Accident Analysis and Prevention 115 (2018) 128–136

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Time-to-collision analysis of pedestrian and pedal-cycle accidents for the development of autonomous emergency braking systems

James Lenard[b,a,*], Ruth Welsh[a], Russell Danton[c]

[a] Loughborough University, Loughborough, UK
[b] Datarye Ltd, Royal Leamington Spa, UK
[c] GBB, Crown House, Burnley, UK

ARTICLE INFO

Keywords:
Time-to-collision
Pedestrian
Pedal cycle
Autonomous emergency braking
AEB sensors
Pre-impact location

ABSTRACT

The aim of this study was to describe the position of pedestrians and pedal cyclists relative to the striking vehicle in the 3 s before impact. This information is essential for the development of effective autonomous emergency braking systems and relevant test conditions for consumer ratings. The UK RAIDS-OTS study provided 175 pedestrian and 127 pedal-cycle cases based on in-depth, at-scene investigations of a representative sample of accidents in 2000–2010. Pedal cyclists were scattered laterally more widely than pedestrians (90% of cyclists within around ± 80° compared to ± 20° for pedestrians), however their distance from the striking vehicle in the seconds before impact was no greater (90% of cyclists within 42 m at 3 s compared to 50 m for pedestrians). This data is consistent with a greater involvement of slow moving vehicles in cycle accidents. The implication of the results is that AEB systems for cyclists require almost complete 180° side-to-side vision but do not need a longer distance range than for pedestrians.

1. Introduction

According to the World Health Organisation pedestrians and cyclists account for 30% of road traffic fatalities in Europe (WHO, 2015). With the further encouragement for a modal shift towards cycling and walking, the protection of vulnerable road users remains a key road safety objective. To this end, autonomous emergency braking (AEB) systems are under continuous development. These are designed to take action on behalf of the driver when the likelihood of an interaction with a cyclist or pedestrian is detected. It is important that such systems are able to perform adequately in a range of scenarios where conflict occurs between a passenger car and a cyclist or pedestrian.

A number of previous studies used real-world data to describe common accident scenarios for cyclist collisions with passenger cars, however these did not report on the relative positioning of the vehicle and vulnerable road user in the moments before impact (Lindman et al., 2015; Prati et al., 2017; MacAlister and Zuby, 2015). An analysis of German in-depth accident data found that half of all pedestrians were detectable 3 s before the accident but for those considered obscured, the time fell to below 1 s (Leimbach et al., 2013). This study raised the question whether time-to-collision (TTC), vehicle speed or both should be varied in AEB test procedures. A Swedish review of 243 pedestrian accidents in the same German database found that all but one of the 57 serious and fatal casualties were within a field of view of 40° (± 20°) and a range of 20 m (Rosén et al., 2009). In another study analysing approach patterns, it was concluded that the time-to-collision for car-to-bicycle near-miss events was significantly longer than that for car-to-pedestrian events (Matsui et al., 2016).

A recent large-scale naturalistic driving study conducted in Europe gathered information of safety-critical events involving passenger cars and pedal cycles (Jansen et al., 2018). Of 36 incidents flagged by a forward collision warning system, only three were found on review to be genuine near-crashes, each a head-on scenario. Compounding the low sample size, the use of a forward-looking system necessarily precluded the detection of lateral incidents.

The general purpose of the present study was to add to this real-world knowledge base and thereby contribute to the further development of effective AEB systems and relevant test conditions (Hobbs et al., 1995). The circumstances of real accidents are described, in particular the requirement on the sensing system to detect pedestrians and pedal cycles at their distance and angle relative to the striking vehicle in the seconds immediately before impact, including when the driver's line of sight may have been obstructed by intervening vehicles or fixed objects. The specific aim of the paper was to specify the position of pedestrians and pedal cyclists relative to the striking vehicle at 1, 2 and 3 s before impact based on in-depth accident data from Great Britain.

* Corresponding author at: Loughborough University, Loughborough, UK.
E-mail address: j.a.lenard@datarye.com (J. Lenard).

https://doi.org/10.1016/j.aap.2018.02.028
Received 15 November 2017; Received in revised form 1 February 2018; Accepted 28 February 2018

2. Material and methods

The results presented in this paper were based on the On-the-Spot module of the Road Accident In-depth Studies project (RAIDS-OTS) commissioned by the UK Department for Transport and the Highways Agency from 2000 to 2010 (Cuerden et al., 2008; DfT, 2011, 2013). The RAIDS-OTS database contains detailed information from at-scene investigations of a random sample of road traffic accidents reported to the police. The information was collected by two research institutes whose teams operated rotating eight-hour shifts seven days per week in two sample regions, South Nottinghamshire and Thames Valley, and attended the scene of accidents along with the police and emergency services. Each team aimed for 250 accidents per year, ultimately completing 4744 cases. The sample regions were designed to be nationally representative and the On-the-Spot study was the primary source of in-depth information on accident causation used by the Department for Transport to guide national policy-making during this period. Data collection was suspended in 2010 for a period of restructuring and progressively resumed from 2012 to 2016.

