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

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A B S T R A C T

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.

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

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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 subsequently project system states. Furthermore, multiple studies have identified the importance of working memory in driving. However, there remains a need to further clarify the role of driver cognitive abilities relevant to acquiring and maintaining SA in driving tasks, as individual variables may directly influence driver SA and consequently safety under hazardous conditions.

1.3. Distraction and workload in driving

In-car distractions have been shown to degrade driving performance and SA while contributing to increased perception of workload. Kass et al. (2007) found that drivers participating in a cell phone conversation committed significantly more driving infractions (e.g., road-edge excursions, stop signs missed, speeding violations, etc.) than those who were not distracted with a cell phone conversation task. Furthermore, in a review of the distracted driving literature, Lansdown, Stephens, and Walker (2015) reported that distractions while driving are almost universally detrimental to driving performance. They identified cognitive overloading and information processing bottlenecks as two key factors responsible for degrading effects distractions have on driving performance. Related to this work, Ma and Kaber (2005) found that the use of a cell phone creating higher perceived workload while driving increased headway distance variability in a defined following task.

Regarding driver distraction and SA, Kass et al. (2007) reported that distractions significantly decreased driver SA; however, Young, Salmon, and Cornelissen (2013) reported that an in-car distraction task did not significantly decrease overall SA, but did alter how drivers sampled environment cues while driving. Contrary to Young et al. (2013) findings, Ma and Kaber (2005) did find a significant negative correlation between perceived workload due to in-vehicle driver distraction and overall SA as well as perceived workload and each level of SA, according to Endsley's (1995a) theory. Taken together, the results of these studies suggest a relationship between distracted driving, workload, and driver SA.

1.4. Motivation

Considering that the ultimate goal of driving research is to enhance safety, studying the role of driver SA in performance under hazard conditions seems of paramount importance. The findings of such research could be important to further understanding the role of cognitive constructs in driving. Given the current prevalence of use of in-vehicle and personal technologies (e.g., navigation aids, cell phones) it also seems important to examine how secondary distracter tasks (e.g., a cell phone call) while driving may reduce cognitive capacity for achieving SA and safe driving under hazardous conditions. Although driver distraction due to cell phone use is a focus of the current research, there is substantial evidence of the negative effects of cell phone use on driver performance under various conditions (e.g., levels of driver experience, types of phones, traffic densities, etc.). In particular, naturalistic driving studies have found that the visual-manual requirements associated with hand-held phones lead to degraded safety and driver performance compared to hands-free conversational tasks, which have demonstrated little degradation of driver safety and performance (e.g., Fitch et al., 2013; Victor et al., 2014). Unfortunately, most studies have simulated normal driving scenarios (Collet, Guillot, & Petit, 2010b). Study of driver cell phone use under hazard conditions may provide for more sensitive assessment of the role of cognition in driving.

On these bases, the objective of this study was to further isolate the relationships between each type of driving behavior and the levels of SA, and to identify any mediating effects of driver cognitive abilities under various roadway and in-vehicle circumstances. We investigated: (1) the effects of a hazard situation on a direct and objective measure of driver SA; (2) the effect of cell phone use on performance of the three types of driving tasks and driver SA; and (3) the influence of individual cognitive abilities and experience on driver SA and performance. The results of the current study (presented below) identified specific connections between the cognitive abilities, levels of SA, and levels of driving behavior. (This work was based, in part, on a thesis executed by the second author with the research concept and direction formulated by the first author (Jin, 2008).)

2. Methods

2.1. Participants

Sixteen participants were recruited from the local population in Raleigh, North Carolina for "a driving simulator experiment". All participants were required to have a valid driver's license with no restrictions and 20/20 vision or to wear corrective glasses or lenses. They were all between the ages of 18 and 36 with a mean of 28.5 years and a standard deviation of 4 years. The mean level of driving experience for our sample was 5.6 years. Shinar, Meir, and Ben-Shoham (1998) observed that driving tasks, including complex manual gear shifting, may approach automaticity around 3 yrs. of experience. Therefore, the role of experience in driver information processing and response execution may decrease with time and the present sample was not expected to show learning effects in terms of the experiment task performance. The sample was also balanced for gender (eight persons of each gender).

