COGNITIVE DISTRACTION IMPAIRS DRIVERS' ANTICIPATORY GLANCES: AN ON-ROAD STUDY

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Summary: This study assessed the impact of cognitive distraction on drivers' anticipatory glances. Participants drove an instrumented vehicle and executed a number of secondary tasks associated with increasing levels of mental workload including: listening to the radio or audiobook, talking on a handheld or hands-free cellphone, interacting with a voice-based e-mail/text system, and executing a highly demanding task (Operational Span task; OSPAN). Drivers' visual scanning behavior was recorded by four different high definition cameras and coded off-line frame-by-frame. Visual scanning behavior at road intersections with crosswalks was targeted because distraction is one of the major causes of accidents at these locations (NHTSA, 2010a). Despite the familiarity of the locations, results showed that as the secondary-task became more cognitively demanding drivers reduced the amount of anticipatory glances to potential hazards locations. For example, while interacting with a high fidelity voice-based email/text system, the probability of executing a complete scan of the intersection was reduced by 11% compared to the no-distraction control condition. These results document the effects of cognitive distraction on drivers' visual scanning for potential hazards and highlight the detrimental role of voice based systems on driving behavior.

OBJECTIVES

Distraction represents one of the main causes of mortality on the road (NHTSA, 2010b). Activities involving manual and visual distraction (see Strayer et al., 2013) such as eating, interacting with the radio, texting and using a handheld cell phone represent the most common sources of distraction for drivers (Stutts et al., 2003). Since these activities often require drivers to take their hands off the steering wheel and their eyes off the road, car-manufacturers and policy-makers have recently focused their attention on voice-based technologies as a way to tackle distraction and its consequences on road safety. Because using voice-based technologies requires limited amount of visual and manual interaction, these devices are claimed to be capable of reducing the amount of driving distraction and, as a consequence, the risk of accidents (see Peissner, Doebler, & Metze, 2011).

The most subtle and hard-to-measure type of distraction is the cognitive (Strayer et al., 2011). Cognitive distraction arises when part of the driver's attentional resources is directed toward the execution of a secondary, driving-unrelated task. The more resources the task requires, the more distractive the task becomes. In the study of Rossi, Gastaldi, Biondi and Mulatti (2012), authors had participants driving a simulated vehicle and executing a cognitive task requiring them to listen to auditory words, process them and produce vocal responses. When these two tasks were executed concurrently, compared to when participants were driving only, they were observed to produce slower braking responses. In a driving simulator study by Taylor et al. (2013), authors were interested in observing how cognitive distraction affected drivers' anticipatory glances when approaching locations where hazards could potentially appear. In the not-distracted condition participants were driving only, whereas when distracted they were instructed to carry on a conversation on a hands-free cell phone. The simulated environment contained a number of hazard locations. An example was a truck parked on the right of the street obscuring the driver's view of a crosswalk where a hazard such as a pedestrian could potentially appear. Although the hazard was never present, undistracted drivers were found to visually scan the front side of the truck in order to anticipate a potential danger. On the other hand, when talking on the hands-free cell phone, drivers were found to significantly reduce the likelihood of glancing at the exact location and, as a consequence, were less aware of what happened within the surrounding environment. This study aims to investigate how drivers' hazard anticipation is affected by executing a number of everyday tasks when driving a real vehicle within a real environment. It is indeed possible that findings obtained in simulated studies, as in the case of Taylor et al. (2013), might not be fully replicated when participants are at the wheel of a real car (Haigney & Westerman, 2010). In addition, as hazard locations we considered road intersections that, unlike locations designed by Taylor and colleagues (2013), are highly familiar to drivers. As tasks, we had participants executing a large number of everyday tasks including listening to the radio, talking on a hands-free cell phone and, more interestingly, interacting with a voice-based messaging system.

METHODS

Participants

Twenty-five undergraduate students (15 women) at the University of Utah participated in this study. They had an average age of 23 years old and a driving experience ranging from 2.5 to 14.5 years with an average of 6.9 years. All participants had normal neurological functioning, normal or corrected-to-normal visual acuity, normal color vision, a valid driver's license, and were fluent in English. All participants owned a cell phone and reported that they used it regularly while driving.

Equipment

Participants drove a 2010 Subaru Outback augmented with four 1080p LifeCam USB cameras that captured the driving environment and participants' facial features. In addition, a global positioning system (GPS) was installed in the vehicle to help coders in identifying drivers' position at intersections. Cellular service was provided by Sprint. The cellular phone was manufactured by Samsung (Model M360) and the hands-free earpiece was manufactured by Jawbone (Model Era). Participants dialed a friend or family member and the volume for both the cellular phone and the hands-free earpiece was adjusted prior to the task. NaturalReader 10.0 software was used to simulate an interactive messaging service with text-to-speech features. The NaturalReader program was controlled by the experimenter who reacted to the participants' verbal commands, mimicking a speech detection system with perfect fidelity. If a participant did not use the correct command, the NaturalReader program would not continue.

Route

The experiment took place in a residential and low traffic density neighborhood in order to guarantee each participant had a similar driving experience. Also, the experiment was conducted in the mid-morning and afternoon in order to avoid rush hours. A 2.75-mile loop in the Avenues section of Salt Lake City, UT, composed by a two opposite traffic lanes road was considered. Thirty-four different intersections were identified. Because of the large amount of distraction-related accidents occurring at these location (NHTSA, 2010a), we defined road intersections as hazard locations. Hazard locations were classified as high or low priority depending on the extent to which failing to properly scan the environment would lead to potential accidents. High-priority hazard locations (18 in total) were intersections having a crosswalk, stop sign, or stoplight where failing to execute a full scan of the road environment, given the large numbers of potential hazards, increases the risk of accidents. On the other hand, low-priority hazard locations (16 in total) were those having neither crosswalks nor stop signs.

Task and instruction

Eight different conditions involving an increasing amount of cognitive load were considered in this experiment. (1) Single-task. Participants drove along the route without performing any other task. (2) Radio. Drivers were asked to choose a radio station that they would like to listen to while driving. (3) Audiobook. Drivers were asked to choose an excerpt from an audiobook to listen to while driving. (4) Passenger. An experimenter sat in the passenger seat of the car and maintained a conversation throughout the scenario about topics the participant provided to the experimenter in advance. (5) Handheld. Drivers were talking on a handheld cell-phone (which was legal in the state of Utah at the time of the experiment). Drivers were instructed to keep conversing throughout the scenario; in case of technical problems (e.g., call drops), the drive was paused until the conversation was restored. (6) Hands-free. Same as condition 5 but with a hands-free cell-phone. (7) Speech-to-text. Drivers used a hands-free email system; they listened and replied to emails read to them from an artificial voice. After each email was read, drivers were instructed to use the following voice commands: “delete”, “reply”, “send” and “next message” in order to navigate through their message inbox. Also, drivers could dictate the text of their responses to the emails. (8) Operation Span task (OSPAN; for a description of the task see Strayer et al., 2013). The OSPAN task is a complex span task that requires participants to simultaneously perform a math and memorization task. It was chosen to anchor the highest level of cognitive workload.

Procedure

Prior to their appointment time, participants were sent the ethics committee approved informed consent document, general demographic survey, and instructions for completing the twenty-minute online defensive driving course and the certification test. We also obtained a Motor Vehicle Record report on the driver to ensure a clean driving record. Before beginning the study, the driver was familiarized with the controls of the instrumented vehicle, adjusted the mirrors and seat, and was informed of the tasks to be completed while driving. Participants drove the loop once in order to become familiar with the route. A research assistant and an experimenter accompanied the participant in the vehicle at all times. The research assistant sat in the rear while the experimenter sat in the front passenger seat and had ready access to a redundant braking system that would operate whenever the driver failed to detect any potential roadway hazards. After the experiment begun, participants drove the loop eight times, one for each of the experimental conditions. For each condition, participants drove across the thirty-four road intersections while performing the same secondary task. The order of the eight driving conditions was counterbalanced across participants through a Latin square design. During the execution of the speech-to-text task, as mentioned above, the system was controlled by the research assistant: after the driver produced a command vocally, the research assistant executed it manually on the computer on which the NaturalReader was installed giving the impression to the driver that the speech-to-text system executed it autonomously instead. The driver was completely unaware of this procedure.

Coding system

At each of these hazard locations, drivers' behavior data was coded frame-by-frame to record: glances to the left and to the right of the forward roadway (hereafter called lateral glances), glances at rearview mirror and dashboard (hereafter called glances at instruments) and lateral head movement. Lateral glances were recorded as complete (2 points) if drivers looked to both the left and right. Partially complete scans (1 point) were recorded where the drivers looked to either the left or right, and incomplete scans (0 points) were recorded where drivers failed to scan for hazards. For coding glances at instruments, 1 and 0 points were assigned to participants if, respectively, at least one and no glances were executed either up or down. Lateral head movements were considered as observed changes in the direction of head movements. Lateral head movements were scored by coding the combined information from the two cameras capturing drivers' facial features (for a similar procedure see, Hancock, Wulf, Thom, & Fassnacht, 1990). In particular, 1 or 0 points were assigned if, respectively, at least one or no movements to either the right or left were executed Points scored for glances and head movements were converted to percentages and then analyzed (100% and 0% as, respectively, complete and minimum scores). Each drive was analyzed by at least two trained coders (seven in total) and any discrepancies in the coding were flagged and reviewed for consistency by a third coder. In general, coders were very accurate and only a small number of events needed to be double-checked. An Intra-class Correlation (ICC) analysis for ordinal variables was performed to measure the consistency. We obtained an excellent ICC value of 0.74.

RESULTS

Scores for glances and head movements were converted to percentages and then analyzed. For lateral glances, 100% and 0% scores were assigned to participants who executed a complete scan of the road environment (right and left glances) either 100% or 0% of the times, respectively.

Lateral glances

Lateral glance probability was analyzed by executing a repeated measures analysis of variance (ANOVA) with task (8 levels: (1) single task, (2) radio, (3) audiobook, (4) passenger conversation, (5) handheld cell phone, (6) hands-free cell phone, (7) speech-to-text, and (8) OSPAN) and priority (2 levels: high and low priority intersections) as within-subjects factors. Significant main effects of task (F(7,168)=4.3, partial η2 = .15, p<.05) and priority (F(1,24)=190.3, partial η2 = .88, p<.05) and interaction task x priority (F(7,168)=3.4, partial η2 = .12, p<.05) were found. Successive pairwise comparisons used Bonferroni correction. All the tasks, except Radio (71%), significantly differed from Single-task (74%, ps<.05). Interestingly, no significant differences were found between tasks 3 through 8 (Audiobook:67%, Passenger:65%, Handheld phone:66%, Hands-free phone:66%, Speech-to-tex:63%, OSPAN:63%). A higher glance probability was found for high priority hazard locations compared to low priority locations (76% vs. 56%). A repeated measures ANOVA with task (8 levels) as a within-subject factor was executed to test for any differences in lateral glance probability recorded at stop-controlled intersections. A significant main effect of task (F(7,168)=5.3, partial η2 = .18, p<.05) was found. Successive pairwise comparisons revealed significant differences (ps<.05) for lateral glances at stop-controlled intersections between single-task (89%) and, respectively, handheld cell phone (81%), hands-free cell phone(82%), and speech-to-text (85%). No differences between these three conditions were found.