The RAIDS-OTS study sampled accidents involving all types of vehicles. The analysis in this paper focussed on collisions between passenger cars and two classes of vulnerable road users: pedestrians and pedal cyclists. The selection criteria for the inclusion of cases were (a) the vulnerable road user was struck by a passenger car, (b) the car was moving forwards at impact, (c) initial contact was to the front or side of the car and (d) the car was not out of control due to a preceding impact. Some cases with inadequate documentation were excluded from the final analysis, e.g. minor incidents where the accident scene was entirely cleared before arrival of the emergency services and research team. This filtering process yielded 175 pedestrians and 127 pedal cyclists from the 4744 accidents on file; of these, 64 pedestrians (37%) and 31 cyclists (25%) were killed or seriously injured (Table 1).

The observations and measurements taken at the scene of the accident by the specialist research teams were supplemented where possible by interviews with involved parties and relevant extracts of police and medical reports. The case files for the selected accidents were reviewed in detail to ensure a consistent methodology with full exploitation of the source material. The paths of the road users involved (passenger cars, pedal cycles and pedestrians) in the seconds before impact were generally well documented. The vehicle speed recorded on the database prior to impact or emergency action (if applicable) was extrapolated backwards in time for up to 3 s using constant-acceleration kinematics, i.e. steady braking, constant speed or steady acceleration, consistent with eye-witness reports and traffic conditions at the time and place of the accident. The location of the vulnerable road user relative to the striking vehicle was recorded in a supplementary dataset using a co-ordinate system based on the longitudinal and lateral axes of the striking vehicle. The methodology was harmonised with previous studies as far as could be ascertained (Schubert et al., 2009; Rosén et al., 2009).

The collection, handling and storage of data in the RAIDS project were subject to strict, high-level ethical and security provisions, exceeding those specified by the UK Data Protection Act 1998, the Cabinet Office's Mandatory Minimum Guidelines and Section 251 of the NHS Act 2006. These were established in liason with security consultants and regularly tested by independent auditors during data collection. In essence only anonymised information was taken from police premises, hospitals and coroners; all information recorded at the site of accident and vehicle examinations was also anonymised during processing of the case and any residual material physically destroyed. These ethical and information governance measures, which have been described in further detail (Cuerden and McCarthy, 2016; Cuerden et al., 2008), protected the right to confidentiality and constituted a precondition to undertaking this type of empirical study.

Table 1
Accident severity level for pedestrians and pedal cycles.

	Pedestrian		Pedal cycle	
	n	%	*n*	%
Fatal	10	6	1	1
Serious	54	31	30	24
Slight	108	62	83	65
No injury	3	2	12	9
Total	175	100	127	100

Table 2
Age–sex grouping of pedestrians and pedal cyclists as proxy for target size.

	Pedestrian		Pedal cycle	
	n	%	*n*	%
0–7 years	23	13	1	1
8–15 years	47	27	39	31
Adult female	41	23	13	10
Adult male	64	37	67	53
Unknown	0	0	7	6
Total	175	100	127	100

3. Results

A grouping by age and sex for the samples of pedestrians and cyclists is shown in Table 2. These age–sex categories were used as a proxy for target size in the lead-up to the introduction of the EuroNCAP AEB pedestrian test (Lenard and Danton, 2010; Lenard et al., 2014). This table suggests that cyclists as a whole present a larger target for vehicle-mounted AEB sensors than pedestrians: a lower proportion of cyclists were in the smallest group, young children 0–7 years old (one cyclist compared to 13% of pedestrians), and a higher proportion were in the largest group, adult males (53% of cyclists compared to 37% of pedestrians).

Most vehicles in pedestrian accidents (87%) were travelling straight ahead rather than turning at an intersection (Table 3). This was determined prior to the introduction by EuroNCAP of straight-line test conditions for pedestrian AEB.

The location of the 175 pedestrians relative to the striking vehicle in the 3 s before impact is shown in Figs. 1–3. Cases in which the driver had a clear view of the pedestrian at that moment of time are distinguished from those in which the driver's line of sight was thought to be obstructed, typically by a vehicle or roadside object. The scale of the *X* and *Y* axes varies in these three figures to accommodate the diminishing range of values for lower times to collision. The number of cases in each cell (10 m by 30°) marked out by the radial guidelines are detailed in Tables 5–7 (Appendix).

In order to provide an overall impression of the paths of individual pedestrians relative to the striking vehicle in the 3 s before impact, Fig. 4 shows the points in Figs. 1–3 joined by lines. It can be seen that most paths lie entirely within 30° (each side) of the longitudinal axis of the striking vehicle. The density of lines is inevitably very high when so many cases are presented in a single figure, particularly close to the origin (point of impact); for this reason an animated version of Fig. 4 is

Table 3
Vehicle manoeuvre in pedestrian accidents.

Vehicle	*n*	%
Straight ahead	152	87
Turning	23	13
Total	175	100