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Modelling how drivers respond to a bicyclist crossing their path at an intersection: How do test track and driving simulator compare?

Christian-Nils Boda[a,*], Marco Dozza[a], Katarina Bohman[b], Prateek Thalya[b], Annika Larsson[b], Nils Lubbe[b]

[a] Chalmers University of Technology, SAFER—Lindholmspiren 3, 417 56, Göteborg, Sweden
[b] Autoliv Research, Wallentinsvägen 22, 447 83, Vårgårda, Sweden

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ABSTRACT

Bicyclist fatalities are a great concern in the European Union. Most of them are due to crashes between motorized vehicles and bicyclists at unsignalised intersections. Different countermeasures are currently being developed and implemented in order to save lives. One type of countermeasure, active safety systems, requires a deep understanding of driver behaviour to be effective without being annoying. The current study provides new knowledge about driver behaviour which can inform assessment programmes for active safety systems such as Euro NCAP.

This study investigated how drivers responded to bicyclists crossing their path at an intersection. The influences of car speed and cyclist speed on the driver response process were assessed for three different crossing configurations. The same experimental protocol was tested in a fixed-base driving simulator and on a test track. A virtual model of the test track was used in the driving simulator to keep the protocol as consistent as possible across testing environments.

Results show that neither car speed nor bicycle speed directly influenced the response process. The crossing configuration did not directly influence the braking response process either, but it did influence the strategy chosen by the drivers to approach the intersection. The point in time when the bicycle became visible (which depended on the car speed, the bicycle speed, and the crossing configuration) and the crossing configuration alone had the largest effects on the driver response process. Dissimilarities between test-track and driving-simulator studies were found; however, there were also interesting similarities, especially in relation to the driver braking behaviour. Drivers followed the same strategy to initiate braking, independent of the test environment. On the other hand, the test environment affected participants' strategies for releasing the gas pedal and regulating deceleration. Finally, a mathematical model, based on both experiments, is proposed to characterize driver braking behaviour in response to bicyclists crossing at intersections. This model has direct implications on what variables an in-vehicle safety system should consider and how tests in evaluation programs should be designed.

1. Introduction

In 2014, 2112 cyclists died in road accidents in the European Union countries. Crashes between vehicles and bicyclists account for the majority of bicyclist fatalities (Schepers et al., 2015), and the majority of these crashes occurred at unsignalised intersections (Schepers et al., 2011), where the driver's response to a bicyclist on a potential collision path is crucial for safety (Prati et al., 2017). Passive safety systems, such as soft bumpers and pop-up hoods, as well as pedestrian airbags, have been developed to reduce injuries sustained by vulnerable road users. Active safety systems (AS), on the other hand, strive to avoid potential crashes. AS first aimed at avoiding vehicle-to-vehicle crashes; then they evolved to detect, and act on, pedestrian hazards. One example is Toyota's Pre-Crash safety system, introduced in 2006 (Hayashi et al., 2013; Tsuchida et al., 2007). New systems are being developed to avoid bicyclists as well, such as Volvo's Pedestrian and Cyclist Detection with Full Auto Brake system which was released in 2013 (Ljung Aust et al., 2015). In line with these developments, Euro NCAP (the European New Car Assessment Programme[1]) has been assessing and promoting passive safety systems for pedestrian protection since 1997 (van Ratingen et al.,

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* Corresponding author.
E-mail address: christian-nils.boda@chalmers.se (C.-N. Boda).

[1] https://www.euroncap.com/.

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2016), and introduced equivalent objectives for active systems in 2016 (Schram et al., 2015). Euro NCAP will begin assessing and promoting AS protecting cyclists in 2018 (Euro NCAP, 2017b).

Following the description by Ljung Aust and his colleagues (Ljung Aust et al., 2015), the activation process of AS has three main phases: 1) detection, 2) decision strategy, and 3) intervention strategy. The detection phase relies mainly on the vehicles' sensors. The decision strategy phase uses the processed data from the first phase to decide if an intervention has to be undertaken by the system. If the decision to intervene is made, the third phase provides the strategy for the system's warning and/or autonomous intervention. All these phases are important for AS' performance. Because the second and third phases depend largely on drivers' behaviour, fine tuning these strategies is complex. The decision strategy has to be a compromise between intervening too early (the system will be seen as a source of nuisance by the drivers) or too late (the system's performance would decrease). The intervention strategy must assess how the intervention can be the most effective and the least frightening for drivers (Lubbe, 2015).

