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Cognitive load while driving impairs memory of moving but not stationary elements within the environment☆

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ABSTRACT

The negative impact of cognitive load, such as cell phone conversations, while driving is well established, but understanding the nature of this performance deficit is still being developed. To test the impact of load on awareness of different elements in a driving scene, memory for items within the environment was examined under load and no load conditions. Participants drove through two different scenarios in a driving simulator, were periodically interrupted by a pause in the driving during, and were asked questions regarding moving and stationary objects in the environment. Participants in the load condition drove while concurrently counting backwards by sevens. Results indicate that driving under load conditions led to diminished knowledge of moving, but not stationary, objects in the scene. This result suggests not all types of knowledge are equally impaired. Potential implications for current theories of cell phone use while driving and applied attention theory are discussed.

Driving is a complex task that requires individuals to monitor and update multiple pieces of information (e.g., speed, direction, road signs, other vehicles), often placing heavy demands on attention and memory mechanisms (see Groeger, 2000; Moray, 1990; Senders, Kristofferson, Levison, Dietrich, & Ward, 1967). Successfully keeping track of this information is necessary to get where you are going, avoid accidents, or other undesirable events such as getting a speeding ticket. However, with improvements in technology that are centered on providing information to the driver (e.g., GPS navigational systems) and the multitude of other technology-based distractions (e.g., cell phones), drivers are increasingly operating under conditions that place a greater demand on successfully allocating attentional resources. Research shows these distractions, particularly conversing on a cell phone, can substantially impair driving (Strayer, Drews, & Johnston 2003; Strayer & Johnston, 2001).

However, this impairment may not be global; that is, when driving with distractions, knowledge of some driving elements may remain intact while others suffer. The current study further examines one possibility by assessing how distracted driving impacts knowledge of both moving and stationary elements in the driving environment using a memory recall task. Measuring knowledge of stationary and moving elements offers insights into how drivers are allocating attention; knowledge of stationary elements indicates attention toward rule following/updating while knowledge of dynamic elements indicates attention toward hazard avoidance.

1. Load and driving

Previous research suggests that conversing on a cell phone while driving (i.e., driving under cognitive load) can significantly impair driving ability above and beyond other distractions such as listening to the radio or conversing with passengers (e.g., Caird, Willness, Steel, & Scialfa, 2008; Drews, Pasupathi, & Strayer, 2008; Horrey & Wickens, 2006; Rakauskas, Gugerty, & Ward, 2004; Redelmeier & Tibshirani, 1997; Strayer & Drews, 2007; Strayer & Johnston, 2001; Strayer et al., 2003). However, as Drews et al. (2008) pointed out, much of the prior work on the impact of cell phone use while driving has focused on assessing the level of impairment, and has glossed over the cognitive mechanisms underlying the impairment. Recent research, however, has begun to examine these mechanisms.

☆ Portions of these data were previously published in the 2009 Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting (Blalock, Sawyer, Kiken, & Clegg, 2009).

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Strayer and Drews (2007) (see also Strayer et al., 2003) argue that cell-phone use while driving can lead to inattentional blindness (the failure to notice prominent objects in the environment; Wickens & McCarley, 2008). More specifically, they argue that the cell phone conversation diverts attention from driving, causing drivers to sometimes miss critical events in the driving environment (e.g., a car in a driver's blindspot; Strayer & Drews, 2007; Strayer et al., 2003; Strayer & Johnston, 2001). Strayer et al. (2003) showed that participants who drove while talking on a hands-free cell phone were also unable to recognize billboards present in the drive in a surprise recognition test – even though a separate eye tracking experiment showed participants fixated on the signs. This evidence provides support for an inattentional blindness hypothesis: even when drivers look at elements in the driving environment, they may not process them.

This inattention also holds true for high priority (e.g., child playing near a road) elements in the driving environment, suggesting that drivers are not strategically diverting attention away from low priority elements (e.g., billboards) to high priority elements when driving under cognitive load conditions (Strayer & Drews, 2007; though see Gugerty, 1997, 1998; for a different view). In fact, Strayer and Drews (2007) report no association between recognition memory of driving elements, and the priority of those elements in terms of safety relevance, suggesting an overall reduction of attention for all driving elements when drivers are under a cognitive load. The interference between a primarily visual task (driving) and a primarily verbal task (cell phone conversation) also suggests the impairment may be due to limited general resource or a central attentional bottleneck (Strayer & Drews, 2007; see also Morey & Cowan, 2005).

