Steering and gaze control modifications from directed or spontaneous use of a visual augmentation cue

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In the perspective of full-windshield HUD in cars, this study investigated whether adding a guidance cue in the visual scene influences drivers' gaze strategies and steering behavior. Participants negotiated a series of bends with or without a visual beacon positioned on the tangent point or close to it. Results revealed that the stability of steering was improved when tracking of the beacon was enforced. The visual cue was not spontaneously used by the drivers and gaze strategy only showed minor changes in that case.

INTRODUCTION

The next generation of head-up displays in cars will most probably allow for wide field of view driving assistance (Charissis & Papanastasiou 2006, Ward et al. 2004). The problem will be to specify the nature of the visual cues that should be superimposed in order to help various aspects of the driving task without yielding information overload or disturbing the normal distribution of attention. This paper investigates how displaying a visual target moving down the road may influence the control of steering and the positioning of gaze.

The visual control of steering has been described as two parallel processes, each fed by different visual signals (Donges 1978, Land & Horwood 1995, Salvucci & Gray 2004). The first level relies on close visual information (a few meters ahead of the vehicle) and contributes essentially to the fast correction of lateral position errors. The second level is fed by more distant visual information and is responsible for anticipating the changes in road curvature, to ensure smooth steering. Land and Lee (1994) isolated a particular feature of the driving scene that may be used to preview oncoming road curvature. Indeed, when approaching and negotiating a bend, the driver spends a significant amount of time looking in the vicinity of the tangent point (TP), i.e. the point where the direction of the inside edge line seems to reverse from the driver's viewpoint. Due to the geometrical relation between the direction of the TP and the curvature of the road, looking in the direction of the tangent point may be the best way of "reading" the curvature of the road at the sensorimotor level. This could provide an input signal to the motor system in charge of steering control.

Mars (2008) investigated the link between drivers' gaze positioning and steering behavior in an experiment where drivers were required to continuously look at a fixation point positioned in the vicinity of the TP. The orientation of gaze relative to the TP was manipulated and the resulting steering behavior was compared to that obtained with a free-gaze strategy. The data revealed that restricting eye movements to the vicinity of the tangent point did not impair steering behavior. On the contrary, the continuous tracking of the fixation point promoted smoother steering control. The effect was observed when the point of gaze was directed to the TP proper, but also when the fixation point shifted to the right or to the left. This suggests that enhancing the TP or any point with the same dynamics in the visual scene may be considered as a way to improve eye-steering coordination and, as a consequence, facilitate the control of the vehicle.

The question remains to be determined whether drivers will spontaneously use such a visual enhancement when ocular fixation is not imposed by instruction. More importantly, adding such a salient cue in the visual scene may considerably modify the natural distribution of gaze while driving. Cognitive capture effects have already been associated with the use of HUD, although these were probably due to the processing of symbolic information (Liu 2003). Here, the visual target has no symbolic content, but its motion in the visual scene may impact on the distribution of spatial attention. To answer these questions, the present experiment replicated some aspects of the study carried out by Mars (2008), with additional manipulation of the instruction given to the participants. In one condition, the drivers were strongly required to look at the fixation point. In two other conditions, they were free to look where they wished, with or without the moving beacon added to the scene.

METHODS

Participants

Four female and 9 male drivers, between 20 and 23 years of age, all students at the University of Nantes, participated in the experiment. They had been licensed drivers for a minimum of 2 years and drove 5708 km a year, on average. In order to obtain a good calibration of the gaze-tracker, only subjects with normal vision or wearing contact lenses for myopia correction could participate in the experiment. Astigmatic subjects and subjects wearing glasses were not eligible to participate.

Apparatus

The experiment was conducted using the fixed-base SIM2 simulator developed by the MSIS laboratory (Espié et al. 2003), which included an adjustable seat, a steering wheel with force feedback, a gear lever, clutch, accelerator and brake pedals, and a speedometer.
The visual environment was retroprojected onto a large translucent screen, viewed from a distance of about 2 m. The visual angle of the stimulus was about 62x51 degrees. The graphic database reproduced a real test track, situated in Satory (France), represented in Fig. 1. The track was 3.4 km long. It consisted of 4 straight lines and 14 bends, 10 turning to the left and 4 turning to the right (total distance = 1940 m; mean radius = 221.1 m). The driving lane was 3.3 m wide and delineated with a broken centre line and a continuous edge line.

