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Driver performance effects of simultaneous visual and cognitive distraction and adaptation behavior

David B. Kaber [a,*], Yulan Liang [b], Yu Zhang [a], Meghan L. Rogers [a], Shruti Gangakhedkar [a]

[a] Edward P. Fitts Department of Industrial & Systems Engineering, North Carolina State University, Raleigh, NC 27695-7906, USA
[b] Liberty Mutual Institute for Safety, 71 Frankland Road, Hopkinton, MA 01748, USA

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ABSTRACT

Driver distraction has become a major concern for transportation safety due to increasing use of infotainment systems in vehicles. To reduce safety risks, it is crucial to understand how fundamental aspects of distracting activities affect driver behavior at different levels of vehicle control. This study used a simulator-based experiment to assess the effects of visual, cognitive and simultaneous distraction on operational (braking, accelerating) and tactical (maneuvering) control of vehicles. Twenty drivers participated in the study and drove in lead-car following or passing scenarios under four distraction conditions: without distraction, with visual distraction, with cognitive distraction, and with simultaneous distraction. Results revealed higher perceived workload for passing than following. Simultaneous distraction was most demanding and also resulted in the greatest steering errors among distraction conditions during both driving tasks. During passing, drivers also appeared to slow down their responses to secondary distraction tasks as workload increased. Visual distraction was associated with more off-road glances (to an in-vehicle device) and resulted in high workload. Longer headway times were also observed under visual distraction, suggesting driver adaptation to the workload. Similarly, cognitive distraction also increased driver workload but this demand did not translate into steering errors as high as for visual distraction. In general, findings indicate that tactical control of a vehicle demands more workload than operational control. Visual and cognitive distractions both increase driver workload, but they influence vehicle control and gaze behavior in different ways.

1. Introduction

The soaring popularity of in-vehicle infotainment systems (e.g., navigation systems, mp3 players, smart phones, etc.) has raised concern for driver distractions and roadway safety. A study that examined the behavior of 100 drivers in a naturalistic environment showed that 78% of crashes ($n = 100$) and 65% of near-crashes ($n = 100$) involved some form of driver inattention, among which distraction by in-vehicle infotainment systems accounted for approximately 25% of all events (Klauer et al., 2006). Roadway safety risks due to inattention have been found to be especially high for young drivers because of their inexperience and high adoption of new technology (Lee, 2007; Stutts, 2001). To mitigate such risks it is important to understand how distracting activities affect driver behavior.

Driving tasks require a driver to monitor and comprehend the roadway in real time and to make timely decisions to maneuver a vehicle safely (Ma & Kaber, 2005). Driving involves three levels of skill or control including operational, tactical

* Corresponding author. Address: 400 Daniels Hall, 111 Lampe Dr., Raleigh, NC 27695-7906, USA. Tel.: +1 919 515 0312; fax: +1 919 515 5281.
E-mail address: dbkaber@ncsu.edu (D.B. Kaber).

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and strategic (Michon, 1985). Operational control refers to driver reactions to roadway situations with limited conscious control, such as reactive steering or braking due to sudden changes in lead vehicle behavior. This level of control relies on sensorimotor skills of drivers and occurs in the millisecond time frame. Tactical control requires drivers to maneuver a vehicle in response to roadway conditions, including negotiation of traffic, intersections, etc. For example, drivers may reduce speed or overtake a slow vehicle based on immediate roadway demands, such as following traffic. This type of control occurs in time frame of several seconds. Strategic control refers to route planning, including goal selection and identification of route criteria, and operates on the time scale of minutes to hours (enroute or offline, respectively). Among these three levels, operational and tactical controls are required by real-time traffic negotiation. Failures in these two types of control can lead to crashes. Young drivers are especially vulnerable to poor performance at these two levels of control because they may be inexperienced in vehicle control skills; they may not be able to correctly identify/anticipate hazards; and they may poorly judge their own abilities in driving (Lee, 2007). These vulnerabilities may also be exaggerated under distraction situations.