2.2. Apparatus

A STISIM Drive™ M400 driving simulator (System Technology Inc., Hawthorne, CA) was used to present participants with the driving environment and to record their performance in various tasks. Prior research has demonstrated that driving performance measurements in a simulator are highly correlated with performance on actual driver road tests, suggesting validity of simulator technology for assessing driver behavior (de Winter et al., 2009). A review on the simulator validation literature concluded that mid-level fixed-based driving simulators exhibited relative validity compared to real-world driving (Kaptein, Theeuwes, & van der Horst, 1996) while another experiment (Wang et al., 2010) found that visual attention and driving performance did not differ significantly between a medium-fidelity, fixed-based simulator and real-world driving when using an in-vehicle information system. The simulator used in this study provided a 135 degree field of view through three 37 in. HDTV monitors (see Fig. 2). The simulator modeled a Ford Taurus (with a drag coefficient of 0.32 and maximum braking rate of 1.4 g). All roadways were simulated as straightaways and the size of blocks (distance between two intersections) was consistent throughout the simulation (1524 m). The roadways were marked with conventional lines, and there were different types of signs, including "speed limit", "intersection ahead", "do not pass" and "school zone". While driving, participants were instructed to obey all roadway regulations, including speed limits (set at 35 mph, 45 mph or 55 mph), traffic signals, stop signs and dividing line conditions for passing, as part of the simulation. Participants drove for roughly 12 min. during each trial. The roadway was approximately 8 miles in length, including the straightaways, hills and curves. There were no left or right turns at intersections. As can be seen on the TV screens in Fig. 1, the roadside environment included parked cars, buildings, houses, trees and pedestrians.

2.3. Tasks

The strategic goal of the driving task was to arrive at a destination within a limited time (12 min). Driving scenarios were two-lane roadways through urban environments. Before experiment trials, participants were provided with simulation training. The content of the training trials was different than the experiment trials in order to ensure as much as possible uniform experience with the simulator across participants. Participants were also provided with a map, including the speed limit in each block and some landmarks. During trials, drivers had to recognize landmarks, identify current vehicle location and make comparison with the destination. Drivers were also provided with a digital display, adjacent to the simulator speedometer, that presented elapsed travel time in order for participants to keep track of their progress to the destination. The task required perception of driving time and comparison with the available time to destination. Related to this, participants formulated their own driving strategy and made modifications while driving, including projection of near-term driving sub-goals (i.e., passing a vehicle, making a turn) and decision making (i.e., selecting operational behaviors for passing and cornering) in order to reach the destination within the limited time. Consequently, driver arrival time at the destination was identified as a measure of strategic task performance.

In order to be successful in the task, drivers needed to pass slow traffic. Participants were informed of this in advance and given safe passing instructions for various roadway conditions. In specific, they were instructed to pass any lead vehicle with a speed below 50 km/h. Drivers had to decide whether they could pass under specific center-line conditions and traffic conditions, including oncoming traffic speed and potential hazards (pedestrian crossings, etc.). A total of four passing conditions were simulated within each test trial.

(a) Speed of lead vehicle (less than 50 km/h) + dotted center lines = passing (mandatory).
(b) Speed of lead vehicle (less than 50 km/h) + double yellow lines = no passing.
(c) Speed of lead vehicle (over 50 km/h) + dotted center lines = passing (optional).
(d) Speed of lead vehicle (over 50 km/h) + double yellow lines = no passing.

Voluntary passing without any roadway regulation violation was also permitted in order to promote driver task completion within the time limit. Driver decisions to pass lead vehicles were recorded by an experimenter and the number of successful passing maneuvers was identified as a measure of tactical driving behavior.

In addition to the strategic and tactical driving tasks, participants were exposed to a hazard situation in each trial. They were instructed in advance to avoid any vehicular hazards and to perform to the best of their abilities. During simulation trials, a car parked on the roadside among several other vehicles turned into the roadway and path of the participant's vehicle. In order to prevent participant expectation of this hazard, all blocks in the driving simulation included parked vehicles at the roadside. In addition, the location of the offending vehicle in the simulation environment was randomly selected between Block 3 and Block 6 (among a total of 8 blocks). The vehicle initiated movement 45 m in front of the participant's car, which was expected to be traveling at 72 km/h (with participants following instructions to maintain the speed limit).

Beyond the hazard avoidance task, participants were informed of the need to perform a secondary cognitive activity through use of a cell phone in half of the experiment trials. Under the secondary task condition, participants were required

Fig. 1. STIMSIM M400 driving simulator setup in Ergonomics Lab at NC State University.

