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The effects of brief visual interruption tasks on drivers' ability to resume their visual search for a pre-cued hazard

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ABSTRACT

Driver visual distraction is known to increase the likelihood of being involved in a crash, especially for long glances inside the vehicle. The detrimental impact of these in-vehicle glances may carry over and disrupt the ongoing processing of information after the driver glances back up on the road. This study explored the effect of different types of visual tasks inside the vehicle on the top-down processes that guide the detection and monitoring of road hazards after the driver glances back towards the road. Using a driving simulator, 56 participants were monitored with an eye tracking system while they navigated various hazardous scenarios in one of four experimental conditions. In all conditions, a potential hazard was visible 4–5 s before the driver could strike the potential hazard were it to materialize. All interruptions were exactly two seconds in length. After the interruption the potential hazard again became visible for about a half-second after which the driver passed by the hazard. The nature of the in-vehicle visual interruption presented to the participants was varied across conditions: (1) Visual interruptions comprised of spatial, driving unrelated, tasks; (2) visual interruptions comprised of non-spatial, driving unrelated, tasks; (3) visual interruptions with no tasks added; and (4) no visual interruptions. In the first three conditions drivers glancing on the forward roadway was momentarily interrupted (either with or without a task) just after the potential hazard first became visible by the occurrence of an in-vehicle task lasting two seconds. In the last condition (no interruptions) the driver could not see the potential hazard after it just became visible because of obstructions in the built or natural environment. The obstruction (like the interruption) lasted for two seconds. In other words, across all conditions the hazard was visible, then became invisible, and finally became visible again. Importantly, the results show that the presence of an interruption (as opposed to an obstruction) negatively impacted drivers' ability to anticipate the potential hazard. Moreover, the various types of interruptions had differential effects on hazard detection. The implications of this study for the design of in-vehicle displays are discussed.

1. Introduction

With the increased prevalence and level of sophistication of In-Vehicle Information Systems (IVIS) as well as portable technologies such as smartphones, frequent, long glances to in-vehicle displays have become a major safety concern (Birrell and Fowkes, 2014)—especially as these glances have been associated with increased crash risk (e.g., Wierwille and Tijerina, 1998; Klauer et al., 2006, 2014). In an attempt to moderate the negative impact of IVIS on drivers' visual attention, the National Highway Traffic Safety Administration (NHTSA) developed guidelines associated with restricting glance behaviors for drivers engaged in a visual-manual non-driving task. According to these guidelines, drivers should be able to complete an in-vehicle task with glances away from the roadway of two seconds or less and with a total cumulative off-road glance duration of 12 s (NHTSA, 2012).

Glancing inside the vehicle for especially long periods of time impairs drivers' ability to anticipate and react to hazardous situations (e.g., Horrey and Wickens, 2007; Klauer et al., 2014). While their eyes are directed inside the vehicle, drivers may miss critical on-road information. As poor hazard anticipation skills have been associated with increases in crash risk (e.g., Horswill and McKenna,

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2004; Horswill et al., 2015) it is clear why the duration of in-vehicle glances should be restricted.

In a recent study we found that drivers' hazard anticipation skills were compromised not only when they glanced inside the vehicle but also in the moments after they return their eyes to the roadway (Borowsky et al., 2014). In the study, we designed hazard scenarios in which a cue regarding an upcoming hazard appeared first, followed by a two second interval in which the hazard became obscured. Following this interruption, drivers were expected to direct their gaze to the area where the pre-cued hazard might materialize to check the potential of the threat. For example, a car coming from a side street to the left started moving towards the main road and then became obscured behind vegetation close to the intersection. After passing the vegetation and right before passing the intersection, drivers should look left to search for the hidden car. For a number of similarly structured scenarios, half of the participants were momentarily interrupted by a visual-spatial task unrelated to driving called the asterisks task that was intended to simulate a two second glance inside the vehicle where drivers need to process spatial information. In this task the view of the roadway on the center screen was occluded by a black screen containing 10 white asterisks. Of these, 9 asterisks were moving and one was stationary. The driver was asked to find and fixate on the stationary asterisk. This task was similar to that reported in Klauer and Zhao (2004). The other half of drivers was not interrupted by the above task and could access the driving scene; however, like the drivers in the interrupted condition, they did not benefit from any additional information regarding the emerging threat because of built and natural obstructions in the environment that obscured their view of the hazard and its location. The results showed that drivers who were momentarily interrupted made fewer anticipatory glances (or no glances at all) towards the hazard locations than drivers who were not interrupted.

