An investigation into the effects of European vehicle type testing regulations on cyclist injury occurrence

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I. INTRODUCTION

Most efforts to reduce the aggressiveness of vehicle fronts have focused primarily on impacts with pedestrians (e.g. Regulation (EC) No 78/2009 UN-R 127 and Euro NCAP Pedestrian Testing Protocol). Due to the reported prevalence of impacts involving the front of the vehicle contacting cyclists from the side in serious cyclist injuries and fatalities [1-2] and their apparent similarity to pedestrian impacts, it was assumed that these efforts would also be suitable for cyclist protection. However, there are differences in the impact conditions, including the higher leg positions of cyclists, which generally result in larger wrap around distance (WAD) than for pedestrians, in turn resulting in more rearward head-impact areas, including areas of windscreen, rear windscreen frame, the A-pillars and the roof [3, 9] and a deviation of impact angles and impact speeds [9].

Between the 1970s and the 1990s there was a reduction in the severity of injuries sustained by both cyclists and pedestrians in Germany, which was assumed to be related to improvements in vehicle design [4]. A recent Norwegian study found a decreasing trend for cyclist/pedestrian KSI numbers of 3.3% for every increase of vehicle registration year [5]. It is not clear, however, whether these effects are due to improvements to the front-end geometry or to the use of softer structures. A recent study of German accident data has shown clear effects of vehicle shape on pedestrian injury outcome [6], but the relationship between front-end geometry and cyclist injury outcome determined from collision data remains unclear. Accordingly, this study investigates: (1) the distributions of cyclist injuries as functions of body region, injury source and impact scenario; (2) whether the introduction of pedestrian safety regulations in 2005 in Europe benefited cyclist lower limb and head protection for vehicle-related injuries.

II. METHODS

A total of 5,117 vehicle-to-bicycle collisions were extracted from the German In-Depth Accident Study (GIDAS) data, based on the following inclusion criteria: (1) involving one cyclist and one passenger car; (2) occurred between the years 2005 and 2018; (3) the case resulted in an injury to the cyclist (MAIS>0); (4) the cyclist had only one major collision with the car; and (5) injuries were coded according to AIS 2005 update 2008. An investigation of injury patterns and sources of injuries was performed for the various impact configurations, determined using Vehicle Deformation Index (e.g. 1-front, 2-right side), which reflects the main contact locations for the vehicle and the cyclist. GIDAS data is generally considered to be representative of road traffic collisions in Germany [10].

For collisions involving impact between the front of the vehicle and the side of the cyclist, logistic regression models were used to assess whether car model year has a significant influence on the odds of head AIS3+ injuries and lower limb AIS2+ injuries caused by vehicle contacts. Vehicle impact speed, cyclist age and car model year were included as predictors (see Table I). The logistic model and injury probabilities are:

$$logit(p) = log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 * x_1 \ldots + \beta_i * x_i , \quad (1)$$

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$$p = \frac{exp\,(\beta_0+\beta_1 * x_1 ... + \beta_i * x_i)}{1+exp(\beta_0+\beta_1 * x_1 ... + \beta_i * x_i)}, \quad (2)$$

where p is the probability of an AIS2+/AIS3+ injury, β_i are the estimated coefficients based on the method of maximum likelihood [7], and x_i are the predictors (vehicle impact speed, cyclist age and car model year). Impact speed and cyclist age were used as control parameters because they are likely to have a significant influence on cyclist injury outcome. In the logistic analysis, the car model year was treated as a discrete variable, including two levels, 'Old' (production ceased before 2000) and 'New' (production commenced since 2005), to distinguish the effects of European legislation. The Wald test was employed to determine whether a predictor has a significant influence on the injury probability (p). A p-value lower than 0.05 for a coefficient (β_i) indicates the corresponding predictor has a significant influence.

TABLE I

SAMPLES FOR LOGISTIC REGRESSION ANALYSIS

Sample	Predictor	Injury severity	Inclusion criteria
1	Speed, age, car model year	AIS2+ lower limb injury (with=20, without=129)	Car front impacts bicycle side, at least one AIS1+ lower limb injury caused by car (Old and New) front, age>15 (adults), speed is known.
2		AIS3+ head injury (with=7, without=43)	Car front impacts bicycle side, at least one AIS1+ head injury caused by car (Old and New) front, age>15 (adults), speed is known, cyclist is non-helmeted.