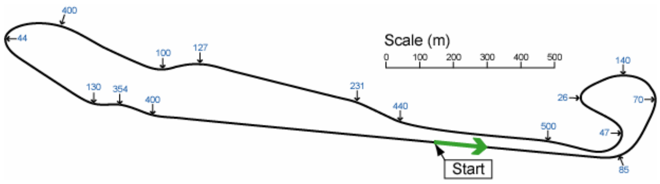

Fig. 1: Layout of the Satory test track (Versailles, France). Subjects drove a simulated version of the track in the direction indicated by the green arrow. The blue numbers indicate the radii of curvature of all bends.

The driver's gaze was monitored throughout the experiment by means of the IviewX head-mounted gaze tracker (Sensomotoric Instruments), sampling eye movements at 50 Hz. The gaze-tracker was coupled with a head-tracking device in order to compensate for head movements and compute gaze position in the reference frame of the screen. Using a 9 points calibration procedure, gaze position accuracy was between 0.5° and 1°.

Procedure

After a training session, all participants performed 12 trials, in which they drove once round the whole track in three different conditions:
- *Strong instruction*: A beacon in the form of a small blue bar (Fig. 2) was displayed and drivers were asked to continuously track its motion.
- *Weak instruction*: The beacon was displayed and participants were encouraged to look at it if they thought it was appropriate and/or comfortable, but it was in no way an obligation.
- *No target (control condition)*: No beacon was added to the visual scene. Participants were instructed to sample the visual scene as they wished.
Each condition (instruction x beacon position) was repeated twice. The order of presentation of the two blocks and the order of presentation of the conditions was counterbalanced across participants.
The lateral position, steering angle and speed of the vehicle, as well as the position of the beacon on the screen (or the position of the TP/LC in the control conditions) were recorded throughout the trials at 50 Hz. The position of gaze was recorded separately. Both records were synchronized.

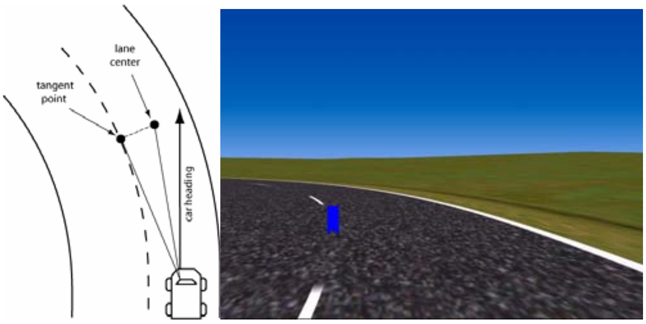

Fig. 2: Left: Positions of the fixation points. Right: Video frame showing the fixation point positioned on the TP while negotiating a left bend.

RESULTS

The track was divided into 18 sections (14 bends and 4 straight lines). Data obtained in straight lines were discarded.

Steering control

The stability of steering control was evaluated by computing the standard deviation of lateral position and the mean number of steering reversals (i.e. the number of times the steering wheel rotation changed direction), averaged across all bends and all participants (Fig. 3). An ANOVA performed on the standard deviation of lateral position showed a significant effect of instruction ($F(2;24) = 6.46$; $p<.01$), no effect of the beacon position ($F(1;12) = 1.90$; *ns*) and no interaction between both variables ($F(2;24) = 1.77$; *ns*). Tukey's tests revealed that the effect of instruction was due to a smaller variability of the lateral position in the *strong instruction* condition, compared to the other conditions, whatever the position of the beacon. The *weak instruction* condition did not differ from the *control* condition. A slightly different pattern of results was observed for steering reversals. The ANOVA showed a significant effect of instruction ($F(2;24) = 4.51$; $p<.05$), no effect of the beacon position ($F(1;12) = 1.90$; *ns*) and a significant interaction between both variables ($F(2;24) = 4.15$; *ns*). Post-hoc tests revealed that the reduction of the number of steering reversals in the *strong instruction* condition was only significant when the fixation point was positioned on the TP.

