Gaze Guidance Reduces the Number of Collisions with Pedestrians in a Driving Simulator

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Our study explores the potential of gaze guidance in driving and analyses 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 30 subjects were equally divided in two groups, a control and a gaze guidance group. For the latter, potentially dangerous events, such as a pedestrian suddenly crossing the street, were highlighted with temporally transient gaze-contingent cues, which were triggered if the subject did not look at the pedestrian. For the group that drove with gaze guidance, eye movements have a reduced variability after the gaze-capturing event and shorter reaction times to it. More importantly, gaze guidance leads to a safer driving behaviour and a significantly reduced number of collisions.

Categories and Subject Descriptors: H.1.2 [**Models and Principles**]: User/Machine Systems

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Additional Key Words and Phrases: gaze-contingent display, driving simulator, driver assistance systems

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1. INTRODUCTION

The analysis of eye movements can reveal where a subject is deploying attention and, in consequence, which aspects of a scene are being processed. Studies as early as that of [Yarbus 1967] have reported a high correlation between eye movements and the task being performed by the observer. For example, the simple task of making a tea involves a series of fixations that are linked step-by-step to the objects needed to perform the task ([Land and Hayhoe 2001]). The task specificity of eye movements can be observed in activities such as reading ([Rayner 1998]), driving ([Land and Tatler 2001]), drawing, or playing a ball sport ([Land 2006]).

Therefore, a key role in modulating visual attention is played by the semantic content of a scene and its correlation to the task being performed ([Hayhoe and Ballard 2005], [Shinoda et al. 2001], [Torralba et al. 2006]). Nevertheless, eye movements can also be influenced by the structure and the saliency of the viewed scene ([Henderson 2003]) and salient items can capture attention even if they are irrelevant to the context of the task performed ([Theeuwes et al. 1998], [Mulckhuyse et al. 2008]). Eye movements can be reliably predicted by low-level features of the visual input. For example, [Itti et al. 1998] have used saliency maps combining features such as colour, intensity and orientation to reliably predict eye movements on static images; [Vig et al. 2009] have predicted saccades on natural high-resolution videos using the intrinsic dimensionality of the visual input.

Driving is one of the best examples of a highly complex, visually guided activity that suffers from limited attentional resources.

Over the last century, driving has become the main transportation modality in many countries. Through extensive safety measures, a significant reduction in traffic fatalities has

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been achieved. A NHTSA research note reports the year 2009 as having the lowest number of deaths resulting from vehicle crashes since 1950. Still, that means 33,808 fatalities in the US only ([National Highway Traffic Safety Administration 2010b]). 16% of these fatalities occurred in accidents for which driver distraction was cited as the main cause ([National Highway Traffic Safety Administration 2010a]). The reported distractions include the use of mobile phones or that of in-car technology, but also misperception errors, such as "failed to look" and "looked but did not see" are often mentioned ([Mosedale et al. 2006], [National Highway Traffic Safety Administration 2009]). As concluded in [Klauer et al. 2006], taking the eyes off the road for more than 2 seconds significantly increases the risk of a collision.

When driving a car, peripheral cues intertwine with foveal scanning to provide the driver with enough information for performing the driving task ([Land and Hayhoe 2001], [Land and Lee 1994]). Driving also provides a good example of how gaze patterns change during the process of learning a task. Significant differences can be observed between eye movement patterns adopted by novice and experienced drivers ([Crundall et al. 1998], [Crundall et al. 2002], [Konstantinopolous et al. 2010]).

Besides driving experience, scene complexity or the presence of distracting stimuli have immediate consequences both on the gaze pattern and on the driving performance. A number of studies that explore the effects of distracted driving on eye movements and on driving safety exist. As examples, we enumerate a few. [Recarte and Nunes 2003] observed the influence of an increased cognitive load created by having subjects perform several mental tasks while driving in naturalistic conditions. In a more recent experiment, [Brookhuis and de Waard 2010] used physiological measures such as heart rate and EEG data to estimate the drivers' mental workload. [McCarley et al. 2004] and [Galpin et al. 2009] investigate "looking but failing to see" driver errors from the perspective of the change blindness paradigm. In a similar experiment in a driving simulator, [Zheng and McConkie 2010] showed that local changes of the scene are frequently not noticed when accompanied by brief blankings (brief intervals in which a grey frame is shown).

