GAZE BEHAVIOR DURING SIMULATED DRIVING: ELEMENTS FOR A VISUAL DRIVING AID

Daniel R. Mestre D [1] , Franck Mars F [2], Sylvain Durand S [1], FabriceVienne F [3], Stéphane Espié [3]

1. UMR Mouvement et Perception, CNRS/ Université de la Méditerranée, Marseille, France

2. Institut de Recherche en Communications et Cybernétique de Nantes (IRRCyN), CNRS/Ecole Centrale de Nantes/Université de Nantes/Ecole Nationale Supérieure des Techniques Industrielles et des Mines de Nantes, Nantes, France

3. Modélisations, Simulations et Simulateurs de Conduite, MSIS-CIR, INRETS, Arcueil, France

Summary. Analyses of optic flow due to observer self-motion and analyses of the driver's gazing behavior during curve driving have suggested that the driver has a tendency to look at a location close to the tangent point on the inside edge of the road. Psychophysical experiments have further demonstrated that this visual strategy can be partly explained as an optimization of information pick-up. The main objective of the present study was to investigate, in an interactive simulation context, if this perceptual strategy might be used to define a visual aid for curve driving. In the framework of the French ARCOS project (Research action for secure driving; www.arcos2004.com), we used a mini-simulator developed by INRETS (MSIS-CIR group) in collaboration with FAROS company, with two main original characteristics : 1) during curve driving, the tangent point can be calculated and inserted in the visual scene in real-time and 2) a real-time eye-recording system (EYELINK ® , SMI) allows us to evaluate the relationships between driving performance, gaze direction and the on-line presentation of the tangent point.

.

INTRODUCTION

The basic problem of the elucidation of useful visual information for the control of self-motion remains a serious one, notably in the field of car driving, due to the singularities and complexity of the road environment. In the 50's, Gibson (1958) introduced the concept of optic flow and suggested that our motion through the environment produces a pattern of optic flow that specifies the properties of our displacement.

In this general "feedback" conception of visual information during driving, alternative sources of useful information for the control of self-motion have been suggested, however (see Wann & Land, 2000; Fajen & Warren, 2000, for an overview). Among potential visual cues for the control of self-motion during car driving, Gordon (1966) already noted that " (..) when the moving vehicle is aligned with the highway, each point on the road border and lane marker falls on the angular position previously occupied by another point of the border, and the road assumes a "steady state appearance". Whereas drivers are keen to use optical flow to control their trajectory, they are equally susceptible to use optical stability to steer their vehicle, using edge lines. Driving corresponds in this case to a tracking task, the problem being to maintain visual stability of edge lines. Riemersma (1981) demonstrated that, during simulated road driving, edge line motion was an effective visual cue for the control of heading and lateral control. One interesting consequence of this is that, under nighttime conditions, delineation systems appear to be a privileged visual cue for facilitating driving on straight and curved roads. It is clear that, beside the global optic flow pattern, singularities in the road environment structure play a role in the perception and control of a car's trajectory.

Following this line of reasoning, Land and Lee (1994) introduced new methodological tools, by recording gaze behavior during car driving. They demonstrated that, in curve driving, the eyes tend to fixate the inside edge of the road near a point known as the "tangent" or "reversal" point of the road, which is a singular point where the inside of the curve changes direction (Figure 1). This suggests that subjects pick up useful information for the control of self-motion around this point. In recent psychophysical experiments (Mestre, 2001; Mestre & Durand, 2001), we evaluated the ability of human observers to discriminate variations in their direction of self-motion during simulated curvilinear trajectories, as a function of the part of the global optical flow field they were looking at. Results clearly show that discrimination thresholds were minimal when subjects looked directly at the tangent point. As the horizontal angle of gaze departed from the tangent point, thresholds increased notably. These results confirm the idea that, in tasks such as curve driving, the tangent point of the curve acts as a singularity in the visual field, enabling optimal control of self-motion.

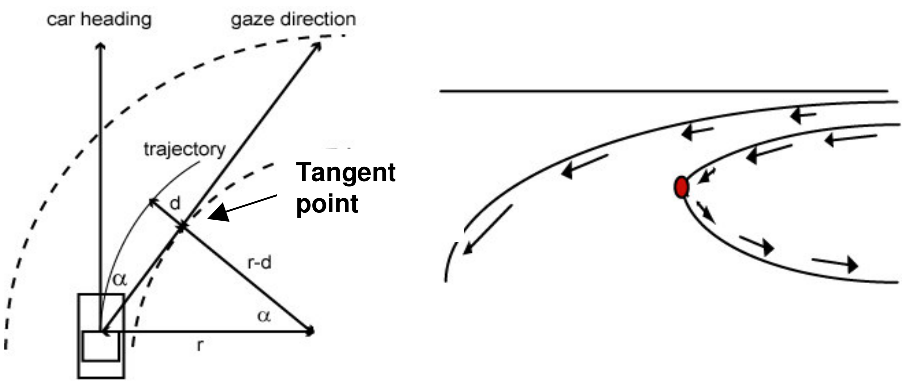

Figure 1. In a curve of radius r, the tangent point is the intersection point between the tangent to the inside edge line of the road (passing though the subject's point of view) and this edge line. On the right, a perspective view of the curve shows that the tangent point (red dot) is visually motionless when the observer's trajectory follows the road geometry (adapted from Land, 1998).