III. INITIAL FINDINGS

The distribution of all impact configurations is shown in Fig. 1. The most common impact scenarios were: vehicle front impacts with bicycle side (F-S: F-RS & F-LS, 2,503 cases, 49%), bicycle front impacts with vehicle side (S-F: RS-F & LS-F, 878 cases, 17%), vehicle side contacts with bicycle side when both moving in the same direction (S-S/SD: RS-LS & LS-RS, 640 cases, 12.5%), and vehicle front impact with bicycle front (F-F, 447 cases, 9%).

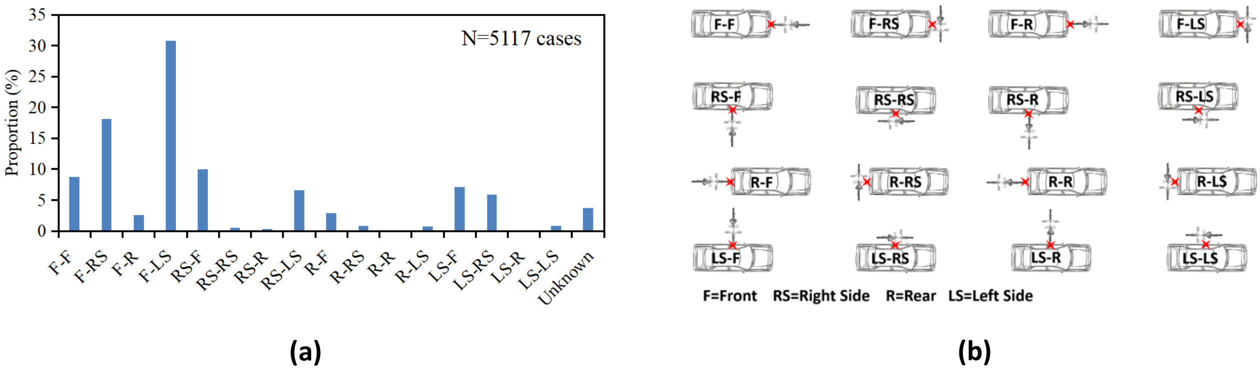


Fig. 1. Distribution of impact configurations among all cyclist collisions.

The injury patterns for cyclists involved in F-F, F-S, S-F and S-S/SD collisions resulting in AIS2+ injuries are shown in Fig. 2. Overall, injuries were most commonly sustained to the head (22%), thorax (11%), arms (25%) and legs (24%).

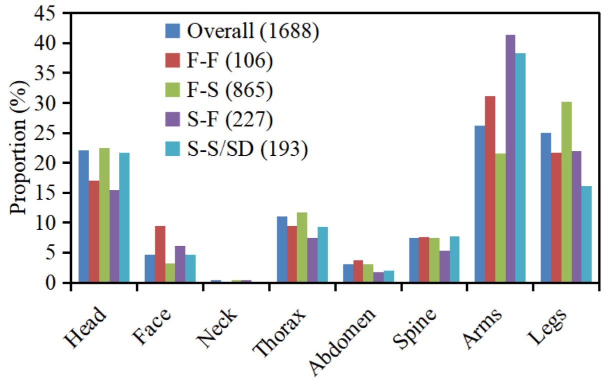


Fig. 2. Cyclist injury patterns for vehicle-to-bicycle collisions involving AIS2+ injuries.

The sources of injury for head, thorax, arm and leg injuries vary between impact scenarios (Fig. 3). In vehicle front-to-bicycle side collisions (F-S): head injuries are primarily a result of ground impact (45%) and windscreen impact (36%); thorax injuries are primarily a result of either bonnet impact (24%) or windscreen impact (18%), though ground impact accounts for about 30% thorax injuries; and lower limb injuries are mostly (47%) from bumper impact followed by ground impact (25%). Impact with the ground is the main source (>45%) for injuries to all body regions in bicycle front-to-vehicle side collisions (S-F) and in vehicle side-to-bicycle side collisions (S-S/SD). For vehicle front-to-bicycle front collisions (F-F): head injuries are mostly from windscreen impact (50%) followed by ground impact (22%) and bonnet impact (17%); thorax injuries are primarily caused by ground impact (40%), followed by bonnet impact (20%) and impact with side structures (20%); and lower limb injuries are mainly from ground impact (43%) and bumper impact (35%).

