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THE EFFECTS OF MOMENTARY VISUAL DISRUPTION ON HAZARD ANTICIPATION IN DRIVING

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Summary: Driver distraction is known to increase crashes, especially when the driver glances for especially long periods of time inside the vehicle. While it is clear that such glances increase risk for the driver when looking inside the vehicle, it is less clear how these glances disrupt the ongoing processing of information outside the vehicle once the eyes return to the road. The present study was aimed at exploring the effect of visual disruptions on the top-down processes that guide the detection and monitoring of hazards on the forward roadway. Using a driving simulator, twelve participants were monitored with an eye tracking system while they navigated various hazardous scenarios. Six participants were momentarily interrupted by a visual secondary task (simulating a glance inside the vehicle) prior to the hazard occurrence and six were not. Eye movement analyses show that interrupted drivers often failed to continue scanning for a hazard when their forward view reappeared. Implications of this study are discussed.

INTRODUCTION

The ability of drivers to identify hazardous situations is an important skill that correlates (negatively) with traffic crashes (e.g., Horswill and McKenna, 2004). Although hazard perception has been studied extensively with respect to differences between novice and experienced drivers (e.g., Chapman and Underwood, 1998; Pollatsek et al., 2006; Borowsky et al. 2010), the effect of momentary visual distractions such as glances inside the vehicle on hazard perception is still not well understood. This becomes ever more critical as the complexity of the instrumentation in the cabin of the automobile increasingly resembles this complexity in the cockpit of an airplane. Drivers, both experienced and inexperienced, are increasingly likely to take only short snapshots of the forward roadway while they are engaged in in-vehicle secondary tasks. It is critical to understand how these glances inside the vehicle affect hazard anticipation.

Insofar as drivers need to remember critical information in between glances to the forward roadway, basic research on interrupted visual search may provide some insight into the role of working memory in the process of hazard detection in driving. In a study of a phenomenon of rapid resumption in interrupted visual search tasks, Lleras et al. (2005) suggested that the process of target detection involves at least two steps: (1) based on an initial glance at a scene, a hypothesis is generated, but not necessarily confirmed (i.e., the task might be interrupted before the hypothesis can be confirmed); (2) the hypothesis is tested (confirmed or rejected) in a second glance at the scene. Fast responses in step 2 might reflect the preservation of a perceptual hypothesis in working memory. In contrast, if the interruption interferes with the perceptual hypothesis, then responding will be delayed.

The nature of the interruption may influence the degree of interference with perceptual hypotheses. Klauer and Zhao (2004) found that spatial short-term memory tasks, such as remembering the location of a dot on a display, are disrupted more by spatial (relating to trajectories and locations) than visual (relating to shapes and colors of objects) task interference. In order to anticipate hazards while driving, a driver needs to quickly process and store information about the spatial (trajectories) of possible threats in the environment and hypothesize where they will be in the near future. However, during glances inside the vehicle, spatial information (e.g., looking for the radio button) potentially interferes with the memory of possibly threatening information outside the vehicle.

With this in mind, the present study was aimed at answering the following question: Are drivers who are momentarily interrupted by a spatial interference task less likely than drivers who are not interrupted to detect a hazard for which they both were given a cue prior to the interruption? To address this question, experienced drivers were asked to drive various hazardous situations in a driving simulator. The hazards were always preceded by a cue regarding the nature of the hazard. For example, drivers might see a pedestrian crossing ahead sign prior to the sudden appearance of a pedestrian at the crosswalk (cues and scenarios are described further below). Half of the participants were momentarily interrupted after seeing the cue and half of the participants were not. Importantly, the scenarios were designed such that participants in the no interruption condition did not receive any additional information regarding the hazard or its location during the interruption phase. Of interest in the current study is whether the driver who is interrupted immediately after seeing the cue will remember to scan to the cued or relevant location and search for hazards when the forward view of the road reappears.

METHOD

Participants

Twelve experienced drivers (M = 41 years old, range 31 – 49 yrs; M = 24 years driving experience) participated as paid volunteers. All participants had normal or corrected-to-normal vision, with Snellen static acuity of (20/35) or better and normal color vision. Drivers were recruited via online ads and participants received $60 for their participation.

Apparatus

Driving Simulator. The advanced RTI (Realtime Technologies Inc.) driving simulator at the Liberty Mutual Research Institute for Safety (LMRIS) consists of a fixed-base open vehicle cab. The driving environments were presented on three 46-inch widescreen LCD displays at 1920 × 1080 resolution, subtending 120^{o} of horizontal visual angle. The various driving environments and traffic scenarios were generated using RTI SimCreator and SimVista software.