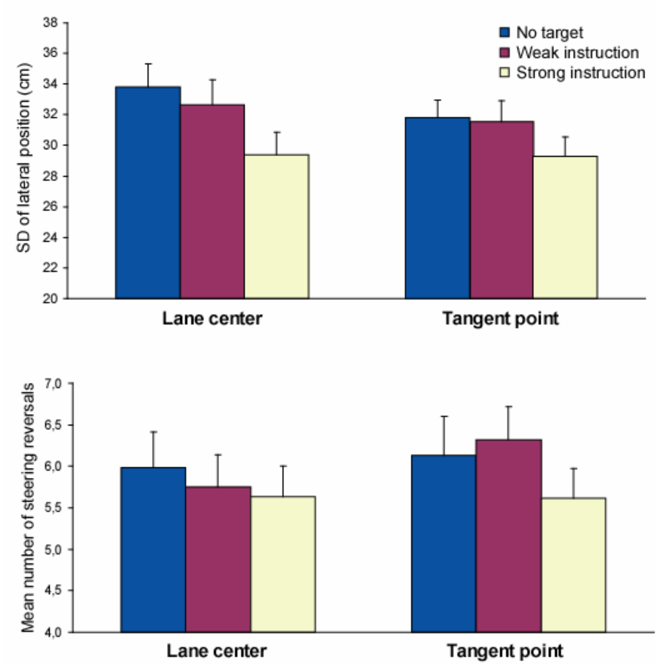

Figure 3: Mean standard deviation of lateral position (top) and mean number of steering reversals per bend (bottom) in the control, weak instruction and strong instruction conditions. Error bars represent S.E.M.

Direction of gaze

Due to technical difficulties, the analyses of gaze data were performed on 12 subjects only. Figure 4 represents averaged gaze positioning relative to the TP or the LC, depending on conditions. In other words, the position of gaze was computed in a dynamic coordinate system, with the origin corresponding to one point or the other. Since the data were not computed the same way in both cases, separate analyses were performed on the two sets of data.

The percentage of time spent looking at the area of interest was computed as the total time when gaze was positioned within 3° of the TP or the LC divided by the total time spent negotiating bends (Fig 4, top graph). For LC, the analyses show a significant effect of instruction ($F(2;22) = 312.8$; $p<.001$). Tukey's tests revealed that all conditions differed one from another. For TP, the effect of instruction was also significant ($F(2;22) = 67.6$; $p<.001$). Post-hoc tests revealed that the *strong instruction* condition differed from the others, but the *weak instruction* condition failed to significantly differ from the *control* condition (p=0.12).

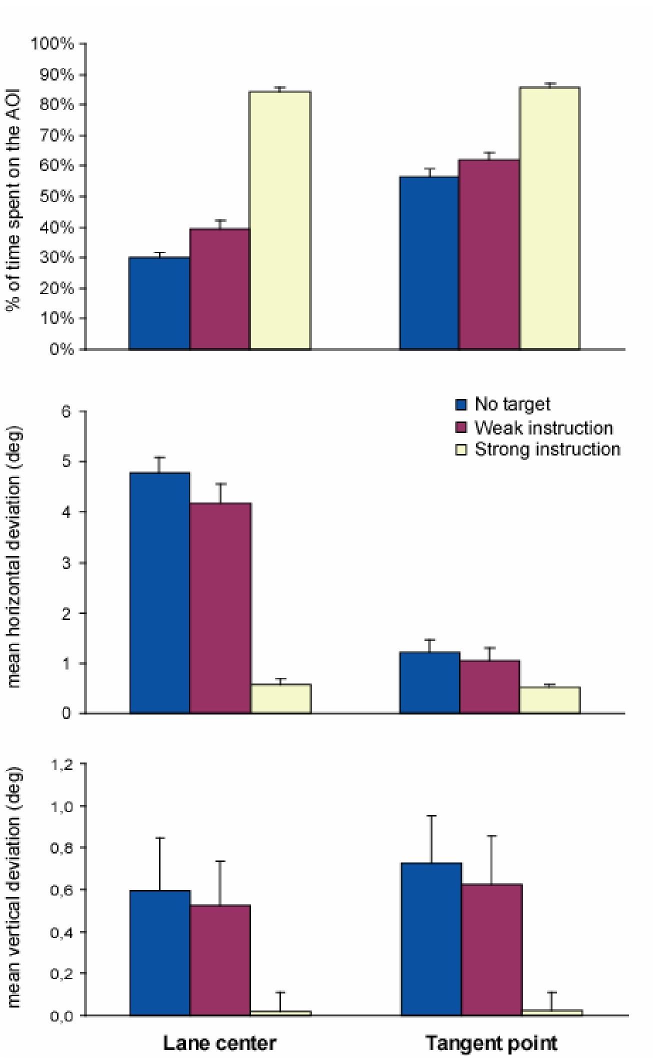

Figure 4: Mean percentage of time the drivers spent looking at the area of interest (top), mean horizontal (middle) and mean vertical (bottom) deviation of gaze from the area of interest in the control, weak instruction and strong instruction conditions, for LC (left) and TP (right). A positive value represents a deviation of gaze in the direction of the inside of the bend (horizontal) or an elevation of gaze (vertical). Error bars represent S.E.M.

