material to analyze the interrelation of the age of the struck pedestrian, the vehicle type and the injury severity. Dataset 2 has been created by drawing accident locations at random from dataset 1 within each severity group. Those accidents have had to fulfill the following additional criteria:

(1) The accident had to have occurred in Scania (the most southern part of Sweden, and the one that has the most comprehensive data registered in STRADA).
(2) If the injury was non-fatal, then a hospital report was required to be able to estimate the severity of the injury. Cases with 'no injury' ($ISS = 0$) were excluded from the dataset.
(3) No icy or snowy road conditions or fog at the time of the accident.
(4) The accident had to have occurred between 7 am and 7 pm to minimize the effects of speed differences between day and night.
(5) Accidents where the injury severity was deemed not to be speed related (for example run-over accidents, where the vehicle travels over the pedestrian) were excluded.
(6) If the accident report mentioned that there was a special situation at the time of the accident (for example if the lane was blocked by a parked vehicle) that could be expected to have considerable effects on the travel speed of the vehicle involved in the accident, the accident was excluded.
(7) The accident location and the direction of the vehicle involved in the accident had to be known.
(8) If any considerable change of the traffic environment occurred after the time of the accident, which could have effects on the speed level, the accident was excluded.
(9) For practical reasons, accident locations with very low traffic volumes (for example small residential streets, parking facilities and reversing accidents) were excluded.

An overview of the numbers and proportions of accidents within each severity group is shown in Table 1. Injuries with an Injury Severity Score (ISS) between 1 and 8 are defined as minor injuries and injuries with $ISS \geq 9$ are defined as severe injuries. Dataset 2 is stratified, with overrepresentation of severe injuries and fatal injuries. This needs to be kept in mind when looking at the results.

4. Method

Spot speed measurements were performed on the traffic flow in the same direction of travel as the vehicle that was involved in the accident at all accident locations in dataset 2, i.e. if the vehicle involved in the accident was turning from street A to street B, then only the speed of vehicles in this turning traffic flow was measured. Only the speed of vehicles in free flow was measured (at traffic signals and pedestrian crossings only those who were unaffected by the red amber or pedestrian flow). The lowest number of speed measurements per accident site was 59; in most cases there were more than 100 speed measurements, which should give a reliable estimation of the mean speed at each individual site (Table 2).

A multinomial logit model was applied on dataset 2. Due to the stratification of the dataset, the regression had to be weighted. According to Washington et al. [35], only the interceptor in this case will be affected,

Table 1
Accidents with different severities in the two datasets.

	Dataset 1	Dataset 2
Minor injuries	6474 (79.3%)	31 (39.2%)
Severe injuries	1420 (17.4%)	29 (36.7%)
Fatal injuries	272 (3.3%)	19 (24.1%)
Total	8166	79