Glances at instruments

Glance probability at instruments was analyzed by executing a repeated measures analysis of variance (ANOVA) with task (8 levels: (1) single task, (2) radio, (3) audiobook, (4) passenger conversation, (5) handheld cell phone, (6) hands-free cell phone, (7) speech-to-text, and (8) OSPAN) and priority (2 levels: high and low priority intersections) as within-subjects factors. Significant main effects of task (F(7,168)=8.4, partial η2 = .26, p<.05) and priority (F(1,24)=70.6, partial η2 = .74, p<.05) were found. Significant differences were found between single-task (31%) and, respectively, speech-to-text (19%) and OSPAN (16%, ps<.05). Glance probability at instruments was lower for high-priority hazard location than for low priority locations (16% vs. 31%).

Head movement

Lateral head movement probability was analyzed by executing a repeated measures analysis of variance (ANOVA) with task (8 levels: (1) single task, (2) radio, (3) audiobook, (4) passenger conversation, (5) handheld cell phone, (6) hands-free cell phone, (7) speech-to-text, and (8) OSPAN) and priority (2 levels: high and low priority) as within-subjects factors. A significant main effects of priority (F(1,24)=811.6, partial η2 = .97, p<.05) was found. Drivers were more likely to scan the driving environment assisted by head movements at high priority intersections when compared to low priority intersections (54% vs. 14%).

CONCLUSION

As the secondary cognitive task becomes more demanding (Strayer et al., 2013), drivers are less likely to execute a complete scan (i.e., right and left glances) of the road environment at intersections and, therefore, anticipate potential hazards. As suggested by the situation awareness model of Fisher and Strayer (2014), this finding may be accounted for as a consequence of the capacity-limited nature of our cognitive system (Kahneman, 1973). As the amount of cognitive resources required by the execution of the secondary, driving-unrelated task increases, the amount left to be directed toward driving is reduced and, as a consequence, drivers become less capable of predicting the occurrence of potential hazards at road intersections. The importance of this finding is twofold. Because intersections are highly experienced by and familiar to drivers, scanning the surrounding environment while at these locations may be considered as a quite automated process (Schneider & Chein, 2003) for drivers. The fact that as the amount of resources required by the secondary task increased drivers made fewer anticipatory glances suggests that cognitive distraction impairs many aspects of driving, no matter the level of experience associated with them. In addition, since cross-roads are considered to be among the most dangerous road sections (NHTSA, 2010a), failing to scan for potential hazards as a result of distraction may therefore increase the probability of accidents.

Because executing auditory-vocal tasks requires a small amount of off-road glances by drivers (Owens, McLaughlin, & Sudweeks, 2011), interacting with voice-based technologies is often thought to reduce the disruptive effects of distraction and, as a consequence, have no negative impact on road safety (see Peissner et al., 2011). In the report released by the National Highway Administration in 2012 (NHTSA, 2012), it is indeed suggested that manufacturers should look more into the auditory-vocal types of interactions when designing new in-car systems. The results obtained in our experiment argue for caution on accepting this recommendation. In fact, interacting with the speech-to-text system not only increased the amount of mental workload compared to the single-task condition (Strayer et al.,2013) but, in addition, it led to a decrease in anticipatory glances by 20% compared to when participants were driving only. These results are even more dramatic given that our system was completely errors-free. Because the system was controlled manually by a research assistant, no errors in capturing and comprehending the drivers' voice as well as executing their commands were performed by the system. Nonetheless, a failure in executing anticipatory glances was observed even at stop-controlled intersections where executing a complete scan of the environment is mandatory and of the primary importance to avoid likely accidents. Another result concerns head movements. As road intersections became more relevant in terms of how important a complete scan of the environment was to avoid likely accidents (low versus high priority intersections), participants were observed to produce more rightward and leftward head movements. These findings are consistent with those obtained by Hancock et al. (1990) who found that as drivers realize the driving task is becoming more complex, they are more likely to execute auxiliary behaviors such as turning their head at road intersections. In conclusion, our results show that anticipating hazards on the roadway is not immune to the cognitive distraction associated with executing secondary tasks such as interacting with voice-based technologies. We suggest that additional research is needed before claiming that voice-based technologies are risk-free. Since a significant number of car-manufacturers and technology companies are making these systems available to drivers, the impact of these technologies on road safety represents an issue of the utmost importance for future research.

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