These compromises require a good understanding of drivers' response processes, i.e. the perception and reaction chain that guides driver response to potentially critical situations (Morando et al., 2016). Many studies have striven to provide better knowledge about drivers' response processes in lateral interactions (crossing interactions at intersections) with vulnerable road users. Studies have considered, for example, the influence of pedestrian arrival timing (Várhelyi, 1998), pedestrian speed (Lubbe and Davidsson, 2015), car speed (Lubbe and Rosén, 2014), infrastructure layout (Bella and Silvestri, 2015, 2016), and social interactions (Guéguen et al., 2016, 2015). When it comes to driver-bicyclist lateral interactions, however, only a few studies have been conducted. Räsänen et al. studied drivers' responses to an interaction with a bicyclist under different intersection priority regulations, using interviews and on-road video recordings (Räsänen et al., 1999). Petzoldt and his colleagues ran a test-track study to determine the influence of bicycle type, road gradient, driver age, and car speed on drivers' gap acceptance when passing bicyclists (Petzoldt et al., 2015). Although research has shown that car speed, pedestrian speed, pedestrian arrival time, and visibility are important in driver-pedestrian interactions, the extent to which car speed, bicyclist speed, and bicyclist arrival time influence the driver response process in lateral interactions with cyclists has been insufficiently investigated so far.

Driving simulators, test tracks and real traffic are the three main testing environments for studying driver response processes. While results from real-traffic analyses offer the best representation of naturalistic driving behaviour, their limitations in term of repeatability and data collection may not result in a homogeneous dataset; thus it is hard to study the influence of factors on the drivers' response process. Test tracks and simulators provide more homogeneous data because most of the parameters can be controlled during the experiments. However, test-track experiments may have higher ecological validity than fixed-base simulator experiments because kinematic cues are preserved. Fixed-base simulators are still of great interest because they offer higher repeatability, lower cost, and higher configurability—and they are faster to set up than test tracks. The extent to which experiments in simulators and on test tracks elicit the same driver response process has scarcely been investigated. Today, the decision whether to use a test-track or driving-simulator experiment to address a specific research question is mainly based on expert judgement (and/or available budget)—rather than on the extent to which driver responses on test tracks or in simulators match driver response processes as currently modelled with real-world data.

In this study, the same experimental protocol was executed in a fixed-base driving simulator and a test track. The visual cues presented to the participants were similar between the two setups, but the deceleration cues were missing in the driving simulator. The extent to which deceleration influences the braking response is unknown. However, visual cues have been shown to directly influence driver braking responses (Markkula et al., 2017, 2016). Markkula and colleagues demonstrated that the accumulation of visual cues, the most predominant kinematic stimuli in rear-end conflicts, might be what triggers the driver braking response. By comparing how drivers respond to kinematic stimuli in two environments, one with visual cues only (simulator) and one in which deceleration cues are also available (test track), we can test our hypotheses that 1) the accumulation of visual—but not deceleration—cues triggers the braking response process, and 2) subsequent braking regulation is influenced by both visual and deceleration cues.

This study tested these hypotheses with these objectives: 1) to assess the influence of car speed, bicycle speed, and bicycle arrival time on drivers' response process, 2) to devise a mathematical model to predict the response process of a driver crossing paths with a bicyclist at an intersection, 3) to compare drivers' response process using identical experimental protocols in a simulator and on a test track to help future studies design their experiments, and 4) to provide recommendations for assessment programmes, such as Euro NCAP, on how to design test scenarios that evaluate AS fairly.

2. Methodology

This study represents a rare opportunity, running the same experiment on a test track and in a driving simulator. The driver response process was investigated under different conditions, to create a driver model that could inform the design and evaluation of AS. The simulator experiment (SIM) was carried out at SAFER Göteborg while the test-track experiment (TT) was carried out at Autoliv, Vårgårda.

2.1. Participants

Selection criteria required the study participants to have a valid driver license and be older than 25 years. The demographics data from both experiments are reported in Table 1. Because of motion sickness (only in driving simulator) or inability to follow driving instructions, 10 participants were excluded from the analysis (Table 1).

2.2. Study setup

The drivers (grey car in Fig. 1) drove through an intersection where a bicycle came from their right side. The drivers started driving from 180 m away from the intersection. The drivers drove on the main road with the right of way. A stationary car (blue car in Fig. 1) was placed 30 m away from the intersection on the opposite lane to simulate oncoming traffic.

The TT took place in Carson City (Rosén and Bostrom, 2012), a test track at the Autoliv facilities. The layout of Carson City is based on a real intersection and includes side-scenes resembling real buildings

Table 1
Demographics of the participants in the simulator and test-track experiments.

Experiment	*Recruited participants*	*Participants included in the analysis*	*Age M ± STD*[a]	*% of females*	*Mean driver license ownership*	*Mean mileage/yrs*
Simulator	47	38	40.6 yrs ± 13.1	37%	21.7 yrs	11500 km
Test-track	44	43	41.9 yrs ± 10.8	32.6%	23.4 yrs	18000 km

[a] Mean ± one standard deviation (M ± STD).