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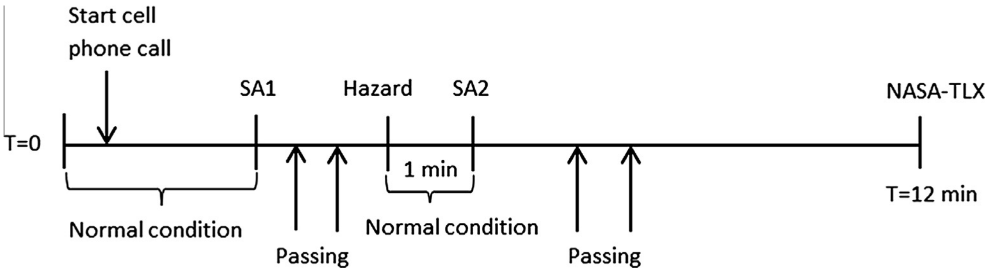

Fig. 2. Schedule of experiment trial events.

to talk with a remote experimenter on a hand-held Samsung cellular phone. The experimenter posed a number of simple arithmetic questions, including addition of two numbers with two digits each and multiplication of two numbers with single digits each (see Kass et al. (2007) for an earlier application). The secondary task was initiated 1 min after the driving simulation started and was delivered every 5 s until the end of a trial. Fig. 2 presents a diagram of the sequence of the various task events in each trial, including the passing opportunities, the initiation of the cell phone call and the hazard occurrence.

2.4. Cognitive ability tests

Cognitive abilities previously identified as being influential in driving task performance included working memory span (WMS) and spatial and perceptual skills (Bolstad, 2001; Tirre & Gugerty, 1999). In general, WMS predicts complex cognitive behavior across domains, such as reading comprehension, problem solving and reasoning (Conway et al., 2005). In the present study, operational span was measured using the "Kiosk-Ready WMS test". Participants were to recall specific letters in words (on a computer screen) while completing math problems between word stimuli. The test was administered using the E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA), and all scoring was handled via a PC. The WMS score was calculated as the total number of letters correctly recalled; a higher score indicated greater working memory span.

Driver spatial and perceptual skills can be assessed using a number of different tests. The Useful Field of View (UFOV) test measures how much information an individual can extract from a dynamic environment and the speed of processing of visual information (Owsley, Ball, Sloane, Roenker, & Bruni, 1991). A version of the UFOV® test by Visual Awareness, Inc. (Birmingham, AL) was administered via a computer utilizing a 17-in. touch screen monitor. Participants viewed a target image (car/truck) at the center of the display and identified the location of a second matching image at the periphery of the screen as fast as possible. Minimum task performance time was recorded in ms (i.e., the minimum time a stimulus can appear on the screen for the participant to perceive and comprehend the stimulus) and converted to a test score. Lower times equate to faster processing speeds. The Embedded Figures Test (EFT) is another type of perceptual test based on cognitive-style theory (Witkin, Oltman, Raskin, & Karp, 2002). The test quickly assesses the ability of a participant to distinguish a target object from an organized visual field. Figures are presented to participants in a booklet and a pencil is used to mark answers. The score is the total number of problems correctly answered from among a predefined set. Selective attention and divided attention reflect the amount of the visual field that drivers are able to perceive, process, and interpret. Similarly, cognitive style reflects driver ability to disassemble relevant information from its surroundings. The ability to identify relevant visual information and process it quickly is especially important in driving, as visual information changes rapidly and drivers need to be able to perceive, process, and interpret information in order to maintain a safe level of performance.

2.5. Response measures

Three types of dependent variables were observed in this study, including driver SA, performance and perceived workload. The Situation Awareness Global Assessment Technique (SAGAT; Endsley, 1995b) was employed to assess driver perception (Level 1 SA), comprehension (Level 2 SA) and projection (Level 3 SA) of roadway environment states. SAGAT is the most widely used and validated SA measurement approach based on Endsley's (1995a) three-level model (see Salmon, Stanton, Walker, & Green, 2006) and has been found to be sensitive and reliable for assessing independent variable manipulations in driving domain studies (Gugerty, 1997; Ma & Kaber, 2005, 2007; Zhang, Jin, Garner, Mosaly, & Kaber, 2009). In this study, the method involved freezing the driving task simulation at two randomly selected times (between 1 and 12 min) before and after hazard exposure and posing a set of SA queries to drivers (12 questions at each freeze with four per level of SA). The freeze times were randomly generated before the beginning of each scenario so that experimenters were aware of the times; however, participants could not predict when freezes would occur. The SA queries were randomly selected from a large pool for each freeze (the entire pool contained 19 Level 1 queries, 18 Level 2 queries, and 9 Level 3 queries) in order to test driver ability to process current information for achieving operational, tactical and strategic goals that were active throughout trials. All queries were administered in a multiple-choice format such that there were limited options for responses. For questions regarding a continuous variable (e.g., vehicle speed, time-to-destination, etc.), ranges were defined for correct responses to the queries. (An example SAGAT questionnaire is presented in the Appendix A.) Upon resumption of the simulation, the participant's vehicle and the surrounding vehicles resumed at the speed and locations they were at just before the simulation pause.