This finding suggests that working memory may play a key role in the process of hazard anticipation and detection. We briefly describe two possible ways that working memory can play such a role in these important driving subtasks. First, in a study by Lleras et al. (2005), it was shown that working memory is important for maintaining a perceptual hypothesis regarding the identity, location and trajectory of an object in the environment when an interruption occurs during the visual search task. In this study, participants were instructed to find a target letter 'T' among various distractors presented on a static display, say the letter 'L'. Each target-distractor configuration was presented for 100 ms followed by 900 ms of gray screen referred to as the interruption. Each specific pair of target-distractor configuration and interruption displays (called an epoch) repeated itself until the subject identified the target. The results showed that participants who identified the target on the first epoch were much slower than participants who identified the target on the following epochs. Lleras et al. (2005) argued that working memory was being used during the second interruption display to maintain the information about the orientation and location of the target. Thus, if some secondary task had been given to participants while the interruption display was present, it could well have degraded memory for the orientation and location of the target. This is exactly what was done in Borowsky et al. (2014). Specifically, during the interruption a secondary task was given to participants. The presence of a secondary (interruption) task in the Borowsky et al. (2014) study could have increased the likelihood that drivers were not able to maintain all the details included in the perceptual hypothesis in working memory (e.g., identity of the hazard, its trajectory, and its location), leading to a lower rate of hazard detection afterwards.

Second, the hazard detection task used in the Borowsky et al. (2014) study may be seen as a prospective memory task (i.e., memory of the intention to perform a planned action sometimes in the future; Stone, Dismukes, and Remington, 2001; Einstein and McDaniel, 2005). That is, providing a driver with a cue signaling an upcoming hazard should indicate to drivers that they need to monitor and track this information, in order to detect the hazard once it appears. Following the brief interruption, drivers should remember to resume the search for the hazard that was cued prior to the interruption. In other words, during the interruption the driver should maintain his/her intention (in working memory) to detect the hazard once the interruption ends. The interruption dilutes the memory of this intention and can lead to a lower rate of hazard detection.

In summary, there are two possible explanations of how a secondary task interacts with working memory to create a decrease in performance. Regardless of which explanation is the correct one (a driver maintains his or her intention to search for a hazard, but loses track of the identify, location and trajectory of the hazard, or the driver forgets his or her intention to search for a hazard, but if asked could recall the location, identity and trajectory of the hazard), it is the observed increase in load created by the performance of the secondary task which it has been argued is presumed to reduce performance (Borowsky et al., 2014). However, it well could have been that visual occlusion by itself was the main contributor to poor hazard anticipation performance as opposed to the workload imposed on working memory during the interruption. This is the first question we address in the current experiment (Question 1).

Furthermore, we go on to answer another question that was not addressed in Borowsky et al. (2014) and is critical to the design of in-vehicle displays. Specifically, recent evidence shows that different types of interrupting tasks may have differential effects on the performance of the primary task (Klauer and Zhao, 2004; Ross et al., 2014). For example, Klauer and Zhao (2004) found that spatial working memory tasks (e.g., remembering the location of a dot on a display) were disrupted more by spatial interference tasks (relating to trajectories and locations) than by visual, but non-spatial tasks (relating to shapes and colors of objects)—an outcome that is consistent with predictions from multiple resource theory (e.g., Wickens, 2002). If one assumes that driving and hazard anticipation require the processing and storage of spatial information (e.g., the location of the target) more than non-spatial information then one might expect that a spatially related in-vehicle secondary task may have a larger effect on hazard anticipation performance than a non-spatial in-vehicle task. This second question is also evaluated below (Question 2).

Next, in addition to the argument that different types of secondary tasks might affect hazard anticipation, the literature also suggests that drivers reduce their longitudinal velocity when their field of view is briefly occluded, whether the driver is asked to perform a secondary task during this occlusion or not (e.g., Curry et al., 1975; Antin et al., 1990; Engström et al., 2005). This has been interpreted as a compensatory effect, where the driver reduces the primary task load (i.e., speed maintenance) in order to maintain driving performance on an acceptable level. Engström et al., (2005) for example, reported results from simulated and real motorway driving and showed that in all experiments the longitudinal velocity was reduced when a secondary visually demanding task (identifying a target arrow oriented differently from similar arrow distractors) was involved. Since we are using different types of visual tasks we are also interested in examining whether the compensation effect is similar across secondary tasks or depends on the level of difficulty of the secondary task. We have designed our study so that we can evaluate this third question (Question 3).

Finally, Borowsky et al. (2014) asked drivers to rate their level of effort and performance on the driving task and on the secondary task. The authors found that while drivers in both the interruption and no-interruption condition reported similar levels of driving performance, drivers who were interrupted by the spatial