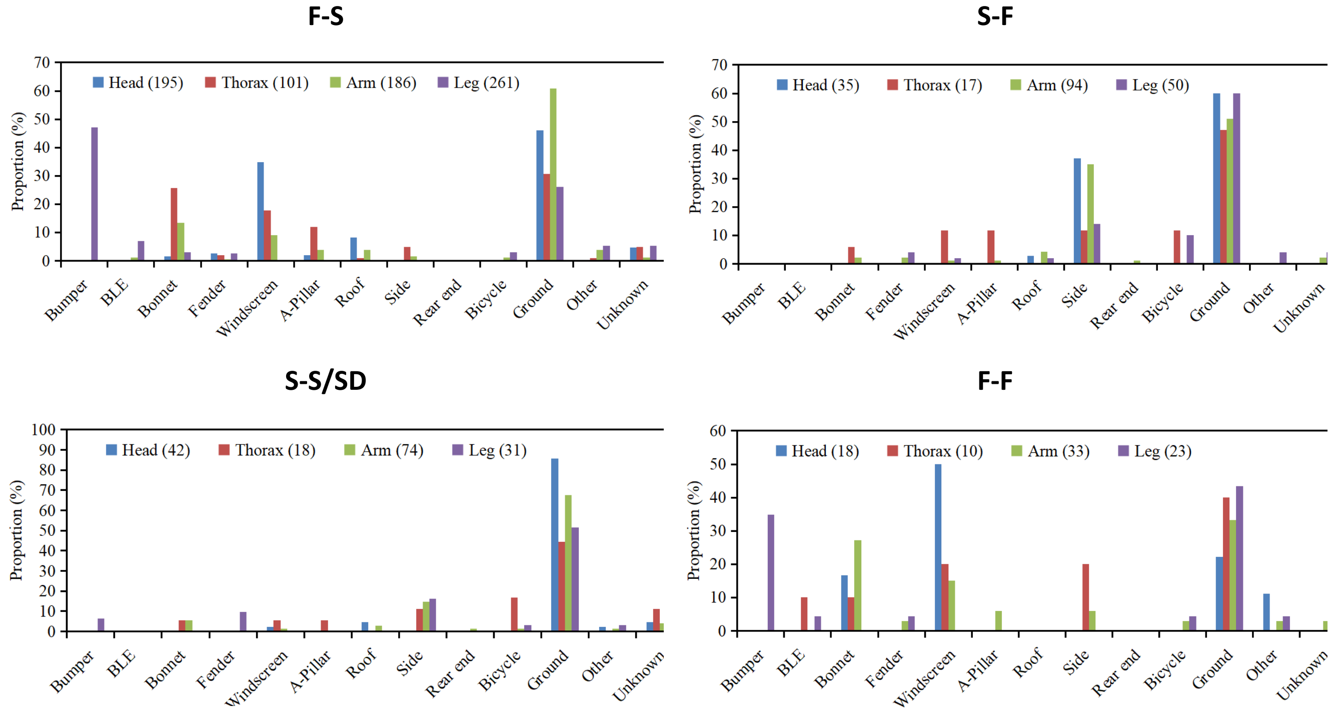


Fig. 3. AIS2+ injury distribution as a function of contact location for the head, thorax, arm and leg in the cases of F-S, S-F, S-S/SD and F-F impact configurations.

Table II shows the logistic regression analysis results for the samples detailed in Table I. All predictors were significant for cyclist lower limb injury odds, but none was significant for head injury risk.

TABLE II

LOGISTIC REGRESSION ANALYSIS RESULTS FOR SAMPLES 1 AND 2

Sample	Injury	Predictor	β	p-value
1	AIS2+ lower limb	Speed	.074	.001
		Age	.041	.005
		Car model year	-.604	.030
2	AIS3+ head	Speed	.027	.413
		Age	.045	.080
		Car model year	-.017	.970

Further analysis was conducted to estimate the difference in cyclist lower limb injury risk between Old and New cars using the logistic regression method (Table III). Table IV shows the logistic regression results for lower limb injury risk for the Old and New car groups. The AIS2+ injury probability for a given car group, impact speed and cyclist age can be estimated based on these data and Eq. (2). Fig. 4 shows the AIS2+ injury risk curves for the Old and New car groups as a function of impact speed for different age categories, where 16<age<65 years is for Adults and age>64 years is for Seniors. The shaded area in Fig. 4 for each car group shows the data for the age range below each graph, where the lower/upper boundary of the area is for the lower/upper boundary of the age range.