Drivers had to constantly keep track of roadway conditions and vehicle status (e.g., dividing lines, speed, etc.) in order to accomplish passing tasks and to arrive at the destination within the limited time. The SA queries were developed to address each of these goals based on a goal-directed task analysis (GDTA; Endsley, 2000a). Endsley (1995a, Page 41) offered that "people are active participants in determining which elements of the environment will be become a part of SA by directing their attention based on goals and objectives and on the basis of long-term and working memory in addition to highly salient cues catching one's attention." Therefore, drivers may actively select information, such as roadway conditions and vehicle status (e.g., dividing lines, speed, etc.), in order to accomplish the tactical task of passing or the strategic task of arriving at a destination within a limited time. In order to ensure a global assessment of driver SA, multiple queries targeting each level in Endsley's model were presented at each freeze. Scores for each level were determined by comparison of participant answers to SA queries during the experiment with actual states of the simulated driving environment recorded by the simulator computer systems. Percent correct responses were calculated for each trial.

Driver perceived workload was measured using the NASA Task Load Index (TLX; Hart & Staveland, 1988). Component demand rankings were collected at the beginning of the study (after task training) and demand ratings were collected at the close of each trial. The components included mental, physical and temporal load, driver frustration, overall effort and perceived performance. The overall TLX score is a rank-weighted sum of demand ratings on a scale from 1 to 100 with higher scores indicating higher perceptions of workload.

Various driving performance measures were recorded targeting each type of driving goal. Lane deviation and brake reaction time to the hazard situation were recorded to assess operational task performance. Brake reaction time was calculated based on the simulator log data files by subtracting the time at which the hazard vehicle initiated movement from the time at which the participant driver began to brake. Lane deviation was also calculated based on the simulator log data files, excluding 15 m of travel distance before and after a deliberate lane change. The standard deviation of lane position was used as a measure of the degree of deviation. As previously mentioned, the number of successful passes of a lead vehicle was recorded to assess tactical task performance. An experimenter manually noted the number of times a driver made a correct or incorrect decision to pass another vehicle under required or voluntary passing situations. Finally, the arrival time at the driving destination was recorded to assess strategic task performance.

2.6. Experiment design

The experiment design included the secondary cognitive (cell phone) activity as a within-subjects independent variable with two levels. Each condition was replicated for each participant. Therefore, all participants completed four test trials, two with the cell phone conversation and two without. A randomized experimental trial order was determined for each participant before the experiment in order to mitigate potential trial order effects.

2.7. Hypotheses

Based on the literature review, hypotheses were formulated and are listed below, grouped by independent variable.

Situation awareness:

H1. The secondary task was expected to decrease SA.

H2. SA was expected to be higher after the hazard than before.

H3. WMS score was expected to be positively correlated with Level 1 SA.

H4. UFOV score was expected to be negatively correlated with SA (less time to acquire a visual target corresponding with higher SA).

H5. EFT scores were expected to be positively correlated with Level 1 SA.

Driving performance:

H6. Inclusion of the secondary task was expected to degrade driving performance, including operational, tactical, and strategic behaviors.

H7. SA was expected to be correlated with tactical and strategic driving task performance.

H8. WMS score was expected to be positively correlated with tactical and strategic driving performance.

H9. UFOV scores were expected to have a positive correlation with operational driving behavior (brake reaction time and lane maintenance; less time to acquire a visual target associated with shorter brake time and reduce vehicle position variability) but a negative correlation with tactical driving behavior (number of successful passes; less time to acquire a visual target associated with more successful passes).

H10. EFT scores were expected to be positively correlated with operational driving tasks.

2.8. Statistical analyses

All statistical analyses were conducted using SAS®. Prior to statistical model analysis, diagnostic tests were performed on the data, including, tests for homoscedasticity (Bartlett's Test and Levene's Test) and normality (Anderson-Darling Normality Test). First, we present analysis of variance (ANOVA) results to identify significant factors in the various responses. Subsequently, we present correlation analyses for assessment of the SA, performance and cognitive ability interrelationships. In addition, beta and omega-squared values were calculated as basis for power and effect-size estimates. Omega-squared values were compared with the guidelines presented by Cohen (1988) for assessing effect sizes.

3. Results

The results of the beta analyses revealed reasonable power of tests (at least over 0.63 in all cases), and the effect-size estimates also revealed medium to large strength of association between predictors and responses, based on guideline values (between 0.100 and 0.543; see Tables 1 and 3 in Cohen, 1988). In addition, we initially included gender as a factor in all statistical models; however, since a multivariate analysis of variance (MANOVA) did not show any significant effect of gender on any dependent variable, we did not report these results.

3.1. Situation awareness

A MANOVA revealed a significant effect of the secondary cognitive task on the scores for each level of SA and an overall SA both before and after a hazard event (before, $F(4,43) = 6.51$, $p = 0.0003$; after, $F(4,43) = 5.47$, $p = 0.0012$). Table 1 presents the means and standard deviations of SA scores for the distracter conditions. Univariate ANOVA results on driver SA indicated the secondary task to be significantly influential in the percentage of correct responses to perception and comprehension of SA queries before a hazard event (Level 1, $F(1,47) = 6.51$, $p = 0.014$, $\hat{\omega}^2 = 0.133$; Level 2, $F(1,47) = 13.54$, $p = 0.0006$, $\hat{\omega}^2 = 0.258$) and influential in the accuracy of responses to all levels of SA queries after a hazard event (Level 1, $F(1,47) = 13.21$, $p = 0.0007$, $\hat{\omega}^2 = 0.253$); Level 2, $F(1,47) = 5.33$, $p = 0.0255$, $\hat{\omega}^2 = 0.107$; Level 3, $F(1,47) = 9.79$, $p = 0.003$, $\hat{\omega}^2 = 0.196$). Accordingly, the overall SA score was significantly affected by the secondary task both before ($F(1,47) = 22.12$, $p < 0.0001$, $\hat{\omega}^2 = 0.37$) and after ($F(1,47) = 22.54$, $p < 0.0001$, $\hat{\omega}^2 = 0.374$) hazard exposure. In general, driver awareness of the simulated roadway situation was 10–20% worse when exposed to the secondary task.

To test the effect of hazardous event exposure on driver SA across secondary task conditions, pair-wise t-tests were conducted at each level of SA response before and after driver exposure to the hazard. Tests revealed significant increases in Level 2 SA ($t(0.025,63) = -4.92$, $p < 0.0001$) and overall SA ($t(0.025,63) = -2.86$, $p = 0.0057$) after the hazard event with and without the secondary cognitive task. However, there were no significant differences for Levels 1 and 3 SA. Table 2 presents the mean and standard deviations for the SA measures before and after hazard exposure.

Further analysis was conducted to test the difference in driver SA before vs. after hazard exposure for each secondary task condition. T-test results revealed significantly higher overall SA after the hazard under the no-secondary-task condition ($t(0.025, 31) = -2.33$, $p = 0.0340$), but there was no significant difference for the secondary cognitive task condition (t

Table 1
Means and standard deviations (in parentheses) for SA and workload measures for the distracter conditions.

Independent variables		Dependent variables								
		Level 1 SA		Level 2 SA		Level 3 SA		Overall SA		NASA-TLX
		SA L1 before	SA L1 after	SA L2 before	SA L2 after	SA L3 before	SA L3 after	Overall SA before	Overall SA after	
Distracter	Cell	0.6328 (0.237)	0.6406 (0.228)	0.4453 (0.226)	0.5937 (0.217)	0.4218 (0.249)	0.4609 (0.229)	0.5000 (0.185)	0.5651 (0.144)	69.45 (12.06)
	No-cell	0.7656 (0.178)	0.8125 (0.179)	0.6484 (0.199)	0.7187 (0.187)	0.5468 (0.272)	0.6328 (0.253)	0.6536 (0.134)	0.7213 (0.149)	50.35 (19.37)

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Table 2
Mean and standard deviation of SA before and after a hazard event across secondary cognitive activity conditions.

	Level 1 SA	Level 2 SA	Level 3 SA	Overall SA
Mean (before) (Std)	0.69922 (0.219)	0.54688 (0.235)	0.48438 (0.267)	0.57682 (0.178)
Mean (after) (Std)	0.72656 (0.221)	0.65625 (0.211)	0.54688 (0.255)	0.64323 (0.165)

Table 3
Means and standard deviations (in parentheses) for driving performance for distracter condition.

Independent variables		Dependent variables				
		BRT (s)	LD (before) (ft.)	LD (after) (ft.)	Passing (#)	Arrival time (s)
Distracter	Cell	1.766 (0.147)	0.739 (0.232)	0.771 (0.314)	5.093 (0.897)	765.28 (55.51)
	No-Cell	1.850 (0.265)	0.716 (0.273)	0.638 (0.202)	6.125 (0.739)	744.67 (53.44)

Note: BRT = Brake Reaction Time; LD = Lane Deviation.