Another direction of research on safer driving deals with modalities to redirect a distracted driver's attention to the road. [Ho and Spence 2005], for example, have concluded that spatially predictive auditory cues could be effective in capturing attention and signaling the fast approach of another car. Also, [Wang et al. 2007] have shown that subjects' responses to a side collision-avoidance signal consistent with the direction of the threat were significantly quicker than for trials where the location of the warning signal was incompatible with that of the threat. They also suggested that the cueing signal might in fact direct the attention of the drivers towards the location of the threat.

With the latest advances in technology, higher-fidelity driving simulators started to become widely available. The number of driving studies performed in a simulator has increased significantly over the past decade ([Boyle and Lee 2010]). Although driving simulators do have important disadvantages compared to naturalistic studies ([Kemeny and Panerai 2003]), the advantages of a simulator experiment are undeniable. Studies on distraction during driving can sometimes be problematic to perform. A study in naturalistic settings might be impractical for collecting sufficient data in a reasonable amount of time, and also cannot offer the same level of control on experimental parameters as an investigation performed in a laboratory. Also, ethics and safety aspects cannot be overlooked. Experiments involving subjects with visual impairments, such as the one performed by [Bowers et al. 2009] to determine how hemianopia affects the detection of pedestrians in hazardous driving conditions, but also benign driving under increased cognitive load experiments can potentially place both the subject and other traffic participants at serious risk when performed in real traffic conditions.

Nevertheless, the research on safer driving has not remained only on a theoretical level. Over recent years, more and more Advanced Driver Assistance Systems (ADAS) have been developed, and have been included as features in real vehicles.

Some ADAS focus on monitoring the driver and they issue warnings when he or she appears to be distracted or drowsy. Some systems use driving parameters (for example the steering behaviour) to monitor when the driver's reactions are inconsistent with a safe driving pattern. Implementations of such driver assistance systems are already commercially available[1,2]. Others can detect directly when the driver's head has been turned away from the driving direction for a certain period of time, or when physiological measures, such as eyelid opening or blinking rate suggest that he or she is sleepy. For example, a system developed by SAAB detects the driver's eye and head direction, their blinking rate, and their eyelid closure, and issues an audible warning when the driver appears tired or distracted[3]. The Lexus driving monitoring system functions in a similar manner, and often comes integrated with a pre-crash application, which can detect if there is an obstacle approaching the car. If at the same time with the presence of an obstacle, the monitoring system concludes that the driver's head has been turned away for too long, warnings are triggered[4].

Other driver assistance applications focus solely on monitoring the street, and warn the driver when an immediate danger has been detected. An ADAS released by Volvo detects pedestrians ahead of the vehicle and issues acoustic and visual warnings if pedestrians are about to walk in front of the car; if no action is taken by the driver, the brakes are automatically applied[5]. The Subaru "EyeSight" system operates similarly[6].

Another direction in ADAS development focuses on creating enhanced-vision systems. Night view systems constitute a good example of this category; they render, either on a display on the dashboard, or directly on a portion of the windshield as a head-up display, an infrared view of the street ahead, sometimes enhanced with pedestrian detection. Night view systems have already been implemented using different technologies by car manufacturers such as Toyota, Mercedes or BMW[7,8].

Finally, head-up displays (HUD) are becoming a common feature offered by the automotive industry. Typically, they are used to display vehicle information such as speed or driving directions in a small portion of the windshield[9,10], but there are also attempts to extend HUDs to the use of the entire windshield. In 2010, General Motors disclosed that research is currently conducted on such a system; as envisioned use, they mention highlighting important aspects of the scene ahead of the car, such as the edges of the road, or traffic signs[11].

Nevertheless, there are downsides to the existing advanced driver assistance systems. Audible warnings are often triggered without taking into consideration the driver's intentions or the current traffic context, and because of that they are perceived as annoying and are turned off. Visual warnings add to an already significant existing visual demand, and even when they do not require the driver to take their eyes off the road, by increasing the cognitive load the driver is subjected to, they risk becoming a source of distraction themselves.