Driver distraction is defined as a diversion of attention away from activities critical to safe driving for performance of a secondary competing activity (Lee, Regan, & Young, 2009). Multiple resource theory (MRT) suggests that secondary tasks that compete for the same resources required by driving could degrade driver performance (Wickens, 2002). Two essential resources for driving are visual attention to perceive the roadway situation and central processing resources to comprehend and project situations and make decisions. Secondary tasks demanding these two types of resources (e.g., cell phone use, navigation aid use) pose visual and cognitive distractions to driving. Visual distraction attracts visual attention from the roadway; cognitive distraction competes with driving tasks for central processing resources.

These two types of distraction can affect driver behavior and undermine driving performance. Visual distractions can cause drivers to look away from the roadway (e.g., to reprogram a navigation aid) and has been found to lead to large and frequent lane deviations, uneven steering control, and slow responses to lead vehicle braking (Dingus et al., 1989; Zhang, Smith, & Witt, 2006). Compared to visual distraction, cognitive distraction has a less overt effect. Cognitive distractions can also cause drivers to fail to perceive critical cues in the roadway environment but, more importantly, fail to project the intent of other drivers (Malaterre, 1990). Recarte and Nunes (2000) found cognitive distraction to cause drivers to concentrate their gaze in the center of the driving scene. This diminished their ability to detect targets across the entire driving scene and to effectively plan vehicle control behaviors. Similarly, Strayer, Drews, and Johnston (2003) found cognitive distraction to impair the comprehension of information related to objects that drivers look at. From a performance perspective, cognitive distraction has also been found to delay driver responses to hazards and cause uneven steering control (Horrey & Wickens, 2006).

However, the effects of distraction are not passively imposed on drivers. Drivers usually chose to engage themselves in a secondary task and adapt their behavior accordingly. During visual distraction, drivers intermittently sample roadway situations before finishing a secondary task. Senders et al. (1967) modeled this behavior sampling based on data from an in vivo experiment in which drivers wore a helmet to obstruct their peripheral vision. They observed that when drivers looked away from the road with focal vision, uncertainty about the roadway situation increased. When uncertainty reached a certain threshold, drivers looked back to the road with focal vision. Wierwille (1993) found the threshold level of uncertainty to occur with an off-road glance duration at 1.8 s on straight-road segments and 1.2 s on curves. He used an instrumented vehicle on public roads with a moving map navigation display as the off-road distraction.

Cognitive distraction has also been found influential in driving behavior. Under cognitive distraction drivers tend to increase headway distance to a lead vehicle in a car-following scenario, which requires mainly operational control (instantaneous braking and accelerating) (Strayer & Drews, 2004; Strayer et al., 2003). However, this behavior may be simply an automatic process or a consequence of lack of attention when drivers perform operational tasks. Such adaptation, increasing headway, may not compensate for the full range of demands in a highly dynamic situation either. Horrey and Simons (2007) found that unlike the car-following scenario, drivers did not increase their safety margin (i.e., headway distance to other vehicles) under high cognitive workload, when overtaking a vehicle. Overtaking requires the negotiation of traffic (i.e., tactical vehicle control) and imposes higher demands than car-following. These findings suggest that cognitive distraction may diminish driver capacity to adapt behavior in specific driving tasks, especially when workload is high and the task is time-constrained.

The majority of prior research on driving distraction focuses on either specific secondary tasks (e.g., cell phone conversation, text messaging, etc.) or one type of distraction (Alm & Nilsson, 1995; Blanco et al., 2006; Dingus et al., 1989; Horrey & Simons, 2007; Lee, 2001). However, to understand the effects of a large variety of secondary tasks, which can impose both visual and cognitive driver distraction simultaneously, it is necessary to identify independent and combined effects of these two types of distraction in highly realistic and varied driving scenarios. One study that compared the effects of visual, cognitive and combined distraction found that visual distraction dominates the effects of combined distraction (Liang & Lee, 2010). However, the characteristics of the visual and cognitive distraction tasks used in this study were confounded in terms of the response modality required of drivers (both required manual responses). Therefore, attentional resource competition with the primary driving task was not unique among the distraction tasks. Beyond this, only a simple car-following scenario was used in a lower fidelity driving simulation, and visual and cognitive distractions were presented in a sequential manner and not simultaneously. Consequently, Liang and Lee (2010) did not assess the interaction effect of the two types of distrac-