(0.025, 31) = −1.78, $p = 0.0845$). Drivers not talking on the phone appeared to perceive a greater need to concentrate on the roadway after hazard exposure.

3.2. Driving performance

MANOVA results revealed a significant effect of the secondary task condition on driving performance ($F(5,42) = 10.63$, $p < 0.0001$). Table 3 presents the mean and standard deviations of driving performance for the distracter condition. An ANOVA on lane deviation before the hazard revealed no significant difference among the secondary task conditions, but there was significantly worse lane deviation with the secondary cognitive task after hazard exposure ($F(1,47) = 4.98$, $p = 0.0305$, $\hat{\omega}^2 = 0.1$). Surprisingly, ANOVA results on brake reaction time indicated no secondary task effect; there was no difference in brake reaction time in response to the occurrence of the hazard between the cell phone use and no conversation conditions.

ANOVA results revealed significant effects of the secondary task condition on both passing ($F(1,47) = 43.86$, $p < 0.0001$, $\hat{\omega}^2 = 0.543$) and arrival time ($F(1,47) = 5.15$, $p = 0.0279$, $\hat{\omega}^2 = 0.103$). The number of successful passes was significantly decreased when exposed to the secondary cognitive activity performed with the cell phone. In addition, arrival time at the destination was significantly increased with use of the cell phone for the secondary activity. These results were in-line with those obtained by Ma and Kaber (2005).

3.3. Driver workload

An ANOVA revealed a highly significant increase in workload when drivers engaged in the secondary cognitive activity via the cell phone ($F(1,46) = 35.19$, $p < 0.0001$). Table 1 shows the mean and standard deviation of workload measures in each distractor condition. However, it also suggested that driver perceptions of cognitive load did not necessarily correspond with performance issues in terms of brake reaction time (i.e., they found workload to be higher but reaction time did not suffer).

3.4. Correlation analyses

3.4.1. Driving task performance and levels of SA

Pearson correlation coefficients were used to assess whether the three types of driving task performance correlated with SA, and how these relationships may have differed for each level of SA. It is important to note that although in engineering experiments correlation values greater than 0.9 are typically considered to be practically significant, in social science experiments researchers often consider correlation values as low as 0.2 (or lower) to be of practical value (Pyzdek, 2014), as there is substantial variability in terms of human behavior in those fields. Fig. 3 depicts the correlations between driver cognitive abilities, levels of SA, and the three types of driving behaviors. Our Results revealed that lane deviation after hazard exposure had a marginally significant negative correlation with Level 1 SA ($r = -0.246$, $p = 0.0501$) and a significant negative correlation with overall SA ($r = -0.257$, $p = 0.0400$). These results partially supported the notion that low-level driving behavior may be automatic and skill-based and rely less on SA under normal driving conditions (Rasmussen, 1983, 1986; Smiley, 2004).

Tactical task performance (number of successful passes) had a significant positive correlation with Level 1 ($r = 0.449$, $p = 0.0002$), Level 2 ($r = 0.469$, $p < 0.0001$) and Level 3 SA ($r = 0.411$, $p = 0.0007$) suggesting that as perceived information, comprehension, and projection increased, driver ability to manage complex driving behavior, such as passing, increased. Passing success also had a significant positive correlation with overall SA ($r = 0.586$, $p < 0.0001$). Regarding strategic task performance (arrival time), Pearson correlation coefficients revealed a marginally significant association with Level 3 SA ($r = -0.227$, $p = 0.0713$) and a significant relation with overall SA ($r = -0.251$, $p = 0.0454$) suggesting that the higher SA was associated with shorter travel times. These additional correlation results support Matthews et al. prior association of

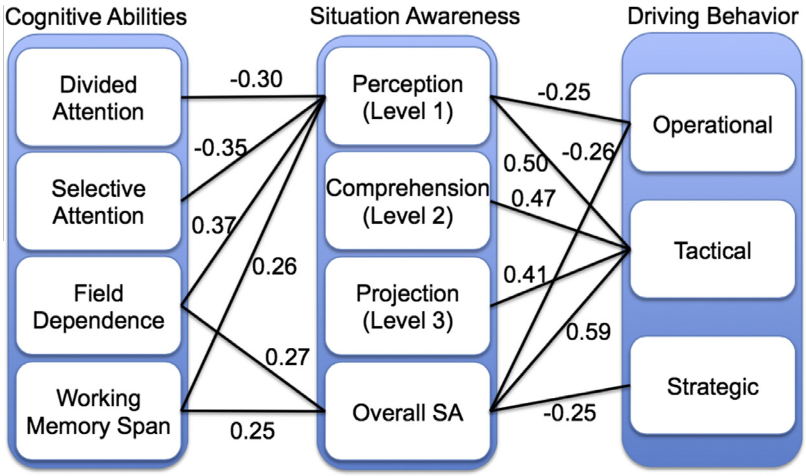

Fig. 3. Model of relations among situation awareness, types of driving tasks and cognitive abilities.

levels of SA with driving behaviors, specifically that strategic task performance has some dependence on driver projection (in addition to simple roadway perception and vehicle state comprehension).

