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Driver perception hypothesis: Driving simulator study

Francesco Bella *

Roma TRE University, Department of Engineering, via Vito Volterra n. 62, 00146 Rome, Italy

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ABSTRACT

According the driver perception hypothesis, horizontal curves appear sharper or flatter when overlapping with crest or sag vertical curves, respectively. Confirmations of this hypothesis are provided by studies carried out using non-interactive techniques that do not allow the analysis of the driver's reactions to the visual perception of the road.

This study was aimed to add to the body of knowledge concerning driver's speed behavior on combined curves, as well as to test the perception hypothesis based on the speed data collected during tests in the interactive CRISS driving simulator.

Speeds on the tangent-curve transition of crest and sag combinations were compared to those on the tangent-curve transition of horizontal curves with the same radii but on a flat grade (reference curves).

For the crest combinations the results of the statistical analyses were fully consistent with the perception hypothesis. On the sag combinations, on the contrary, the driver's speed behavior did not differ in any statistically significant way from that on the reference curves. Therefore this finding did not support the perception hypothesis on the sag combinations. The effects of the combined curves on the driver's speed behavior did not change in function of the level of the radius. Some implications of these findings have been highlighted.

1. Introduction

The information the road provides to the driver is essential in order to modulate the driving control parameters and avoid risky behavior (Saad, 2002; Theeuwes & Godthelp, 1995). Most of the information required by the driver during the driving task is perceived visually and it is known that a relevant quote of accident occurs in curves. For example about 5000 fatalities each year have resulted from single-vehicle run-off-road crashes on the curve sections of two-lane rural roads in the United States (National Highway Traffic Safety Administration, 2011). Such statistics are deemed to be due to the erroneous perception of the features of the alignment that induces drivers to assume an inadequate behavior compared to the geometric design of the curved section (Cartes, 2002).

Several researches have pointed out that the occurrence of erroneous perception increases as the complexity of the alignment increases and that erroneous perception could be significantly relevant in the conditions of horizontal curves overlapping with sag vertical curves or with crest vertical curves (Bidulka, Sayed, & Hassan, 2002; Mori, Kurihara, Hayama, & Ohkuma, 1995; Smith & Lamm, 1994; Wooldridge, Fitzpatrick, Koppa, & Bauer, 2000). In particular Smith and Lamm hypothesized that an overlapping crest curve may cause the horizontal curve to look sharper while a sag curve may cause

* Tel.: +39 06 57 33 34 16; fax +39 06 57 33 34 41.
E-mail address: francesco.bella@uniroma3.it

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the horizontal curve to look flatter than it actually is (called driver perception hypothesis). Then the driver may adopt a lower or higher speed, respectively, than if the radius were on a flat grade. Therefore the erroneous perception of the horizontal curve may be particularly hazardous for the horizontal curve overlapping with sag vertical curve (called sag combination) where the drivers may perceive a sharp curve as a flat one.

The hypothesis of Smith and Lamm was based on studies carried out in Germany at the beginning of 1970s and on one study on the accident locations (Smith & Lamm, 1994). This study was carried out on three sag combinations and one horizontal curve overlapping with crest vertical curve (called crest combination), and established that the accident rate at the sag vertical curves was higher than the average accident rate over the entire lengths of the observed state routes. It ascertained also that excessive speed was the most frequent cause of accidents. On the crest combination, on the contrary, the accident rate was less than the average accident rate. However it is important to notice that the accidents were few and the authors pointed out that the results were not statistically valid and recommended more studies on the driver's perception.

Later, the perception hypothesis was studied with methods based on the drawing of the perspective of the road and, more recently, it was validated from studies on the visual perception of the road through the use of visualization techniques (Bidulka et al., 2002; Hassan & Sayed, 2002). These studies made use of software to draw perspective views of the road and create short sequences simulating the view of the driver during the driving. Computer animations of horizontal curves overlapping with crest vertical curves or with sag vertical curves (test curves) and of horizontal curves with the same radius but overlapping with flat grade (reference curves) were showed on a computer monitor simultaneously to a sample of subjects. Each subject was asked if the computer animation of the reference curve appeared "same sharp" as, "less sharp" than, or "sharper" than the computer animation of the test curve. The responses of the drivers confirmed the perception hypothesis of Smith and Lamm. With these techniques, models were also set to estimate the horizontal radius perceived on the combined curves as a function of the actual radius (Hassan, Sayed, & Bidulka, 2002). The perceived horizontal radius has been proposed in order to determine operating speeds by means of predicting models that have been obtained from speeds which have been collected on non-combined curves. This implies accepting the hypothesis that to a different perception of the horizontal radius corresponds a different speed adopted by the driver. It must be said that this assumption was not verified by an experiment.

Furthermore it should be noted that visualization techniques are non-interactive and do not allow to evaluate the driver's reaction to its perception of the road scenario. They allow only a qualitative evaluation by subject on the basis of a visual representation of the road scenario.

The driving simulation is deemed to be the most accurate method in order to study the drivers perception (e.g. Bella, 2009; Lamm, Psarianos, & Mailaender, 1999; Zakowska, 1999). Driving simulators offer several advantages such as low costs entailed in carrying out experiments, easy data collection, the utmost safety for test drivers, the possibility of carrying out experiments in controlled conditions. Besides such important benefits, driving simulators are interactive. They allow the test driver to manipulate the pedals and steering wheel of the vehicle during the task of driving and allow the recording of the effects of the road configurations on driver behavior in terms of speeds, trajectory, braking, and the like. Such features are the reason for the growing use of driving simulators for modeling driver visual demand on three-dimensional highway alignments (Easa & Ganguly, 2005; Easa & He, 2006), for testing the effectiveness of road treatments on rural roads with crest vertical curves (Auberlet, Pacaux, Anceaux, Plainchault, & Rosey, 2010; Auberlet et al., 2012; Rosey, Auberlet, Bertrand, & Plainchault, 2008) as well as for evaluating the effect of the interaction between overlapping horizontal and vertical alignments.

Concerning this last topic two interesting studies are in literature. Garcia, Tarko, Dols Ruíz, Moreno Chou, and Calatayud (2011) used a driving simulator to study the effect of vertical crest curves overlapped with horizontal curves on driver's perception and behavior. The results indicated that the operating speeds did not significantly vary across studied curves even where these curves differed by design or type (flat or crest combinations). Therefore the driver perception hypothesis was not confirmed.

Hassan and Sarhan (2012) carried out a driving simulation experiment that was aimed to examine the effect of a driver's misperception of horizontal curvature on the driver's speed behavior. The experiment used the same curves as previous animation experiments (Bidulka et al., 2002; Hassan et al., 2002). The simulation data provided support for the hypothesis that drivers' misperceptions of horizontal curvature affects their choice of speed. More specifically, the authors found that the maximum speed reduction between tangent and curve was consistent with perception hypothesis (the mean maximum speed reduction was higher for crest combinations and was lower for sag combinations). However, the differences between flat horizontal curves and sag combinations were slight, indicating small differences among driver responses.

In both of these studies the combined curves had symmetrical tangential vertical grades. Therefore the approach tangent to the crest combination was always uphill (positive grade) whereas the approach tangent to the sag combination was always downhill (negative grade). Such configurations do not allow to exclude that the results could have been affected by grades of approach tangents.

The driving simulator study reported here was carried out within this context. It was aimed to add to the body of knowledge concerning driver's speed behavior on combined curves, as well as to test the perception hypothesis based on the speed data collected during tests in the driving simulator along several crest combinations, sag combinations and horizontal curves with flat approach tangent.

More specifically, the study set out to test if, on the basis of the speeds adopted by the driver: