Safer Driving with Gaze Guidance

Laura Pomarjanschi[1 2], Michael Dorr[1 3], Christoph Rasche[4], and Erhardt Barth[1]

[1] Institute for Neuro- and Bioinformatics, University of Lübeck,
Ratzeburger Allee 160, 23538 Lübeck, Germany
`{laura,barth,dorr}@inb.uni-luebeck.de`
[2] Graduate School for Computing in Medicine and Life Sciences, University of Lübeck
[3] Schepens Eye Research Institute, Harvard Medical School
[4] Image Processing and Analysis Laboratory, University "Politehnica" Bucharest
`rasche15@gmail.com`

Abstract. Our study explores eye movements and driving behaviour in safety-critical situations. We collected eye movements from subjects instructed to drive predetermined routes in a driving simulator. While driving, the subjects performed various cognitive tasks designed to divert their attention away from the road. The subjects were divided in two groups, a control and a "gaze-contingent cue" (GCC) group. For the latter, potentially dangerous simulator events, such as a pedestrian suddenly crossing the street, were highlighted with temporally transient GCCs, which were triggered if the subject did not look at the event. Preliminary results, with 11 GCC subjects and 9 controls, show a significantly diminished accident rate for the group that drove with gaze guidance.

Key words: eye movements, driving, attention, gaze guidance, driver assistance

Introduction

Driving is a visually guided behaviour and driving performance often suffers from limited attentional resources.

The analysis of eye movements can reveal where a subject is deploying attention and, in consequence, which aspects of a scene are being processed. Eye movements are influenced by the structure and the saliency of the viewed scene as well as by the task performed by the observer (Yarbus [1967], Hayhoe and Ballard [2005], Henderson [2003], Torralba et al. [2006]). Everyday tasks involve using complex eye movement patterns (Land and Hayhoe [2001], Rayner et al. [1998], Land and Lee [1994]). Nevertheless, eye movements can be reliably predicted by low-level features of the visual input (Vig et al. [2009]).

When driving a car, peripheral cues intertwine with foveal scanning to provide the driver with enough information (Mourant and Rockwell [1970], Land and Lee [1994]). The increase in scene complexity or the presence of distracting stimuli have immediate consequences both on the gaze pattern and on the driving performance (Crundall et al. [1998], Chapman and Underwood [1998]).

Along with excessive speed and reckless behaviour, driver inattention and misperception errors are listed as major contributing factors for fatal traffic accidents (Mosedale et al. [2006], NHTSA [2009]).

One way to help inattentive drivers is to build enhanced vision systems that can direct their eye movements towards regions of increased risk. By using gaze-contingent interactive displays to display the visual information with increased salience in desired regions, a gaze guidance effect can be obtained (Barth et al. [2006]).

In the following we will show that gaze guidance techniques applied in a driving simulator improve the eye movement pattern of the drivers and considerably reduce accident rates.

Methods

Our experiments took place in a PC-based driving simulator with integrated eye tracking and with the ability to display gaze-contingent events.

The simulation environment reproduced a virtual city populated with cars and pedestrians involved in realistic traffic scenarios. Subjects drove predetermined routes inside the simulated city, while performing additional cognitive tasks. To guide the driver along the route, transparent directional arrows were overlaid on the road at intersections.

For the experiment, we designed three distinct routes, each stretching on average over a distance of 900 m. Amidst benign traffic scenarios, each route had approximately four critical sections. They consisted of pedestrians crossing or coming close to the street from angles of low visibility, creating the risk of a crash with the egocar (the subject-controlled car).

Fig. 1: Simulator scene. Because the driver is looking away, the pedestrian beginning to cross the street is highlighted with a gaze-contingent cue.

The cognitive tasks were designed to act as a distractor. In the first task, the observers were instructed to count the number of floors on all buildings along the route, and to remember the approximate location of the one with the highest count. In the second task, the observers had to search for an item (e.g. a copy shop) on the route, and to report how many occurrences of it they observed, and where they were located. In the last trials they were told to drive freely, but they were verbally distracted by conversation with the experimenter.

An experiment consisted of nine trials resulting from the combination of each route with each task. Each subject drove each route three times, every time with a different cognitive load. All the experiments began with a short training route, in which the drivers were allowed to drive freely in a remote part of the city. Only when the observer was able to drive safely on the simulated road, the actual trials would begin. On average, an experiment lasted approximately thirty minutes.

For one subject group, the potentially critical events were highlighted with gaze-contingent cues (GCC). The chosen cue material was a simple, opaque, red overlay shaped like four rays converging on the pedestrian (see Fig. 1). Several shapes and colours were tested in order to make the cue as unobtrusive as possible, while leaving it salient enough to capture the driver's eye movements. The cue was only triggered if the observer did not look at the critical event, and was turned off immediately when the subject looked at it. The control group was not exposed to any GCCs.

We recorded data from 20 volunteers with normal or corrected to normal vision (7 female and 13 male, with ages between 20 - 45 years). All had a driving licence and at least one year driving experience. Their computer gaming experience was variable. 11 subjects were part of the gaze guidance aided group, with the remaining 9 being controls.

The setup consisted of two computer workstations, one running and displaying the simulation, the other acting as a server controlling the events and the eye tracking device. The server and the simulator were connected through a direct ethernet interface.

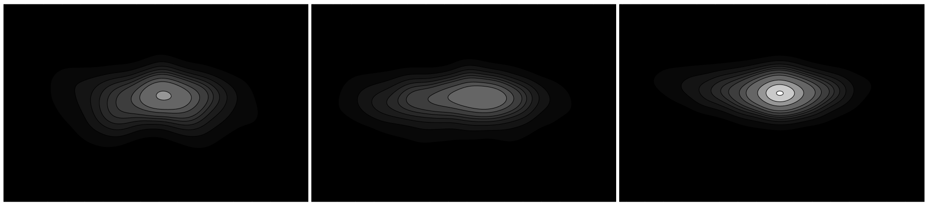
The participants were seated 70 cm away from the 22" display. They controlled the simulator with an off-the-shelf pedals and steering wheel system. Eye movements were recorded using a SensoMotoric Instruments RED250 remote eye tracker running at a sampling frequency of 250 Hz. The eye tracker device was connected via USB to the server. The display had a spatial resolution of 1680x1050 pixels and was viewed under an angle of about 38x24 degrees. Before each trial, a 9 point calibration was performed.

From the over 280 minutes of gaze data recordings, more than 54,000 saccades were extracted using a velocity-based algorithm (Böhme et al. [2006]). The simulator also recorded driving parameters such as speed, pedal position and steering wheel inclination at a frequency of 60 Hz.

Results

Influence of Cognitive Load

We first analyzed how the subjects' gaze was distributed across the screen. The three heat maps (Fig. 2) show the statistical distribution of the eye movement data across the display for each condition, throughout the experiment. The distribution was computed for all subjects ($N = 20$).



(a) Counting task (b) Search task (c) Free driving

Fig. 2: Gaze distribution across the display. In the free driving task, the subjects fixated more in the centre of the screen; counting the number of floors led to a more vertically stretched gaze distribution.

Next, we examined the degree in which the saccade amplitudes varied with the cognitive load (Fig. 3). We plotted the empirical cumulative distribution function of the saccade amplitudes for every task. For each task, the saccade amplitudes follow significantly different distributions ($p << 0.001$, Kolmogorov-Smirnov test).

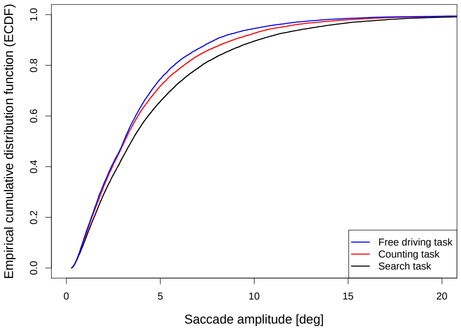


Fig. 3: Saccade amplitude distribution. In the free driving task (uppermost curve), the subjects performed more short saccades, while in the search task (bottom curve) there were more large, exploratory, saccades.

Efficiency of Gaze Guidance

For the analysis of the GCC influence on driving performance, no distinction was made between the cognitive tasks. The data were pooled for each observer group over all three conditions.

Reaction times We examined the reaction time between the triggering of a critical event and the first gaze hit on the pedestrian of interest (Fig. 4). The latency between the onset of a critical event and the first gaze hit tends to be smaller for the GCC subjects.