Eye tracker. The SMI (SensoMotoric Instruments) head mounted Eye Tracking System (ETS) model iViewX-HED was used to collect the eye-movement data (sampled at 50 Hz) for each participant during the virtual drives. The lightweight optical system, consisting of an eye camera and a color scene camera, were mounted on a bicycle helmet. The gaze position accuracy of this system is between 0.5^{o} and 1^{o} visual angle.

Driving Scenarios and interruption task

Twenty short driving scenarios (1 to 2 minutes long) were designed and used for evaluation. Scenarios included both suburban and rural environments. Of these scenarios, 12 were experimental scenarios and 8 were filler scenarios.

Hazard scenarios. Each hazard scenario was designed to have a visual cue regarding an upcoming hazard followed by either a moving or non-moving threat. Some hazards materialized from behind an obstruction (e.g., a pedestrian behind a truck parked near a crosswalk). Six of the scenarios included hazards that were expected (consistent with the visual cue, e.g., a pedestrian ahead sign followed by an obscured crosswalk) and 6 included an expected hazard as well as an unexpected one (inconsistent with the cue, e.g., a pedestrian ahead sign followed by a hidden driveway from where a car might emerge). To keep the terminology simple, the latter combined scenarios will be referred to as simply unexpected scenarios.

Figure 1 presents an example of one expected (left panel) and one unexpected (right panel) hazardous scenario. In the first case (left panel) the light-shaded car at the top was visible to drivers as it approached the intersection ahead. Right before the interruption that car became obscured by a truck parked on the side of the road. In the second case (right panel), the driver has been cued that a car in the parking lane on the right might enter the driver's lane (it started to move forward). But a concurrent unexpected threat, the stationary pedestrian near the edge of the sidewalk, becomes visible on the opposite side of the roadway.

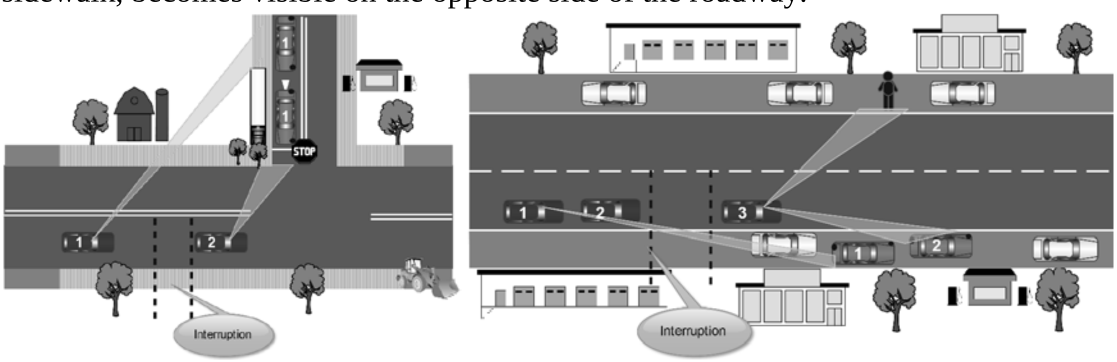


Figure 1. Examples of an expected hazard (left) and an unexpected hazard (right) The simulator vehicle is shaded dark (The interruption occurs in between the vertical dashed lines. Note that drivers who are not interrupted cannot see the hazard instigator (threat) that might emerge when they are driving between the dashed lines.)

Filler scenarios. The filler scenarios did not include any manipulated hazard, but were similar to hazard scenarios in road and ambient elements. The purpose of these filler scenarios was to reduce participants' expectations regarding the purpose of the experiment and their ability to form a link between a cue and a hazard.

Interruption task. Each hazard scenario included a 2-second interruption where the view of the forward roadway (only the center display) was replaced with a spatial memory interruption task. During the interruption drivers maintained control over the simulator vehicle. When the interruption task ended the forward view reappeared. The interruption task was modeled after Klauer and Zhao (2004). For this task, a black screen containing 12 white asterisks was presented. All asterisks were moving in a linear but randomly determined direction (approximately 0.05^{o} of visual angle every 150 ms) across the screen except one. Drivers were asked to find and stare at the stationary asterisk.

At the end of the task, drivers received brief visual feedback (an image with a red circle surrounding the stationary asterisk). For participants in the no interruption condition the secondary task was not presented. For the hazard scenarios, the interruption task followed the cue given regarding the location of the hazard. The interruption task ended at a point on the roadway approximately 200-300 ms before the hazard was visible. As noted above, during the critical interval (interruption segment) participants in the no interruption condition were not given any additional cues regarding the hazard or its location and they could see the hazard only approximately 200-300 ms after the point on the roadway where the interruption ended for drivers in the interruption condition. To accomplish this, all hazards were completely obscured during the interruption phase by environmental features such as vegetation. In addition to the interruptions surrounding the hazard events, additional interruption tasks were randomly incorporated into the drives in order to increase uncertainty regard the events which followed an interruption.