[1] http://www.daimler.com/dccom/0-5-1210218-1-1210332-1-0-0-1210228-0-0-135-7165-0-0-0-0-0-0-0.html
[2] http://automotivediscovery.com/ford\%E2\%80\%99s-driver-alert-wakes-sleepy-european-drivers/928340/
[3] http://www.saabnet.com/tsn/press/071102.html
[4] http://www.lexus.eu/range/ls/key-features/safety/safety-driver-monitoring-system.aspx
[5] http://www.volvocars.com/en-ca/top/about/news-events/pages/default.aspx?itemid=17
[6] http://www.autoblog.com/2010/04/22/subaru-introduces-new-eyesight-system/
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What we propose is to build enhanced-vision systems that can unobtrusively direct the drivers' eye movements towards critical events. Previous work has already shown that by using gaze-contingent interactive displays to render visual information with increased salience in selected regions, a gaze guidance effect can be obtained ([Barth et al. 2006], [de Graef et al. 2009]).

Here, we have used a special gaze-contingent driving simulator to investigate how gaze guidance can be used to help drivers to more efficiently distribute their attentional resources and drive more safely. Preliminary results of the experiment, obtained with an incomplete data set and with limited analyses have been published as a work-in-progress paper in [Pomarjanschi et al. 2010]. In the current manuscript, we report the final results of the study, obtained after completing the experimental recordings. The final analyses are focused more on identifying and highlighting the effect of the gaze guidance both concerning driving behaviour and eye movements.

2. METHODS

The experiments took place in a PC-based driving simulator. The simulator was integrated with a high speed remote eye tracker and allowed the gaze-contingent placing of gaze-capturing events. The virtual environment modelled an existing urban area (the city of Osnabrück) with its roads and buildings. The subjects viewed the virtual city from a car driver's perspective, and controlled their car (the egocar) using an off-the-shelf pedal-steering wheel system.

Subjects drove along pre-established courses inside the simulated city while performing additional cognitive tasks. Three distinct routes were selected, each of them on average stretching over a distance of 900 m. The drivers were guided along these routes by transparent directional arrows overlaid on the road at intersections.

The graphical simulation provided a basic static content layer (comprising streets, buildings and green areas) to which dynamic content could be added. The dynamic content consisted of pedestrians and cars, road signs and traffic lights, but also of textures that could be overlaid either relative to the simulator screen, or "attached" to a traffic participant. Pedestrians could be chosen from a set of eight distinct characters, while for vehicles, both variations in type and colour were possible, therefore generating a large available set. Apart from the directional arrows, the traffic was guided and regulated with the help of a coherent traffic sign network. The available traffic sign set contained fifteen regulatory signs controlling the right of way and the allowed traffic direction. Because of limitations of the simulator engine, scenarios in which the subject was forced to stop at a red light could not be created. Therefore, the only light signal that was added to one of the routes was designed to turn green as soon as the subject approached it.

Both for pedestrians and for cars, their attributes as well as the trajectory they followed had to be preprogrammed. For that reason, it was not possible to alter their behaviour in response to specific actions of the egocar. Therefore the actions of other traffic participants were triggered as an event, in response to the 2D position of the egocar on the map of the virtual city. Because of this, all events were triggered in a similar fashion for all subjects, making the trials fully comparable.

During the experiment it was possible to manually switch between eight speed levels, by pressing a key on the keyboard. Since it proved quite difficult for subjects unacquainted to the driving simulator to control the egocar at higher speeds, the whole experiment was run at a maximum speed of about 30 km/h. This consistent speed also simplified the data analysis.

Amidst benign traffic scenarios, each route had four or five potentially critical sections consisting of pedestrians unexpectedly crossing or coming close to the street. In total for the three routes, seven of the fourteen potentially critical sections would result in a collision between the egocar and a pedestrian in the absence of a prompt reaction from the driver.

Fig. 1: Simulator scene. Because the driver is looking away (red 3D marker), the pedestrian beginning to cross the street is highlighted with a gaze-contingent cue. Bottom right: gaze-contingent cue enlarged for better visibility (not shown during the experiment.)

The additional cognitive tasks were designed to act as a distractor, thus contributing to a more realistic driving experience. In the first task, the subjects were instructed to count the floors on all buildings along the route, and to remember the approximate location of the tallest one. In the second task, they 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.

An experiment consisted of nine trials resulting from the combination of each route with each task. In other words, each subject drove each route three times, every time with a different cognitive load. As the events on each course would repeat themselves in a very similar fashion, we tried to minimize the habituation effect for each subject by maximizing the time interval between two repetitions of the same route, and by making sure that the maximum level of distraction would be attained during the first repetitions. To that end, the tasks were repeated in decreasing order of their difficulty. In the first stage, all three routes were repeated with the counting task, in the second stage the subjects drove again all three routes, this time performing the visual search task, while in the last stage, they were allowed to drive freely, only with conversation acting as a distractor. The task difficulty was assessed empirically during preliminary trials. The route sequence was always presented in the same order.