EXPERIMENTAL STUDY

In the present study, we aimed at searching whether the tangent could be used to define a visual aid for curve driving. In order to do so, we defined a simulation paradigm. We used a simulation facility, developed by INRETS (MSIS-CIR unit, Arcueil, France). During interactive simulations of car driving along a sinuous road, we investigated the role on performance of the figuration of the tangent point, while recording gaze behavior.

Methods

Subjects. Seven undergraduates, aged between 25 and 32 years, participated in the experiment. They all had normal vision (for correct eye recording). They all were active drivers, for at least five years. Before the experiment, they signed an informed consent form.

Driving simulator. We used the driving simulator developed by INRETS in collaboration with FAROS company (figure 2, left). It enables full control of driving scenarios, real-time interactive driving, visual and auditory feedback, and on-line recording of simulated trajectories, for off-line analyses (Espié et al., 2003). The visualization part of the simulation software was upgraded, in order to allow real-time computation of the tangent point during curve driving, and presentation of this tangent point in the visual environment during simulated driving (figure 2, right). The angular position of this point was calculated from the driver's viewpoint.

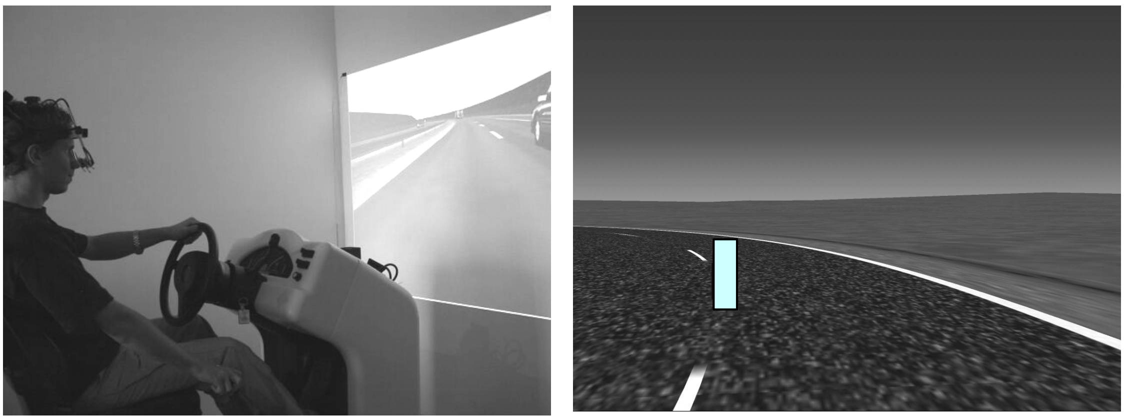

Figure 2. Left: Experimental set-up showing the simulator in front of a wide-angle visual scene representing the road environment. Right: Snapshot of the visual road environment. The tangent point (white vertical post) is situated on the dotted center line during a curve to the left. Its position in the visual scene is dependant upon the instantaneous driver's position and the road geometry

Gaze recording. Gaze direction was measured on-line during the simulated driving task (figure 2), using a video-oculographic system "Eyelink" (Sensomotoric Instruments GmbH). Using this system, gaze direction is directly available, with reference to a calibrated visual scene. The

Eyelink system has thus the great advantage of allowing the subject to have his/her head free of motion, while gaze is monitered.

Experimental procedure. In a first step, subjects were trained on the simulator, during three trials on a road, with radii of different curvature, to the left and to the right, separated by portions of straight lines. This initial step was meant to let the subjects get used to this particular simulator and to sharp curve driving. They were instructed to drive at sustained speed without leaving the right lane (3.5 meters wide). Subjects were selected for the actual experimental sessions, provided they could drive this road in "reasonable" time (as compared to a baseline defined by the experimenters), without running off the road.

