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Impact of perceptual treatments on lateral control during driving on crest vertical curves: A driving simulator study

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ABSTRACT

Approximately 48% of all fatal collisions in Europe are classified as single-vehicle run-off-road or head-on collisions. These crashes relate to trajectory control (road departure) and represent a safety challenge. In France, single-vehicle run-off-road crashes represent 21% of all crashes and head-on collisions represent 11%. This study evaluated the effectiveness of four perceptual treatments (i.e., a painted center line, post-delineators, rumble strips on both sides of the center line and sealed shoulders) in supporting the driver to maintain lateral control; that is, to support the driver to keep in the center of his/her lane. Forty-three participants drove a fixed-base driving simulator, on a simulated straight 3 km rural road with two crest vertical curves (CVC). Four sections were chosen for analysis: a reference section (i.e., the first CVC), a test section (i.e., the second CVC), a pre-test section (i.e., immediately before the second CVC) and a post-test section (i.e., immediately after the second CVC). The results showed that drivers drive more at the center of their lane with the rumble strips on both sides of the center line and with the sealed shoulders than with the actual marking (here center line) or other treatments.

1. Introduction

In Europe, more than 80% of all fatal collision crashes occurring on rural roads, out of the urban context, are represented by three accident types: single-vehicle (e.g., run-off-road and head-on collision with culverts and utility poles); head-on collisions; and collisions at intersections. Single-vehicle run-off the road and head-on collisions (which relate to trajectory control), represent 48% of all crash types (OECD, 1999) and inappropriate lateral positioning is one of the primary factors leading to crashes (RISER, 2006). Nevertheless, the topic of trajectory control, and more specifically the "lateral position" dimension and general vehicle path, has received little attention per se. Indeed, in very few studies has lateral position been used as a central variable (e.g., Rasanen, 2005). The majority of studies use lateral position variability as an indicator to evaluate countermeasures concerning workload problems (e.g., Dukic et al., 2006; Reynaud et al., 2002; Rosenbloom, 2006; Sivak et al., 2006).

While human error is estimated to contribute to around 90% of crashes (Dewar and Olson, 2002; Wegman, 2007), road layout has been identified as a contributing factor in about 30% (O'Cinneide, 1998; Rumar, 1985). Furthermore, a Road Federation Belgium report (2002) has shown that 20% of crashes are related to the road layout and 15% to road shoulders. Thus, it is often the situation which is primarily responsible for drivers' failures, not drivers' response to it. These failures could result from misleading perception of the environment induced by the road design. Indeed, studies have highlighted drivers' difficulty in understanding road markings (e.g., Mutabazi et al., 1998; Watts and Quimby, 1980) that can lead to incorrectly perceived situations (e.g., Watts and Quimby, 1980). Furthermore, psychological research on perceptual processes have shown that, for the same road geometry, changes of surroundings influence driver's perception (e.g., Bidulka et al., 2002; Bressan et al., 2003; Smith and Lamm, 1994; Vaniotou, 1990). In short, adequate roadway delineation both supports foremost the driver's immediate needs for continuous lane tracking and provides for the long-range visual needs of the driver (Schieber, 2000). With respect to delineation, McKnight et al. (1998) found that lane lines with low contrast coincide with reduced lane-keeping performance. Furthermore, in a study with a driving simulator, De Waard et al. (2004) have shown that adding painted material to the road surface affected position on the road. While participants drove at a fairly central position on the non-delineated road, adding a center line and dividing the asphalt into two lanes immediately resulted in drivers driving in their lane, and accordingly driving more towards

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the edge of the road. It was found that variability in lateral position was reduced when a center line was added. Thus, the concepts of driver expectancy and geometric consistency appear important in safety and road design, because inconsistencies on a road can surprise drivers and lead to errors that increase crash risk. This is understandable. First, road marking is the most important road characteristic with respect to the recognition of road types that are used in a sustainably safe traffic system and, with respect to the speed at which one is permitted to drive on different types of roads (Davidse et al., 2004). Second, the information provided by the road and road environment is essential for the driver in order to modulate driving control parameters and avoid risky behavior (Saad, 2002; Theeuwes and Godthelp, 1995).