Before the experiment, subjects were instructed to drive through the city following the directional arrows, while acting as if they were driving a real car through an inhabited city. They were told that it was of utmost importance to follow traffic regulations and to drive as safely as possible. Nonetheless, they were not explicitly warned about the possibility of pedestrians attempting to unexpectedly cross the street. 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 subject was able to drive safely on the simulation road, the actual trials would begin. Including instructions and training, an experiment lasted on average thirty minutes.

For one subject group, the potentially critical events were highlighted with gaze-contingent cues (GCC) attached to the risk pedestrian and overlaid on the simulator scene. Several cue shapes, colours and transparencies were tested in pilot experiments in order to select a cue as unobtrusive as possible that would still be salient enough to capture the subjects' gaze. The chosen cue material was a simple red overlay shaped like four rays converging on the pedestrian (see Figure 1). The cue would be triggered only when the subject

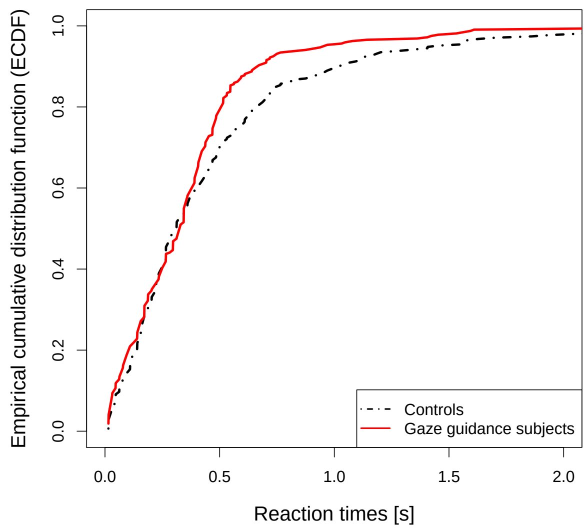


Fig. 2: Empirical cumulative distribution function (ECDF) of time to first fixate a critical scenario pedestrian. Gaze guidance subjects show decreased reaction times, meaning that they fixate on the pedestrian sooner (mean/s.d. 0.375/0.37 s for GCC subjects, 0.487/0.72 s controls). The results are significant ($p = 0.011$, Kolmogorov-Smirnov test).

was looking away from the danger element, and would be triggered off as an immediate result of the subject looking at it. The control group was not exposed to any GCCs.

We recorded data from thirty volunteering subjects with normal or corrected to normal vision (ten female and twenty male, with ages between 20 - 55 years). All had a driving licence with at least one year driving experience and variable computer gaming experience. Fifteen subjects were part of the gaze guidance aided group, while the remaining fifteen were 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. 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 400 minutes of gaze data, more than 75,000 saccades were extracted using the velocity-based algorithm described in [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.

3. RESULTS

3.1. Efficacy of Gaze Guidance

In the analysis of the influence of GCCs on the driving performance of the subjects, no distinction was made between the cognitive tasks. The data were pooled for each subject group over all three conditions.

3.1.1. Reaction times. We examined the reaction time measured between the triggering of a critical event (a pedestrian crossing) and the first gaze hit on the pedestrian of interest, comparing the GCC and the control group.

Because we cannot assume a specific shape of the distribution of reaction times, we used the Kolmogorov-Smirnov test, which is a powerful non-parametric statistical test. It is based on the empirical cumulative distribution function (ECDF), which essentially is the integral of the probability density function; in other words, the ECDF at the point x denotes the proportion of samples that have a value of x or less:

$$F_n(t) = \frac{1}{n}\sum_{i=1}^{n} \mathbf{1}_{x_i \le t},$$

where $\mathbf{1}_{x_i \le t} = \begin{cases} 1 & \text{if } x_i \le t \\ 0 & \text{otherwise} \end{cases}$. In Figure 2 for example, 80% (0.8 on the y-axis) of the control subjects (black dashed curve) had a reaction time of 650 ms or less. For the gaze-guidance group (red solid curve), the 80% mark was reached earlier, already at 500 ms, i.e. gaze-guided subjects reacted faster. The Kolmogorov-Smirnov test actually measures the maximum vertical distance D of the two curves, which here is statistically significant at $D = 0.1291$, $p = 0.011$.