Similarly, in examining change blindness in driving McCarley et al. (2004) measured change detection performance and eye movements while participants viewed snapshots of real-world driving scenes. Change detection was impaired when participants held an ongoing, naturalistic cell phone conversation even though they were not actively driving. Importantly the cell phone use condition also resulted in less efficient visual search; in other words, more saccades were required to detect changes, and participants exhibited a slower fixation time. McCarley et al. thus argued that changes in visual scanning as a result of load suggested reduced visual encoding of objects in driving scenes, which could be related to inattentional blindness. There is therefore some evidence to suggest that load during driving could result in both change blindness and inattention blindness (although we caution that both do not have to jointly apply).

Converging evidence is found in examining the literature on driver situation awareness. Situation awareness refers to operators' ability to perceive, understand, and predict events in the environment (Durso & Gronlund, 1999; Endsley, 1988, 1995a, 1995b, 2000). The dynamic nature of driving makes it a good domain for applying the construct of situation awareness. Relevant to the discussion of how load impacts drivers, Kass, Cole, and Stanny (2007) examined how cognitive load impacts situation awareness by comparing experienced and novice drivers who drove under non-distracted (driving normally) or distracted (simulated hands-free cell phone conversation) conditions. Regardless of experience level, drivers conversing on the phone suffered significant situation awareness deficits (measured as subjective recall such as "how many cars backed out in front of you?"), providing evidence that cognitive load plays a role in the attention-related components of driving.

Taken together, the above research suggests the driving impairments found while talking on a cell phone can be attributed to reduced attention resources (e.g., Strayer et al., 2003), inefficient visual search patterns (McCarley et al., 2004), and poor situation awareness (Kass et al., 2007). However, in all of this research, the impairment was examined at a global level; that is research has not yet compared whether drivers allocate attention differently to different types of elements in the driving scene. The current experiment examines this question.

2. Current experiment

The key issue for the current study was to examine knowledge of elements that differed in a key characteristic (moving or stationary locations) in the driving environment, and how this knowledge may be altered under conditions of cognitive load. Although driving naturally induces changes in the egocentric location of elements (i.e., relative to the driver's viewpoint, such as buildings or signs moving past the driver), some elements also change in allocentric location (i.e., relative to a fixed point in space, such as other moving cars). There is evidence that memories for egocentric and allocentric information are derived independently but in parallel (for a review, see Burgess, 2006). Once motion begins, almost all elements within the driving scene would require constant updating relative to an egocentric frame of reference. This updating process could promote reliance on an allocentric spatial representation to lower the cognitive costs of updating, which would require working memory resources (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Miyake, Friedman, Rettinger, Shah & Hegarty, 2001; Shah & Miyake, 1996).

However, variations in the allocentric location also exist for objects within the driving environment. We define *moving elements* as those changing in allocentric location, and *stationary elements* as those with fixed allocentric locations. Crucially these two distinctions in allocentric location characteristics are highly related to different primary tasks in driving. Driver navigation and rule following/updating depend primarily on information from within the environment that is fixed in allocentric coordinates (for example, road signs and lane indicators). In contrast, hazard avoidance depends on monitoring and predicting elements in the environment with changing allocentric coordinates (such a nearby vehicles; e.g., Gugerty, 1997, 1998, 2004).

Establishing which types of knowledge are affected by cognitive load during driving provides additional explanatory power in understanding the role of distraction. Contrasting predictions, though not necessarily mutually exclusive, can be made for how these different types of information might be impacted. On the one hand, static elements within a driving scene tend to be by their very nature in the periphery when drivers are looking forward, since stationary items within the roadway itself would tend to impede traffic. Thus, reduced attentional capacity may differentially impact these items given that cognitive load is known to reduce scanning of the periphery (e.g., Recarte & Nunes, 2003), and should lead to worse memory for the static items within a driving scene. On the other hand, changes in allocentric location might make maintaining effective representation of those items harder, especially given reduced activity in the parietal lobe areas responsible for spatial processing occurs when a secondary verbal task is added to driving (Just, Keller, & Cynkar, 2008). This reduction in spatial processing would suggest that a differential impact might occur for the higher bandwidth spatial elements (such as other road users' locations) compared to lower bandwidth items. This would lead to lower memory for dynamic items within a driving scene. The current study sought to investigate how driver distraction impacts memory for different, yet critical, types of information (moving versus stationary elements) present in a typical driving environment.

3. Method

3.1. Participants and design

Thirty-three Colorado State University undergraduate students (mean age = 19; 20 males, 13 females) with valid driving licenses