From previous sections, on the one hand, the situations at risk could have a two-fold origin: infrastructure layout and/or the perception of the road environment and the infrastructure. On the other hand, the problems of trajectory control, more specially those of lateral position, appear well as a safety aim. Indeed, trajectory control comprises a lateral dimension (i.e., vehicle position) and a longitudinal dimension (i.e., speed). Since 2000, in France, there has been heavy enforcement of automated speed control. Thanks to this policy, a decrease in vehicle speed of 8 km/h (i.e., shift of 90.7 km/h to 82.4 km/h) was observed in the period 2002–2006. This speed decrease contributed to a 75% reduction in deaths. Nevertheless, this tendency has slowed down since 2005 (Sécurité Routière, 2007). Consequently, the dimension of trajectory control (i.e., vehicle position) appears be interesting to explore, especially given that the road safety consequences of changes in the lateral position of road users (e.g., as a result of altered road markings) are less clear.

Relatively few studies have examined the impact of crest vertical curves (CVC) per se on driver performance. Usually they have examined the impact of CVC on driving performance and/or driver perception on horizontal curves (e.g., Bella, 2006; Bidulka et al., 2002; Hassan and Easa, 2003; Hassan and Sayed, 2002). Crest vertical curves interfere with trajectory control because as they reduce sight distances; they hide the long-range visual information needed to predict the path of the road ahead and to anticipate future events (e.g., Rumar and Marsh, 1998) and to allow better lane keeping (e.g., Summala, 1998). This absence of long-range information is all the more a threat since, during daytime, drivers stare frequently to the far field than to the road edges (e.g., Serafin, 1994). Furthermore, with respect to vertical curves, design policy is based on the need to provide drivers with adequate stopping sight distance (SSD). That is, enough sight distance must exist to permit drivers to detect an unexpected or otherwise difficult-to-perceive information source, recognize the source or, to see an obstacle soon enough to stop for it under some set of reasonable worst-case conditions (Staplin et al., 2001; Texas Department of Transportation, 2006). With respect to steering control on straight roadways, the driver must determine where the car should be directed for straight driving and resolve any discrepancies between the intended and actual path. A two-stage visual process is involved in steering (Donges, 1978; Land and Horwood, 1995; Land and Lee, 1994). The first relates to how drivers look downrange for preview information and the second examines the short range and minute corrections required to stay in the lane. Nevertheless, in the case of CVC, on narrow roads (i.e., 3 m) with the temporary loss of visibility the driver cannot see if a vehicle arises in front – and if the driver, influenced by the roadway environment, tends to drive close to the center line (in reference to Blana and Golias, 2002; Harms, 1993; van Driel et al., 2004), he/she risks colliding with the vehicle on the contra flow lane. Furthermore, the fact that a vehicle arises in front can lead to an over-correction which would result from a surprise effect and lead to a run-off-road incident. Otherwise, run-off-road incidents also result from driving close to shoulders. These over-corrections, if the speed is too high, can lead to a fatal crash (e.g., collision or run-off-road).

The context for the conduct of the present study is the French national multidisciplinary research project PREDIT-SARI. This project aims to inform drivers and road managers more effectively of a heavy control loss risk on the rural network road. More specifically, our study concerns the risk related to the CVC on straight rural roads.

The aim of the present study was to examine the impact of a representative range of perceptual countermeasures (PCM) on lateral control; that is, which could allow the driver to better stay in the center of his/her lane, especially when driving on a CVC on a straight road. The results would provide a better understanding of how drivers deal with potentially useful guidance information that roadside elements (such as center line rumble strips, post-delineators . . .) provide with the acceptability level that is associated with their presence. The background problem was to provide additional visual cues about the road alignment and thus provide guidance information sufficiently in advance of any change in roadway heading, to allow the driver to plan and execute steering and speed control movements as smoothly as is needed for path maintenance.

2. Method

2.1. Participants

Forty-three participants with full French driving licenses (i.e., not learners' or restricted licenses) were recruited. The participants were required to have a driving license for at least 2 years and normal or corrected-to-normal vision. One participant stopped because of sickness discomfort, leaving 16 women and 26 men ranging in age from 22 to 58 years (average age 38.6; S.D. = 10.83). Their average driving experience was 19 years, ranging from 5 to 35 years, and they drove on average 12,373 km per year, ranging from 5000 to 30,000 km. Fifty five percent of participants had more than 15 years of driving experience. Upon their arrival in the laboratory, each participant was briefed on the requirements of the experiment and all read and signed an informed consent document.

2.2. Apparatus

The study was conducted using the INRETS-MSIS SIM^2 driving simulator (Fig. 1), which is an interactive fixed-base driving simulator with a complete Citroën Xantia car which hosts the user interface. The hardware is composed of four networked computers: one processes the motion equations and three generate the images.

Fig. 1. View of the fixed-base INRETS-MSIS SIM^2 driving simulator. © 2007 MSIS INRETS.