TABLE III

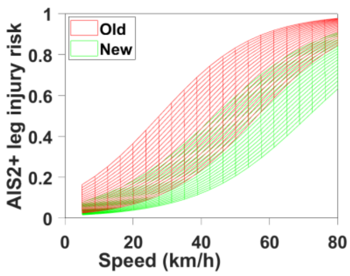
SAMPLE FOR COMPARISON OF CYCLIST LOWER LIMB INJURY RISK BETWEEN THE OLD AND NEW CARS

Body region	Injury severity	Predictor	Sample	
			Old cars (pre-2000)	New cars (post-2005)
Lower Limb	AIS2+	Speed and age	with=12, without=67	with=8, without=82

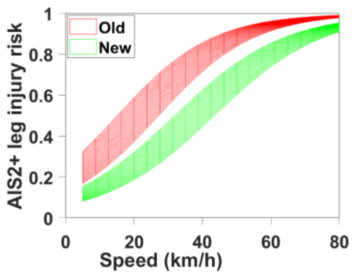
TABLE IV

LOGISTIC REGRESSION ANALYSIS RESULTS FOR OLD AND NEW CARS

Sample	Injury	Predictor	β	p-value
Old cars	AIS2+ lower limb	Speed	.072	.019
		Age	.043	.028
		Constant	-4.745	.000
New cars		Speed	.063	.023
		Age	.036	.036
		Constant	-5.073	.000



(a) Adults (aged 16–64)



(b) Seniors (aged 65–85)

Fig. 4. The estimated average AIS2+ lower limb injury risk as a function of impact speed for different cyclist age levels (year) and car groups (Old and New), the shaded area shows the data for the age range below each graph.

IV. DISCUSSION

The results indicate that impacts between the front of the vehicle and the side of the cyclist comprise only half of cyclist collisions involving passenger cars in GIDAS, which is broadly considered representative of Germany, and that non-traditional impact configurations comprise a large share (51%). In particular, the results highlight the high proportion of collisions involving: (1) impacts between the front of the vehicle and the side of the cyclist; (2) impacts between the front of the cyclist and the side of the vehicle; (3) impacts between the side of the cyclist and the side of the vehicle; and (4) impacts between the front of the cyclist and the front of the vehicle. Furthermore, a significant proportion of the injuries are associated with impact with the ground, particularly for the head and arms, indicating that secondary impacts require injury prevention strategies, a point previously noted by [8]. The up to date standard vulnerable road user test configuration for legislative and NCAP tests (a side-struck pedestrian) accounts for only about half (49%) of the cases observed here. However, current legislative and NCAP tests do not yet focus on cyclist protection. It has been examined and is currently under discussion within Euro NCAP to which extent bicyclists benefit from the pedestrian assessment. Similar discussions are ongoing in terms of implementing acts to the new General Safety Regulation, including possible modifications for the future inclusion of cyclists. The current test and assessment procedures clearly represent a lateral vehicle to pedestrian impact, also underlined by the perpendicular legform impactor test at ground level (+75mm), not covering any bicyclist leg orientations.

Newer cars have a lower incidence of lower limb injury of cyclists than older cars, although the same effect was not observed for head injuries. Furthermore, impact speed which is found to be partially different to the speed observed in pedestrian accidents and cyclist age have been shown to have direct relationships with lower limb injury risk. In our preliminary study, vehicle front-end shape was found to have no significant influence on lower limb injury risk, nor on head or thorax injury risk. However, simulations indicated the dependency of impact parameters from vehicle front geometry. [9] These results indicate that passive safety efforts other than geometric changes, such as softer bumper structures, may have reduced the occurrence of lower limb injuries. The reason for not observing an effect of vehicle shape on cyclist injuries compared to the previously reported influence of vehicle shape on pedestrian lower limb injuries [6] from the same data source (GIDAS) is uncertain, though the higher and seated position of cyclists may be a contributor (sometimes the impact force could be mainly through the bicycle rather than directly on the rider, etc.).

V. References

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