The examination of the mean horizontal deviation of gaze showed it was biased toward the inside of the bend in all conditions (Fig. 4, middle graph). The effect of instruction was significant for LC (F(2;22) = 113.1 ; p<.001) and TP (F(2;22) = 6.82 ; p<.001). Post-hoc tests indicated that, in both cases, the *strong instruction* condition differed from the *weak instruction* condition and the *control* condition, which did not differ one from another. Finally, Figure 4 (bottom graph) shows that the mean vertical position of gaze was deviated above the area of interest. The effect of instruction was significant for LC (F(2;22) = 4.19 ; p<.05) and TP (F(2;22) = 8.16 ; p<.01). Post-hoc tests indicated that, in both cases, the *strong instruction* condition differed from the *weak instruction* condition and the *control* condition, which did not differ one from another.

DISCUSSION

The experiment was carried out in order to determine whether a beacon moving down the road in the vicinity of the TP may serve as a visual aid for steering, with or without a specific instruction to look at it. The influence of the visual enhancement on gaze positioning was also scrutinized.

In the *control* condition, when no visual augmentation was introduced into the driving scene, the analysis of gaze position confirmed that drivers spend a considerable proportion of time looking at the TP (Land & Lee 1994). This proportion amounted to 56% in the present experiment, although it should be noted that the driving task was mostly limited to steering control. In day-to-day driving, drivers also frequently look at traffic signs or other vehicles and perform secondary tasks in the cockpit. Hence, the TP steering strategy may not be so important in a more complex environment. Drivers also looked inside the lane boundaries, within 3° of the LC at the distance of TP. The amount of gaze directed to that region of the visual scene reached 30%. When the driver did not look at the TP or at the LC, gaze was most often directed further down the road. This explains why the mean position of gaze was deviated upward and even further inside the bend than the TP (to the left for a left bend, to the right for a right bend).

In the *strong instruction* condition, participants were required to look at a visual beacon moving along the TP or the LC. The participants followed the instruction for most of the track, about 85% in both conditions. The results confirmed that continuously tracking the TP increases the stability of steering control (Mars 2008). The improvement was observed both at the trajectory and steering action levels, as evidenced by the reduction of lateral position variability and number of steering reversals, respectively. These effects were similar when the target was positioned on the LC, although the effect on the number of steering reversals was not statistically significant. In normal driving, previewing the road curvature by tracking the TP or another relevant target is not a continuous process, since drivers need to attend to other features in the visual scene. We hypothesize that enforcing the continuous tracking of the road curvature enhanced eye-steering coordination. This is consistent with the two-level control models, according to which close visual information essentially contributes to the fast compensatory control of lateral position, whereas distant visual information determines anticipatory steering manoeuvres and ensures smooth trajectories (Donges, 1978; Land & Horwood, 1995; Salvucci & Gray, 2004). According to Salvucci & Gray (2004), the anticipatory control process can be modelled by a standard proportional-integral controller. The distant visual cue may be the vanishing point when driving down a straight road or any salient point in the visual scene when negotiating bends, such as the TP or, if present, a lead car. The TP is a good candidate for this because it can be easily isolated in the visual scene. However, its angular position relative to the car's heading does not appear to be a critical factor, contrary to the hypothesis made by Land & Lee (1994).

In the *weak instruction* condition, when looking at the beacon was not mandatory, the benefits of visual augmentation nearly disappeared. Thus, it does not appear that drivers spontaneously used the beacon as an aid for steering control. However, it did attract significantly more of the drivers' glances than in the control condition. The magnitude of the effect was small and the anticipatory gaze strategy that consists of looking much farther ahead than the region of TP was preserved. So, there was clearly no "fascination" phenomenon due to the visual enhancement.

To conclude, this experiment confirmed that enhancing eye-steering coordination by means of visual augmentation can promote smoother steering control (Mars 2008). It also demonstrated that superimposing a salient visual cue moving along the TP did not disturb the well-trained gaze strategies of drivers. However, the visual enhancement was not spontaneously used by drivers. Since the visibility conditions were excellent and, in this case, steering was easy, the drivers may have not expected to gain any real benefit from looking at the beacon. Further work is needed to evaluate if such a visual assistance becomes more relevant to the driver in low visibility conditions or when steering is otherwise impaired.

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