The experiment itself consisted of three sessions, each lasting for about 30 minutes. The road environment consisted in a randomly ordered succession of curves of various radii (50, 100, 200, 500 meters), with each radius appearing in each direction (right and left), giving a total of 8 curves separated by portions of a straight line. In each session, three runs were conducted. Gaze direction was always recorded. In the first session, the tangent point was not represented. This enabled us to evaluate driving performance and gaze behavior in initial (no tangent point) conditions. In the second session, the tangent point was represented (figure 3). In the last (third) session, it was no longer presented. This manipulation aimed at separating potential effects (both on performance and gaze behavior) of the representation of the tangent point from strict learning effects. The road edge lines were continuous, while the center line was discontinuous (figure 3).

Data Analysis

Data were analysed for each curve in the experimental runway. Driving performance was characterized by the standard deviation of the lateral position of the simulated vehicle, with respect to the road centerline. This is a simple way to characterize the "stability" of a trajectory. Gaze behavior, during each curve, was measured as the average angular distance between gaze direction and angular position of the tangent point in the visual scene. .

RESULTS

Driving performance

Subjects were required (and managed) to stay in the right lane of the road, being 3.5 meters wide. On average, the standard deviation (SD) of the lateral position (across sessions and subjects) is equal to 0.29 meters (± 0.2), meaning that the overall driving performance was quite satisfactory (the subjects managing to always stay in the right lane).

A repeated-measure analysis of the variance (ANOVA) reveals a main significant effect of the curve direction (left or right). SD of lateral position is equal to 0.32 (+/- 0.12) meters for curve to the left and to 0.27 (+/- 0.12) meters for curves to the right. This first result suggests that left curves are harder to drive that right curves. It might be due to the fact that, on right curves, subjects visually rely on a continuous edge line, while, on left curves, they are using a "dotted" line (figure3), which might hamper the monitoring of its visual motion and/or the extraction of the tangent point visual motion. However, it seems also plausible that drivers have a tendency to "cut" curves, and that imposing them to stay in the right lane in left curves might have induced lateral performance degradation. Nevertheless, there is a significant interaction effect between the curve direction effect and the "session" factor (figure 4).

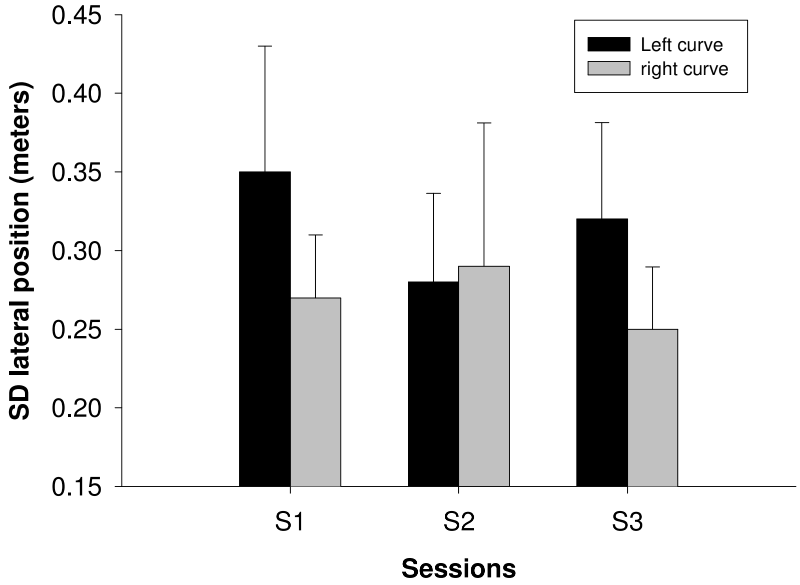

Figure 4. Average values of the SD of lateral position as a function of session, for left (black) and right (gray) curves.

A figure 4 show that lateral position variability is reduced when the tangent point is superimposed on the visual scene (S2), only in the case of left curves, for which initial performance is worse (S1). Such effect cannot be a simple "learning" effect, since lateral position variance for left curves increases in session 3, as compared to session 2, as the tangent point is no longer present (S3). No significant variation is observed for right curves. This might be related to a floor effect.

Gaze behavior

The main result here is that the average distance (across subjects and conditions) between gaze direction and tangent point is equal to about 4 degrees, and in all cases inferior to 8 degrees (see figure 5). This simple result confirms Land & Lee (1994) data, in showing that in our conditions subjects also have a "natural" tendency to locate their gaze near the tangent point, during curve driving.