3.1.2. Provoked accidents. As mentioned before, of the total number of events for which a GCC would be triggered if the driver looked away, seven had the potential to lead to a collision of the subject-driven car with the critical event pedestrian. To evaluate the subjects' driving performance, we looked at the number of accidents caused in the experiment.

Since the simulator did not provide any collision feedback, we used a distance-based algorithm to detect pedestrian-egocar collisions. We computed the distances between the centre of the egocar and the critical scenario pedestrian. Based on the dimensions of an average city car, we set the distance threshold for a collision to 1 m from the car centre. Nevertheless, the following result holds qualitatively also for other distance thresholds (Figure 3).

We computed the accident rate as the total number of accidents for the group, divided by the total number of events which could have led to an accident for that group. We found that the accident rate is strongly reduced for the gaze guidance subjects (0.026), being less than half of that of the controls (0.068). This reduction is highly significant (99.8% confidence interval). In order to check whether the significance of the accident rate reduction holds also for thresholds other than that of 1 m, we computed the 95% confidence intervals for all distances larger than 0.5 m, up to 2 m, in increments of 10 cm. The results confirmed that for any of these thresholds, the collision rates for the two subject groups were signficantly different.

Because of the reduced sample size, the differences between accident rates for each task did not reach statistical significance. However, it is interesting to note that for the control group, the largest collision rate was registered during the counting task (0.10), followed by the free driving task (0.06). The smallest collision rate was recorded for the search task (0.04). For the gaze guidance group, the order of the accident rates over tasks was the same (counting task, 0.05; free driving, 0.02; search 0.01).

In the following, we attempted to establish whether the differences suggested by the collision rates were consistent for the entire subject group, or whether they only apply for isolated cases which came near the critical accident distance. We also sought for evidence of the effect of gaze guidance in differences between the eye movement distributions of the two groups. To this end, we analysed the data recorded during a four second interval from the triggering of the critical event, i.e. the interval corresponding to the entire duration of the event (after which the pedestrian had crossed the street). We divided this interval into 200 ms time windows, and for each event, we plotted all egocar-pedestrian distances in

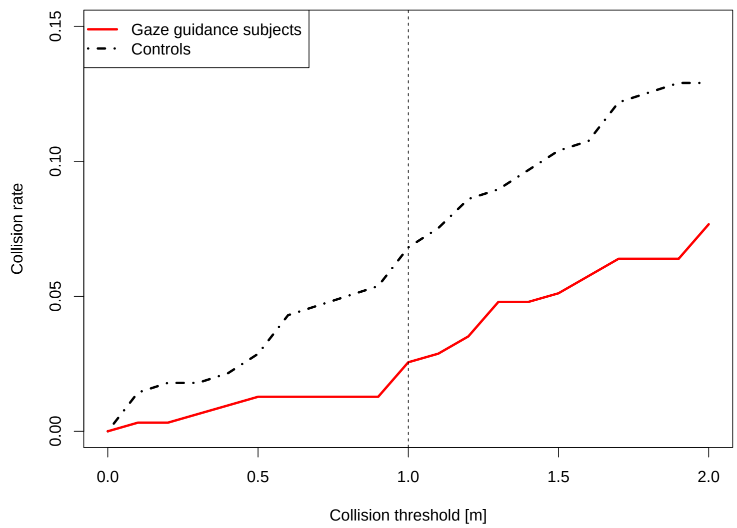


Fig. 3: Collision rate as a function of distance threshold. The collision rate was computed as the fraction of critical event sequences where the minimum distance between the centre of the egocar and the critical pedestrian was smaller than the collision threshold. These data show that the collision rate does not critically depend on the distance threshold; for further analyses it was set to 1 m.

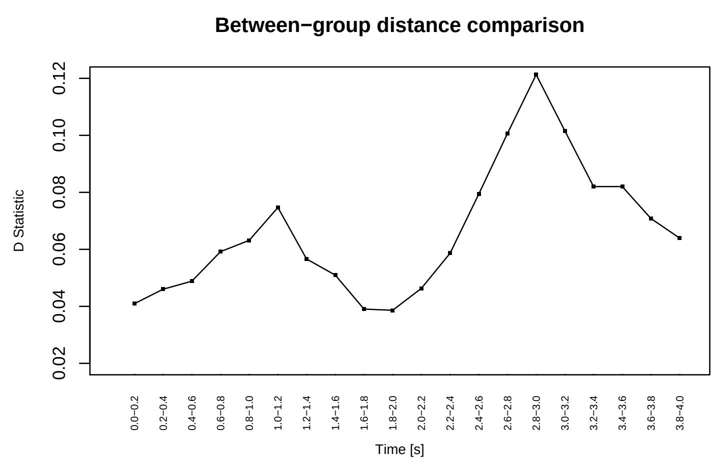


Fig. 4: Maximum vertical distance between the ECDF curves of the egocar-pedestrian distance distribution (D statistic). The distance distribution in each time window contains data pooled from all seven potentially critical events.