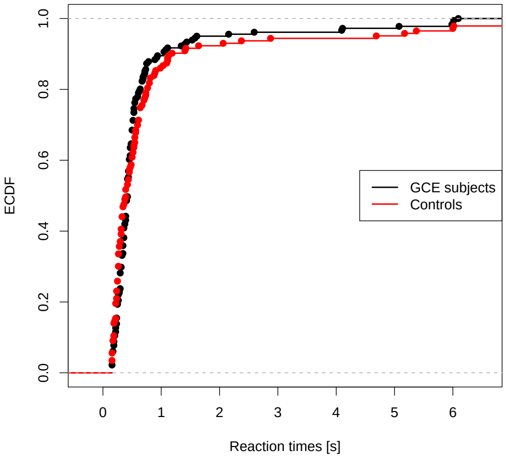


Fig. 4: ECDF of the reaction time to a critical scenario pedestrian (mean/s.d. 0.27/0.71 s for GCC subjects, 0.39/1.1 s controls)

Provoked accidents To evaluate the subjects' driving performance, we looked at the number of accidents caused in the experiment. An accident was considered a crash of the egocar against one of the critical scenario pedestrians.

Crashes were detected using a distance based-algorithm. An “encounter” was considered to be a crash if the distance between the centre of the egocar and the pedestrian was smaller than 1 m.

We found that the accident rate is substantially decreased for the gaze guidance subjects (0.021), being less than a third of that of the controls (0.067). This reduction is highly significant (95% confidence interval: $[0.0393, 0.1004]$).

Conclusions

We have performed experiments in a gaze-contingent driving simulator to study the impact of gaze guidance on driving performance. We found that subjects exhibited different gaze behaviour under different cognitive tasks. When safety-critical events were highlighted with briefly flashed, gaze-contingent cues, drivers attended to these events more quickly. More importantly, such gaze guidance led to a significantly reduced number of accidents. Subjects reported that they were not distracted by the cues; a part of the cues went unnoticed.

Acknowledgement

Our research has received funding from the European Commission within the GazeCom project (IST-C-033816) of the FP6. All views herein are those of the authors alone; the European Commission is not liable for any use made of the information. Further support has been received from the Graduate School for Computing in Medicine and Life Sciences funded by Germany's Excellence Initiative [DFG GSC 235/1].

References

Erhardt Barth, Michael Dorr, Martin Böhme, Karl R Gegenfurtner, and Thomas Martinetz. Guiding eye movements for better communication and augmented vision. In *Perception and Interactive Technologies*, volume 4021 of *Lecture Notes in Artificial Intelligence*, pages 1–8. Springer, 2006.

Martin Böhme, Michael Dorr, Christopher Krause, Thomas Martinetz, and Erhardt Barth. Eye movement predictions on natural videos. *Neurocomputing*, 69(16–18):1996–2004, 2006.

Peter R Chapman and Geoffrey Underwood. Visual search of driving situations: Danger and experience. *Perception*, 27:951–964, 1998.

David E. Crundall, Geoffrey Underwood, and Peter R. Chapman. How much do novice drivers see? the effects of demand on visual search strategies in novice and experienced drivers. In Geoffrey Underwood, editor, *Eye Guidance in Reading and Scene Perception*, pages 395–417. Elsevier Science Ltd, 1998.

Mary Hayhoe and Dana Ballard. Eye movements in natural behavior. *Trends in Cognitive Sciences*, 9(4):188–94, 2005.

John M. Henderson. Human gaze control during real-world scene perception. *Trends in Cognitive Sciences*, 7(11):498–504, 2003.

Michael F Land and Mary Hayhoe. In what ways do eye movements contribute to everyday activities? *Vision Research*, 41:3559–65, 2001.

Michael F Land and D N Lee. Where we look when we steer. *Nature*, 369: 742–744, 1994.

Jonathan Mosedale, Andrew Purdy, and Eddie Clarkson. Contributory factors to road accidents. Technical report, Department for Transport, UK, 2006.

Ronald R. Mourant and Thomas H. Rockwell. Mapping eye-movement patterns to the visual scene in driving: An exploratory study. *Human Factors*, 12(1): 81–87, 1970.

NHTSA. An examination of driver distractions as recorded in NHTSA database, 2009.

Keith Rayner, Erik D Reichle, and Alexander Pollatsek. Eye movement control in reading: An overview and model. In Geoffrey Underwood, editor, *Eye Guidance in Reading and Scene Perception*, pages 243–68. Elsevier Science Ltd, 1998.

Antonio Torralba, Aude Oliva, Monica S Castelhano, and John M Henderson. Contextual guidance of eye movements and attention in real-world scenes: The role of global features on object search. *Psychological Review*, 113(4):766–86, 2006.

Eleonora Vig, Michael Dorr, and Erhardt Barth. Efficient visual coding and the predictability of eye movements on natural movies. *Spatial Vision*, 22(5): 397–408, 2009.

Alfred L. Yarbus. *Eye Movements and Vision.* Plenum Press, New York, 1967.