Beyond the driving performance and SA associations, perceived workload was negatively correlated with SA. As the workload score increased, SA decreased, supporting a finding of the previous driving research (e.g., Ma & Kaber, 2005).

3.4.2. Level of SA and cognitive abilities

Spearman's rank correlation coefficient (or Spearman's rho) was used to test the linear relation between each level of SA and cognitive abilities. Results revealed that greater WMS allowed for increased accuracy in roadway perception (Level 1 SA) ($\rho = 0.261$, $p = 0.037$). The influence of hazard exposure on this relationship was also tested by performing correlation analyses on the before and after hazard exposure SA data sets. In general, WMS was related to a greater fraction of variability in SA after the hazard exposure. The relations of WMS with Level 1 SA ($\rho = 0.275$, $p = 0.028$) and overall SA ($\rho = 0.303$, $p = 0.024$) were significant after the hazard exposure.

Regarding the role of UFOV in driver SA, divided attention ($\rho = -0.298$, $p = 0.0168$) and selective attention ($\rho = -0.345$, $p = 0.0052$) measures revealed significant relations with Level 1 SA. In general, shorter target visual perception time was associated with higher driver Level 1 SA. Further analysis to determine the influence of hazard exposure revealed divided attention to address a significantly greater fraction of variability in Level 1 ($\rho = -0.345$, $p = 0.005$), Level 2 ($\rho = -0.254$, $p = 0.043$) and overall SA ($\rho = -0.269$, $p = 0.032$) after hazard exposure vs. before. It is important to note that UFOV measures showed a higher correlation with Level 1 SA than with Level 2 and 3 SA. These results indicate an increased dependence of low-level driver SA on perceptual ability after hazard conditions.

Finally, correlation analyses revealed a significant positive association between EFT scores (driver field dependence) and Level 1 SA ($\rho = 0.371$, $p = 0.0026$). Less field dependent drivers were able to achieve higher Level 1 SA. Similar to the results on the WMS and UFOV measures, the Spearman rank correlation coefficient for EFT scores and Level 1 SA recorded after hazard exposure was significantly greater than for SA before the hazard event (before, $\rho = 0.274$, $p = 0.028$; after, $\rho = 0.361$, $p = 0.003$).

3.4.3. Driving task performance and cognitive abilities

Spearman's rank correlation coefficient was also used to assess the degree of association of cognitive abilities with driving task performance. With respect to WMS and operational task performance, brake reaction time showed no significant correlation with WMS; however, lane deviations before a hazard situation had a significant negative association with WMS ($\rho = -0.303$, $p = 0.015$; greater span was related to reduced lane deviation). The correlation coefficients between WMS scores and tactical task performance (number of successful passes) revealed a significant positive correlation ($\rho = 0.378$, $p = 0.0021$; greater span was related to more successful passes). Similarly, greater WMS was significantly associated with better strategic task performance ($\rho = -0.292$, $p = 0.0194$; i.e., shorter arrival time). In general, these results indicated that higher working memory capacity might support better driving performance under hazardous conditions.

Correlation analyses on the UFOV test results also revealed significant associations of divided attention with lane deviations both before and after hazard exposure (before, $\rho = 0.275$, $p = 0.028$; after, $\rho = 0.283$, $p = 0.0235$), suggesting that slower visual processing speed was related to greater lane deviations. Spearman's rank correlation coefficients also revealed significant negative associations of divided ($\rho = -0.348$, $p = 0.0048$) and selective attention ($\rho = -0.373$, $p = 0.0024$) ability with tactical task performance (number of successful passes). This means that faster visual processing speed was related to greater passing success. Strategic task performance (arrival time) shared no significant relations with the UFOV measures.

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There appeared to be no direct relation between visual information processing speed and arrival time at the destination, which is a long-term outcome of the driving task.

