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Effects of directional auditory and visual warnings at intersections on reaction times and speed reduction times

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ABSTRACT

Intersection collision warning systems (ICWSs) have an important impact on driving safety because making the potential collision at intersection predictable, allow reducing the probability and severity of accidents. Among the several types of alarms to alert the driver of an imminent collision, those most used concerning the auditory and the visual stimulus. However, it is unclear whether is more effective an audio or a visual warning. In addition, no study compared the effects on drivers' behavior induced by an acoustic and a visual directional warning. The main objective of the present study was to assess, in response to a potential conflict event at the intersections, the effects of directional auditory and visual warnings on driving performance.

A driving simulator experiment was carried out to collect drivers' behavior in response to a vehicle that failed to stop at the intersection. The parameters reaction time and speed reduction time were used for the evaluation of the effects on driving performance. These duration variables were modeled following the survival analysis, by the use of the accelerated failure time duration model with a Weibull distribution.

Results showed that when the directional warning system (auditory or visual) was present, the drivers were able to detect earlier the violator vehicle. This effect led to a more comfortable braking maneuver and, thus, less possibilities of an unexpected maneuver for the following vehicle, avoiding the car – following collisions. The effectiveness of ICWSs was more evident for the directional auditory speech message; for this condition, in fact, the lower reaction time and the longer speed reduction time were obtained.

The outcomes of the present study provide useful suggestions about the most effective collision warning systems that the automotive industry should develop and equip on vehicles.

1. Introduction

The intersections are essential elements of the road network but constitute hazardous locations, because imply opportunities for conflicts among vehicles. Although intersections are a slight part of the road system, they emerge as the road sections where a remarkable portion of the accidents occurs. The 2012 annual statistic report by DaCoTa project (DaCoTa, 2012), which further develops the contents of the European Road Safety Observatory (ERSO), showed that in the 2010, almost 6.800 people were killed in road traffic accidents at intersections in 18 EU member states. In Italy, the last statistic report showed

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that over 42% of all road accidents occurred at intersections (ACI-ISTAT, 2014). All over the world, the statistics show that intersections are hazardous locations. The European database of the road accident CARE (CARE, 2015) reports that the intersection related fatalities are more than 20% in the EU during the last decade (2004–2013). In the United States more than 40% of the crashes occurred at or near an intersection while in Canada more than 30% of the deaths and 40% of serious injuries on the road occurred at intersections (Tay, 2015).

There is agreement to believe that this situation is linked to the fact that driving at intersection is one of the most dynamic and difficult task of drivers (e.g. Werneke & Vollrath, 2013). It requires large cognitive efforts by the driver to perceive and process the amount of information related to the specific intersection configuration (type of intersection, traffic signs), the traffic condition (crossing vehicles, vehicles driving ahead and oncoming) and the maneuver to act (crossing, turn on the left or right). The complexity of this driving task can be often linked to inadequate drivers' behavior and in the occurrence of accidents.

Understanding the main factors that influence the occurring of the intersection accidents and developing systems that encourage proper drivers' behaviors and help drivers in the complex task of drive at the intersections are deemed to be the keys to improve the road safety at intersections. For this reason, a lot of research were and continue to be aimed on the factors contributing to crashes at these hazardous locations (e.g. Tay, 2015) and on the development of effective driving assistance systems such as intersection collision warning systems (ICWS).

The intersection collision warning systems (ICWSs) are in – vehicular warning systems which detect obstacles with sensors in vehicles and devices located at intersection, such as detecting radar, and alert the driver of an imminent collision. These systems have an important impact on driving safety because making the potential collision at intersection predictable, allow reducing the probability and severity of accidents (Atev, Masoud, Janardan, & Papanikolopoulos, 2004; Lee, McGehee, Brown, & Reyes, 2002; Penney, 1999).

Among the several types of alarms (auditory warnings, visual warnings, vibrotactile warnings and haptic warnings), those most used concerning the auditory and the visual stimulus. The first type of alarm consists in audio signals as beep sounds, auditory icons (i.e. car horn, skidding tires) or speech message, that are sent to the driver through a vehicle on board audio system (e.g. Gray, 2011; Haas & Van Erp, 2014; Yan, Liu, & Xu, 2015a). The second type consists in a visual warning signal such as a car symbol, flashing orange warning circle, triangular warning that appears on the vehicle dashboard (e.g. Chen, Cao, & Logan, 2011; Penney, 1999; Scott & Gray, 2008; Werneke & Vollrath, 2013).

Several studies were oriented to the comparison of the effects on driver's behavior at the intersections due to different types of auditory warnings and different types of visual warnings.

Chang, Lin, Fung, Hwang, and Doong (2008) used a driving simulator equipped with collision warning system to analyze the effect of different auditory warning alarm contents on driving performance at intersections. The alarm contents were a beep sound and a speech message automatically generated when a violator's vehicle entered an intersection from left or right. The beep sound was a pure tone while the speech message provided also the information about the direction of the violator. The results indicated that the reaction time was shorter for the speech message alarm. The authors argued that the largest information content of the speech message was extremely important in advising the driver of the direction of a danger and, thus, allow an earlier reaction.

Yan, Zhang, and Ma (2015b) carried out a driving simulator study focused on right–angle collisions caused by red-light running and aimed to analyze the effects of the absence of warning, the speech message with and without the information about the direction of the violator and the delivery time of warning (from 2.5 to 5 s). It was found that the reaction time under directional information warning messages was largely decreased in many scenarios. The authors concluded that if drivers had the information of the direction of the violator vehicle, they need less time to locate the violator vehicle, and hence performed faster reactions.

In a driving simulator experiment (Zhang, Yan, & Yang, 2015) examined the effects of directional and non-directional auditory warnings on driving behavior and crash avoidance performance at signalized intersections. The results showed that drivers benefited from auditory warnings that include the direction of the danger. The reaction time when a directional information warning is given was smaller than that in the case of the non-directional information warning. Moreover, the mean deceleration in the case of a directional information warning was smaller than that in the case of a non-directional information warning, indicating that a directional warning help the driver to take more comfortable and appropriate braking action to avoid the collision.

Werneke and Vollrath (2013) analyzed the effects of three visual warnings (a flashing orange warning circle) that were presented to driver in a simulated head-up display to help to face a critical situation at an unsignalized T-intersection. Two visual signals were showed to the driver in the focus of drivers' view but with different timing (early-middle and late-middle warnings); the third signal was showed in the driver's peripheral vision and was delayed (late-sidewise warning). A clear positive effect (fewer collision and a more proper driver behavior) of the early-middle warning signal was found.

With respect of the comparison of warnings that involve different senses (i.e. the comparison between audio and visual) only few studies were conducted.

Scott and Gray (2008) examined the effectiveness of rear-end collision warnings presented in different sensory modalities (tactile, auditory and visual warnings) as a function of warning timing (3 or 5 s) in a driving simulator. All the three warnings were non-directional warnings. Driver reaction time was captured for analysis. It was found that the reaction times for all warning modalities were significantly shorter than that for no-warning condition. Despite the reaction time for visual warning was higher than that for the auditory warning, the difference was not statistically significant.