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The effect of driver cognitive abilities and distractions on situation awareness and performance under hazard conditions

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ABSTRACT

The objective of this study was to investigate the role of cognitive abilities in driver situation awareness (SA) and performance. Sixteen participants drove a high-fidelity driving simulator and experienced a hazard condition (a vehicle turning into their lane). In general, exposure to the hazard resulted in a subsequent increase in driver SA in follow-on driving. Working memory and visual-cognitive skills appeared to be critical to supporting driver SA after hazard exposure. Findings indicated that tactical driving tasks place greater demands on cognitive abilities and levels of SA for successful performance, as compared to operational and strategic tasks. Correlations among measures of driver cognitive ability, SA and performance provide a basis for future development of a relational model of the roles of cognition and SA in driving.

1. Introduction

Today's drivers are exposed to a multitude of in-car distractions and these distractions can have a negative effect on driver awareness of the driving environment, vehicle control, and safety. With respect to safety, it is important to develop an understanding of how distractions affect driver behavior so that in-car technologies can be developed to minimize potential hazards of driving task interruptions. Regarding driving behavior, Michon (1985) previously identified three types of behavior, including 'strategic,' 'tactical,' and 'operational.' At the strategic level, the goal of driving is established (e.g., navigate to a destination) and specific driving sub-goals are developed, such as selecting a route to avoid a traffic jam during rush hour. At the tactical level, required roadway maneuvers are selected to achieve predetermined sub-goals, such as passing or overtaking other vehicles. At the operational level, tactical maneuvers are converted into specific actions, such as braking, and steering. Some studies have focused on Michon's operational driving behaviors and have revealed evidence of a positive correlation between situation awareness (SA) and driving performance (e.g., Kass, Cole, & Stanny, 2007; Ma & Kaber, 2005, 2006, 2007). Thus, "good" driver SA may be a building block for safe driving.

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1.1. Situation awareness in driving

Definitions of SA in complex systems control commonly identify the need for operators to know what is going on, what specific events mean, and what might happen next (Dominguez, Vidulich, Vogel, & McMillan, 1994; Fracker, 1991; Sarter & Woods, 1991; Smith & Hancock, 1995). With respect to driving performance, SA is dependent upon driver perception of roadway elements, understanding of their meaning to current driving goals, and the state of one's vehicle, as well as the ability to project near-term states of the roadway environment and long-term routes of navigation. Prior research has identified potential relations between operational, tactical, and strategic driving tasks and Endsley's (1995a) three levels of SA: (1) perception, (2) comprehension, and (3) projection. Matthews, Bryant, Webb, and Harbluk (2001) and Ward (2000) postulated that, in general, SA requirements in driving would be greater when addressing higher level driving goals. Their models of SA in driving proposed that achieving strategic driving goals required the ability to project future states of the driving environment (Level 3 SA), while achieving tactical goals required a high level of comprehension of cues in the driving environment (Level 2 SA). Finally, operational goals were considered to require little SA at any level because of the autonomous nature of operational activities, such as steering and speed control (cf., Horrey & Wickens, 2006). While the frameworks of the models proposed by Matthews et al. (2001) and Ward (2000) are clear and seem intuitive, neither study provided quantitative data supporting connections between the three levels of driving behavior and the three levels of SA.

In an attempt to better understand any relationships among driver SA and vehicle control under distraction (concurrent secondary task demands), Ma and Kaber (2005) conducted a study on the effect of adaptive cruise control (ACC) and cell phone use on driving performance, perceived workload, and SA. They found that use of ACC and a cell phone while driving generally decreased SA. Furthermore, correlation analyses revealed a significant negative association between SA with workload, headway distance, and following speed. The authors also found significant negative associations of Level 3 SA with headway distance and following speed. These correlation results suggest that there exists a relationship between SA (Level 3 and overall) and tactical driving behaviors. In a follow-up study, Ma and Kaber (2007) investigated the effects of in-vehicle navigation aids on driver performance reliability. Correlation analyses revealed a significant negative association between Level 3 SA and navigation errors, providing further evidence of a link between Level 3 SA and strategic driving behaviors, as suggested by Matthews et al. (2001). However, there remains an incomplete understanding of which levels of SA are more or less important across all types of driving behavior.

1.2. Cognitive abilities required for driving

Prior research on the relation between cognitive abilities and SA has identified prominent cognitive factors in SA including: working memory capacity, time-sharing ability, and spatial and perceptual skill (Endsley & Bolstad, 1994; O'Hare, 1997). Working memory refers to the cognitive structures and processes that are used to temporarily store and manipulate information, and is generally regarded as having limited capacity (Miller, 1956). Spatial skills in driving refer to the ability of the driver to monitor other vehicles or other obstacles to determine their spatial locations between moving objects in three-dimensional space. This is done by using side mirrors, rear-view mirrors, and the forward out-of-cab view.

Tirre and Gugerty (1999) identified the importance of working memory capacity, time-sharing ability, dynamic visual processing skills, and perceptual skills in driver SA under normal driving conditions. They found that greater abilities facilitated overall SA; however, they did not examine specific levels of SA, as in Endsley's (1995a) theory. In another study, Bolstad (2001) found that visual processing skills were significantly correlated with overall SA, but other measures such as perceptual speed and dynamic working memory were not. Horrey and Wickens (2006) found that working memory, as a means for perceiving hazardous roadway conditions and projecting future states, was related to driver brake reaction time. Salvucci and Beltowska (2008) found that a lack of working memory resources contributed directly to degraded lane maintenance and braking response time. However, Bolstad (2001) showed no significant relationship between dynamic working memory, measured using the Weschler Adult Intelligence Scale-III (WAIS-III), and SA in both moderate and high complexity driving scenarios. The reason for these contradictory results may be attributed to automatic components of SA. As noted by other researchers, SA may have automatic components operating without conscious control that do not require the use of working memory (Kennedy & Ordy, 1995; Orasanu, 1996; Orasanu & Fischer, 1997). Related to this, skill-based behavior or operational goals in driving (e.g., lane keeping) represent automatic information processes and may not require working memory to the extent of higher level driving behaviors (e.g., passing, navigating). On this basis, there is a need for further analysis of the role of working memory in each level of SA and performance of various types of driving tasks. Such research would serve to provide a cognitive explanation of driving task performance depending upon SA.

Taken together, these results indicate that visual processing skills have a significant effect on driver SA; visual processing skills are necessary in perception of environment cues, which is a necessary foundation for the ability to comprehend and