Procedure

At the start of the two-hour session, participants completed the informed consent and their visual acuity was tested using a Titmus Vision Tester. They were then seated in the driving simulator and fitted with the ETS. Following a short calibration process, participants were asked to drive as they would normally drive in similar real-world situations. They were further instructed to drive at approximately 30 mph. Participants then drove two 5-minute practice drives to acclimate to the simulator and to the secondary task. After practice, participants were randomly assigned to the interrupted or non-interruption condition and began the experimental drives. After driving 10 scenarios, were offered a break. Then, participants drove an additional 10 scenarios. The order of scenarios was pseudo-randomized across participant. Finally, participants were paid for their participation.

RESULTS

The results were analyzed according to a mixed factorial design with one within-subjects factor -- Scenario number -- and one between-subjects factor -- Driving Task type (non-interrupted vs. interrupted). The results section focuses on drivers' performance in identifying the hazardous scenarios (eye movements). Eight out of the 12 hazardous scenarios have been analyzed to date. The eight scenarios are described in Table 1.

Table 1. Description of the eight scenarios analyzed

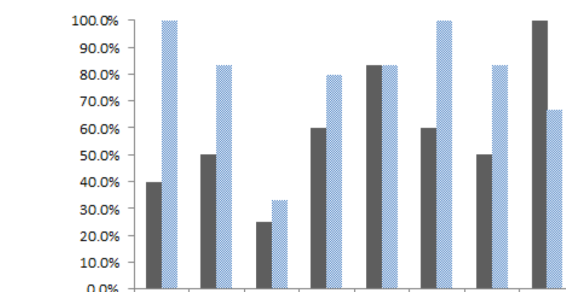
Scenario	Description
5 & 10	See Figure 2 right and left panels respectively.
6	Approaching a right T intersection from the main road (2 lanes), the driver sees a pedestrian approaching from the right (cue) toward the main road. Then the pedestrian becomes obscured. >>*Interruption*>> The driver passes the intersection and should scan to the right behind the bushes for the pedestrian (expected hazard)
11	The driver approaches a bus that stops at a bus stop (cue) on a two lane road. >>*Interruption*>> The driver should

	monitor the front left side of the bus for a potential pedestrian. At the same time there is also a pedestrian standing on the left between parked cars (unexpected hazard).
14	Approaching a crosswalk, the driver sees a crosswalk ahead sign (cue). >>*Interruption*>> The driver should scan the obscured left and right side of the crosswalk for a possible pedestrian (expected hazard). Right before the crosswalk there is a side road with a stop sign that should be scanned (unexpected hazard)
15	Driving on a 4-lane road, the driver approaches a stop controlled, 4-way intersection where the driver has the right of way. The driver sees a truck stopping at the stop line on the left lane of the right hand side of the intersection. The driver then sees another car driving on the right lane which becomes obscured by the truck (cue). >> *Interruption* >> When crossing the intersection the driver should scan the adjacent lane to the truck (expected hazard)
17	Approaching a left T intersection from the main road (2 lanes), the driver sees a car approaching from the left (cue) toward the main road. Then the car becomes obscured before the intersection. >>*Interruption*>> Once passing the intersection the driver should scan to the left behind the bushes for that car (expected hazard). Before passing the intersection there is a car approaching the main road from a driveway on the right that is partially obscured (unexpected hazard)

Based on the videos produced by the ETS, identification of a potential hazard was scored as "1" if the participant was fixating on the target during a certain period of time (launch zone; Pollatsek et al., 2006). Otherwise, identification of the potential hazard was scored zero. A logistic regression model with a random intercept within the framework of GEE was utilized to analyze the results. The identification analysis was done in two steps: (1) Analyzing whether or not participants fixated the cue given before the interruption. For this model the fixed effects were Secondary Task type, Scenario number, and their interaction. (2) For those who fixated the cue, analyzing whether or not they fixated the hazard once the interruption period was over. This model included one fixed effect, Secondary Task Type. Scenarios were not included as a fixed effect because some scenarios were identified by all participants of at least one group and that created a convergence problem with the model. Unexpected hazard were not analyzed because participants hardly ever identified them. Possible reasons for that will be discussed.

Cue Identification. The final model yielded one main effect for Scenario number (Wald X^2_3=886, p<0.01). Post hoc analysis using sequential Bonferroni tests showed that the likelihood of participants identifying the cue in scenario 9 (58%) was lower than all other scenarios. Based on this step it was decided to omit scenario 9 from the analysis.