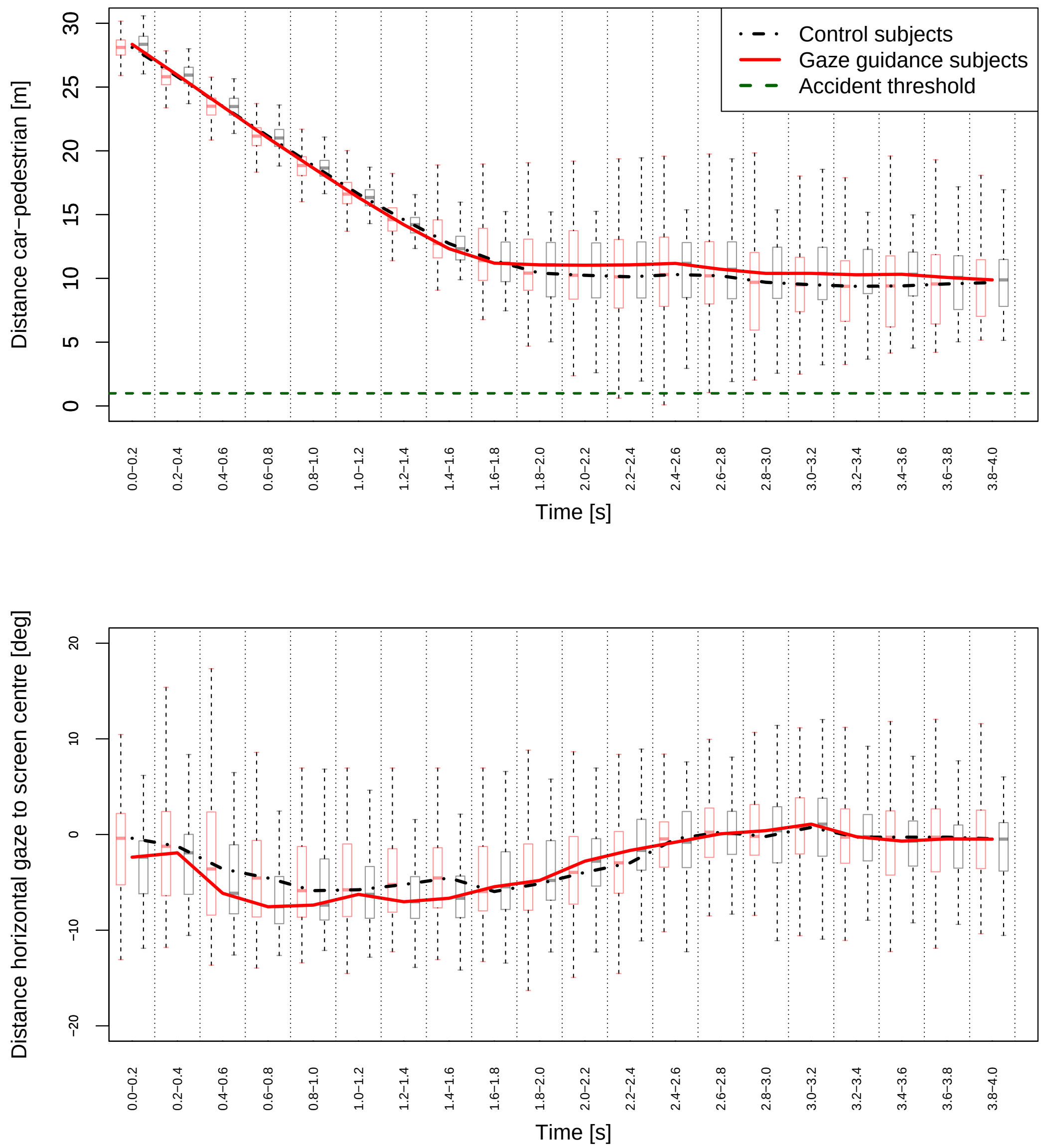


Fig. 5: Example of car-pedestrian distance and horizontal gaze position during a high-risk event (see text for more details).

the corresponding time window. To evaluate the eye movements performed by the subjects during critical events, we also analysed the horizontal gaze component for the same time intervals. A plot for a single event is shown in Figure 5. For better visualization, outliers have not been plotted.