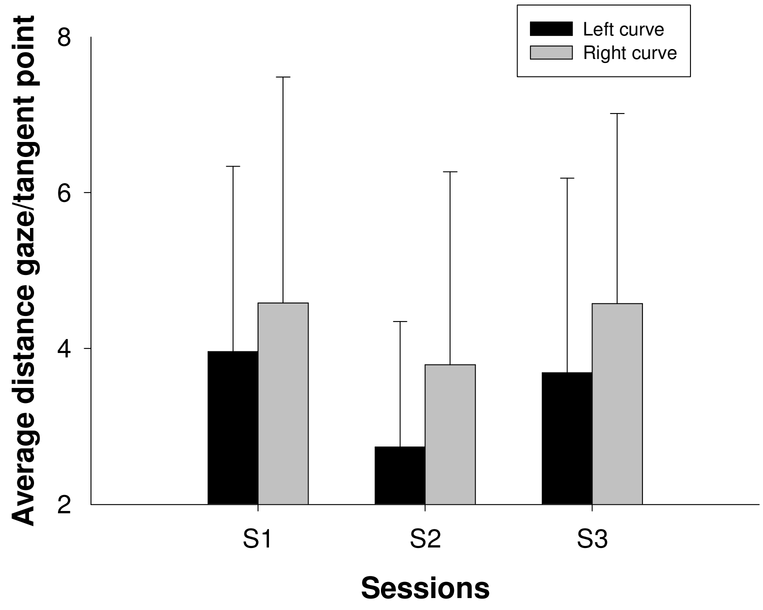

Figure 5. Average values of the average angular distance between gaze direction and tangent point, for the 3 sessions (S1 to S3), for left (black) and right (gray) curves.

Figure 5 shows a decrease in the distance "gaze-tangent point" between Session 1 and Session 2 (when tangent point is visible), both for left and right curves. This index increases again between Session 2 and 3, when the tangent point is no longer present. This result is in line with what was observed concerning lateral position control. It further adds support to the suggestion that no learning affect may explain the pattern of results.

CONCLUSIONS

This paper further demonstrates the feasibility and interests of coupling eye movements recording systems to a driving simulator. Results confirm that, during curve driving, the tangent point to the inside of a curve "attracts" gaze and is a useful informational location for the driver. They also suggest that its "on-line" figuration during curve driving might constitute an actual driving aid. This seems to be especially true for difficult situations, such as sharp curves in degraded visual conditions. This opens possibilities using head-up displays, for instance.

However, further analyses are required to determine when it is beneficial to present the tangent point. It might be interesting to link the presentation of the tangent point to a deterioration of the trajectory. On a more fundamental level, a closer analysis of spatio-temporal aspects of the coupling between the direction of gaze and the location of the tangent point during a curve is also required. In this study, the analysis "unit" was the whole curve, and we presented only data concerning the average angular distance between gaze direction and the instantaneous location of the tangent point in the road scene. We already know from studies on car driving (i.e. Land & Tatler, 2001), that anticipatory behaviors are involved. For instance, gaze deviates toward the curve apex before the actual turn. In this study, we defined a curve from a geometrical point if view. It obviously has to be defined in a more functional point of view, taking into account the driver's anticipatory motor and oculomotor behavior, both at the beginning and end of a curve.

ACKNOWLEDGMENTS

This study was supported by PREDIT (ARCOS project), CNRS and the University of the Mediterranean.

REFERENCES

Espié S., Mohellebi H., Kheddar A. (2003) - A high performance / low-cost mini driving simulator alternative for human factor studies - in proceedings of HYPERLINK "http://www.dsc-na.org/"DSC 2003 North America - Dearborn (USA), October 8-10, 2003 ISSN 1546-5071.

Fajen, B.R. & Warren, W.H. (2000). Go with the flow. *Trends in Cognitive Sciences, 10*, 319-324. 369-370.

Gibson, J.J. (1958). Visually controlled locomotion and visual orientation in animals. *British Journal of Psychology, 49*, 182-194.

Gordon, D.A. (1966). Perceptual mechanisms in vehicular guidance. *Public Roads, 34*, 53-68.

Land, M. and Lee, D.N. (1995). Which parts of the road guide steering? *Nature, 377*, 339-340.

Land, M. (1998). The visual control of steering. In L.R. Harris & M. Jenkin (Eds.), *Vision and Action*. Cambridge University Press. pp 163-180.

Land, M. and Tatler, B. (2001). Steering with the head: The visual strategy of a racing driver. *Current Biology*, 11:1215–1220

Mestre, DR., Durand, S. (2001). Flow matters. Arvo Annual meeting, Fort Lauderdale, Florida, 29 April-4 May 2001. *Investigative Ophthalmology and Visual Sciences, 42,* 4977.

Mestre, DR (2001). Dynamic evaluation of the useful field of view in driving. Human Factors in Driver Assessment, Training and Vehicle Design, Snowmass Village at Aspen, Colorado USA, August 14- 17, 2001. *Proceedings of Driving Assessment 2001*, University of Iowa, pp 234-239.

Riemersma, J.B.J. (1981). Visual control during straight road driving. *Acta Psychologica, 48,* 215-225.

Wann, J. & Land, M. (2000). Steering with or without the flow. Is the retrieval of heading necessary? *Trends in Cognitive Sciences, 8*, 319-324.