Expected Hazard Identification. Before presenting the model, Figure 2 presents the observed proportions for identifying the hazard given the cue was identified. As shown in the figure, participants who were not interrupted were more likely to identify the hazard than those who were interrupted. The effect was especially pronounced in scenario 5. The obvious exception to this pattern was scenario 17.



	5	6	9	10	11	14	15	17
Interrupted	40.0%	50.0%	25.0%	60.0%	83.3%	60.0%	50.0%	100.0%
Not-interrupted	100.0%	83.3%	33.3%	80.0%	83.3%	100.0%	83.3%	66.7%

Figure 2. Observed proportions of hazard identification given cue identification

Careful post hoc consideration of this scenario suggested that it might be due to a design flaw (discussed further below). As such, it was decided to run the model with and without it. Without scenario 17, the Secondary Task Type effect was marginally significant (Wald X^2_1=2.851, p=0.09). The estimated likelihood of identifying the hazard was much higher for the no interruption condition than for the interruption condition [0.88(SE=0.08) vs. 0.58(0.143) respectively]. With scenario 17, Secondary Task Type effect was not significant (Wald X^2_1=1.51, p=0.22). Nevertheless, the differences between the groups was still large [0.85(0.92) vs. 0.65(0.122) respectively]. Below, we speculate regarding the observed differences across the various scenarios.

DISCUSSION

Much evidence has shown that glances for especially long periods of time inside the vehicle increase crash risk (e.g., Horrey and Wickens, 2007). Nevertheless, it is yet not clear how glances inside the vehicle disrupt the ongoing processing of information outside the vehicle. The present study explored the effect of glances inside the vehicle on the top-down processes that guide the detection and monitoring of hazards on the forward roadway.

The general findings revealed that interrupted drivers in five of seven scenarios failed more often than un-interrupted drivers to continue scanning for an expected hazard when their forward view reappeared (Figure 2). Nevertheless, it seems unlikely that interrupted drivers forgot all information regarding the hazard they were looking for. If such were the case, one might have expected them to identify the hazard much less often than they did. In fact, these drivers were able to rehabilitate their visual search (although not as good as drivers who were not interrupted) and find the expected hazard in most scenarios.

Nevertheless, there was one scenario in particular (scenario 5; Figure 1 right panel) that showed a large benefit for the un-interrupted group over the interrupted group. In this scenario, participants were given a cue that a parked car on the right is planning to merge into their path. This car became obscured by another car before the interruption began. Drivers who were interrupted had to maintain information about the location of the car with respect to the environment (absolute) and also with respect to their location on the roadway (their point of reference). Unlike for the other scenarios, it was more difficult for the driver to maintain his or her point of reference with respect to the location of the hazard. In other words, when the forward view of the road reappears there are many parked cars on both sides of the road. Thus, even if the driver glances towards the right side of the road he or she does not have completely reliable information regarding whether or not the hazard was passed. Therefore, it is arguably the case that in situations that require continuous monitoring of the hazard, drivers who are interrupted will be less likely to rehabilitate their visual search if they do not have a clear reference point regarding where the hazard might be. To support this argument, note that in all other situations the hazard occurred at an intersection which is a clear reference point regarding where the hazard might be and whether the driver had already passed it.

With regard to the unexpected hazards the present study did not show any benefit of one group over the other. In fact, both groups performed poorly in the detection of such hazards. One possible reason for this floor effect is that the unexpected scenarios selected for the study were too obscured and hard to notice. For example, in scenario 5 there was a pedestrian standing on the curb between two parked cars that intended to cross the road. No driver saw this pedestrian and we believe it is because he was in the periphery and did not make any movement.

Finally with respect to scenario 17 that shows an apparent advantage for the interrupted group, it is noted that in this scenario some fixations made by the un-interrupted group were made during the interruption period and were thus not counted. We believe that this apparent effect was caused by an inappropriate design of scenario 17 were the hypothesis regarding the location of the hazard could be verified during the interruption period.

To summarize, the present study has shown that momentary distractions may negatively affect drivers' ability to identify hazards that require continuous monitoring. For such hazards the driver needs to hold information regarding the location of the hazard with respect to the driver and the environment. From a theoretical perspective, future studies should focus on expanding the diversity of scenarios and situations and improve the unexpected hazard design so it would be possible to determine whether un-interrupted drivers are more or less likely to identify such hazards. From an applied perspective, future studies of distraction should measure not only on the effect of in-vehicle tasks on the distribution of glance durations inside the vehicle but also on the effect of in-vehicle tasks on the detection of hazards when the driver is glancing on the forward roadway. Current National Highway Traffic Safety Administration (2012) guidelines do not address this problem and, arguably, should do such.

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