In order to check whether the differences between the distance distributions for control and for gaze guidance subjects were significant, we pooled in each time window the data from all seven potentially critical events and then for each time window we computed and plotted the D statistic (Figure 4). The variation of the maximum distance between the two distributions confirms the tendencies illustrated in Figure 6.

Because of the relatively short duration of a critical event (a maximum of 4 seconds), not enough saccade samples were available to establish the statistical significance of the differences between the eye movement distribution for each time window. That is why, concerning gaze distributions, we will only describe tendencies.

There are slight variations from event to event, depending on various factors such as the direction and the distance from which the pedestrian appears, or the characteristics of the scene at event onset. Nevertheless, some observations remain valid for all events. For the first part of the event, the egocar-pedestrian distance decreases in an approximately linear fashion and for all subjects, and the variance of the distance distributions is small. After approximately 1 s, typical reaction time, the egocar-pedestrian distance stabilizes near a constant value which, depending on the nature of the event can be close to the collision threshold. In this latter section, the distance tends to be larger for gaze guidance subjects.

Certain tendencies can also be distinguished in the horizontal gaze distribution. The variability of the gaze distributions for the first part of the event tends to be smaller for GG subjects. Also a shift in gaze position between the two subject groups can be noticed for that interval.

Next, we analysed the cumulated data over all events. For each time window of each event, we computed the difference between the medians of the distances, and also between the statistical dispersion (see below) of the gaze positions (Figure 6).

We chose the median as a measure of the central tendency of the distance distributions because of its resilience to outliers. The trend of the curve remains the same when using the mean instead of the median. GG subjects maintain longer distances to the pedestrian; the effect is particularly strong in time windows where accidents occur.

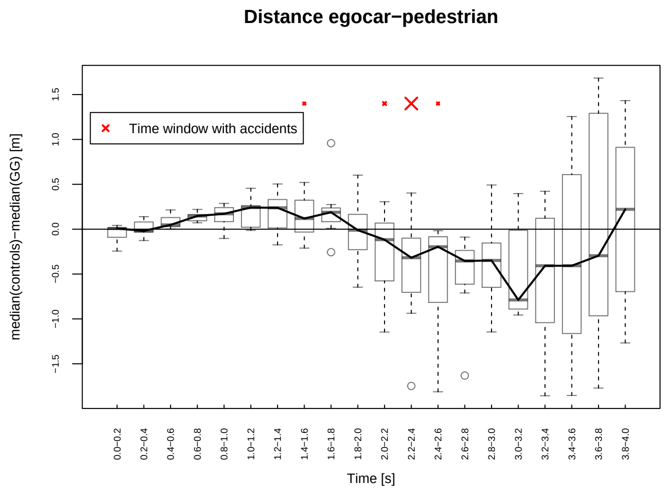
To quantify the statistical dispersion of the eye movement coordinates we also used a robust measure with regard to outliers, specifically the median absolute deviation (MAD). The MAD is computed as the median of all the absolute deviations from the sample's median. In the time windows between 600 ms and 12000 ms, the variability of the gaze positions of the GG subjects is smaller than that of controls. This time interval also corresponds to a local maximum in the distances between the medians of the horizontal eye movement distributions of the two groups (plot not shown here).

4. DISCUSSION

4.1. Gaze guidance efficacy

Subjects in the gaze guidance group showed shorter reaction times and looked at the critical events sooner than control subjects. Still, as shown in Figure 2, approximately 60% of all subjects immediately fixate the pedestrian. However, the gaze guidance did help reduce the upper bound of the reaction time distribution, suggesting that for the 40% inattentive drivers, gaze guidance would have made a significant difference in a real scenario. We would argue that compared to a real traffic scene, the graphical environment of the simulation offers a relatively low number of cars and pedestrians, no real street life, etc. and therefore, the subjects were more likely to look at the pedestrians anyway. Also, the high frequency of “accident-generating scenarios” occurring during the trials increased significantly the gaze-capturing potential of the pedestrians that walked into the street. In real driving scenarios it is not likely that seven critical situations with pedestrians occur in less than 30 minutes of driving. Should that nevertheless happen, the driver would allocate significantly more cognitive resources to anticipating similar events. Therefore, we could expect an even stronger effect of the gaze-capturing cues in real life situations.

A further gaze guidance effect that we found was that before a potential accident eye movements were less variable in case of the GG group compared to the controls. Since the



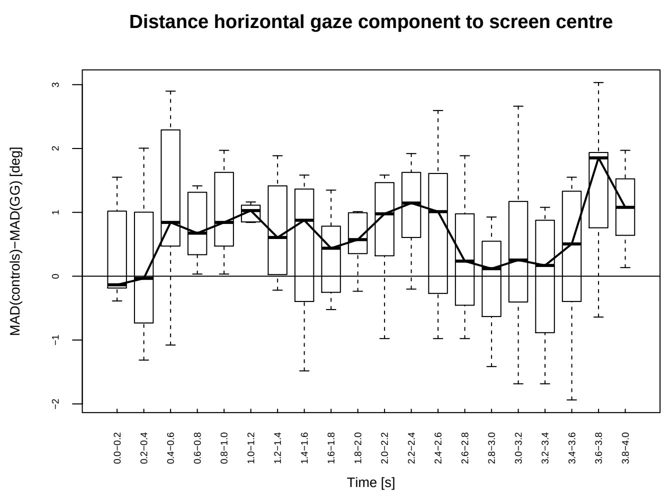


Fig. 6: Analysis as in Figure 5 for aggregated data on all events. The top plot shows the difference between the medians of the distance samples for each time window during a critical event. Crosses indicate time windows where accidents took place. Note that cross size is proportional to the number of accidents in the corresponding time window. The bottom plot illustrates the differences between the variabilities (median absolute deviations - MAD) of the eye movement horizontal positions for the corresponding time windows.

GG and the control conditions differ only in the presence of the GCC, the reduced variability of the gaze positions must be attributed to the GCC. We could further assume that the GG subjects were better focusing on the pedestrians, but we cannot verify this assumption because the position of the pedestrian on the screen is not precisely known.

The major finding, however, is that gaze guidance led to safer driving because GG subjects braked earlier and thus maintained a larger distance to the pedestrian. Note that this increased safety zone cannot be observed during normal driving but just before the potential collisions. Overall this change in driving behaviour due to gaze guidance led to a major reduction in the number of accidents.

4.2. Application in real world scenarios

An early proposal to use unobtrusive gaze guidance for better driving was made in [Barth 2001]. Meanwhile, unobtrusive gaze guidance has been demonstrated and implemented in a prototype car at the Volkswagen AG [Kiss 2009].

Regarding real-world scenarios, the VW prototype uses a row of LEDs underneath the windshield. The LEDs can be selectively turned on and already lead to a guiding effect which becomes mostly unobtrusive after some time (the driver learns to consciously ignore the lights). One could significantly improve the VW prototype by (i) using a larger head-up display instead of just a row of lights, and (ii) adding a gaze tracker that would allow for gaze-contingent stimulation. Both extensions seem realistic but additional efforts are required to match car safety and cost criteria.

Naturally, in order for such a system to be useful it should be 100% reliable, give no false warnings and signal all potential dangers, but that holds true not only for gaze guidance, but for any driver assistance system.

The benefits of unobtrusive, subconscious guidance can be better understood by acknowledging that visual perception is widely determined by our expectations, i.e. by a model. This model is only selectively updated because of limited attentional resources. Warnings such as beeping attempt to avoid critical situations by forcing the driver to change their current model, whereas subliminal guidance would change the way the model is updated. The latter process is faster and less distracting, and therefore more efficient.

5. CONCLUSIONS

We studied the impact of gaze guidance on driving performance by performing experiments in a gaze-contingent driving simulator. We found that subjects exhibited different gaze behaviour when performing 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 safer driving behaviour and a significantly reduced number of accidents although subjects reported that they were not distracted by the cues, part of which went unnoticed.

We hope that our results may inspire car manufacturers to build systems for driver assistance that would help drivers deploy their attentional resources more effectively. This would involve already available components such as pedestrian detection, pre-crash sensing and attention monitoring, but also novel developments such as a wide-angle gaze-contingent head-up display.

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