There was no significant correlation of perceptual style with operational driving performance (i.e., brake reaction time or lane deviation (before and after hazard exposure)) or strategic driving performance (i.e., arrival time). However, results showed a significant correlation between EFT scores and tactical driving performance (number of successful passes; $\rho = 0.291$, $p = 0.0195$). Greater field independence was related to greater passing success.

4. Discussion

4.1. SA in driving

Based on the SAGAT results, engagement in the secondary cognitive activity via the cell phone under normal and abnormal driving conditions (i.e., hazard exposure) led to degraded SA, meeting our expectation in H1. Cell phone use appeared to reduce driver attention and perception for recognizing essential roadway information. Drivers may experience distractions to information processing, involving use of WMS and visual processing ability, and this may adversely impact SA. It is generally accepted that individuals depend on attention and perception abilities, as well as working memory, in order to achieve SA (Durso & Gronlund, 1999; Endsley, 1995a). Similar to the results of prior research, there was a negative impact of the secondary task (cell phone conversation) while driving at each level of SA (perception, comprehension and projection; also see Collet, Guillot, & Petit, 2010a; Gugerty, Rakauskas, & Brooks, 2004; Kass et al., 2007; Ma & Kaber, 2005; Stanley & Kelly, 2005).

Regarding the associations between cognitive abilities and SA, our findings supported H3–H5, which posited significant correlations between cognitive test results and SA. Based on the comparison of SA before and after hazard exposure, drivers appeared to concentrate more on the roadway environment after the hazard in order to perceive and comprehend more information, and to attempt to avoid any additional hazards. It is possible that drivers allocated additional cognitive resources to the driving task to deal with the unstable environment. Such behavior would be in-line with H2. Related to this, the strength of association of visual perceptual processing and style abilities (UFOV and EFT measures) with low-level SA (Level 1) significantly increased after drivers encountered a hazard condition. That is, as the drivers met with risky conditions, achieving SA appeared to have a greater dependence on visual attention speed and field independence (sorting critical stimuli from the background).

Paying attention to the roadway before encountering a hazard event can be regarded as a selective attention task. Drivers scan various sources of information for roadway and traffic conditions in order to maintain safety and achieve driving goals (Sanders & McCormick, 1993). However, once a hazard occurs, the attention allocation strategy may change by focusing on a limited set of sources, which are highly related to vehicle safety (e.g., warnings signs, disabled vehicles at the roadside, etc.). The task can then be regarded as a focused attention or monitoring task. Considering Wickens' (1984) model of human information processing, attentional resources are generally selectively distributed to perception, response selection (decision making), and execution. Under hazard conditions, drivers may focus attentional resources on perception of safety related information and on response selection and execution for tactical and strategic tasks vs. simple operational tasks. In general, it can be inferred from our results that drivers rely heavily on visual abilities for safety under abnormal driving conditions.

4.2. Driving task performance

4.2.1. Operational performance

Supporting H6, driver lane keeping before hazard exposure was not significantly influenced by the distracter condition (i.e., cell phone use). This finding is in line with the results of Horrey and Wickens (2006) who found that cell phone use did not affect lane keeping. One explanation for this finding is that lane keeping is considered to rely on relatively automatic performance without conscious control. However, lane deviations after encountering a hazard were significantly influenced by the presence of the distraction. As discussed, drivers showed an increase in SA after hazard exposure under the no cell phone condition (supporting H2). Taken together, these results suggest that drivers who are not distracted pay more attention to the roadway environment and attempt to drive more carefully after encountering a hazard. This inference seems intuitive and is also supported by the results of the correlation analyses between lane deviation and SA (i.e., no associations between SA and lane deviation before a hazard event, but significant associations after a hazard). Under normal driving conditions, low-level driving behavior may be automatic or skill-based and rely less on SA (Rasmussen, 1983, 1986; Smiley, 2004). However, such behavior may become more conscious under non-normal driving conditions and rely on SA, as perception of roadway information (Level 1 SA) and overall SA were significantly correlated with lane deviations post-hazard exposure (i.e., SA increased and deviations decreased). Perceptuo-motor coordination tasks requiring limited attentional resources in a normal driving environment (yielding low SA) may require greater attentional resources under hazard conditions for achieving better driving performance and yield greater SA.

The significant association between WMS and SA also supported the notion of greater dependence of driver task performance on SA and cognitive abilities after hazard exposure. Perception of roadway information (Level 1 SA) is dependent on temporary memory capacity. The span score showed significant association with lane deviation before a hazard situation and even more so after hazard exposure. These results indicate drivers with large WMS may be able to keep track of more roadway information to improve lane keeping. These findings are in-line with results of prior study (e.g. Salvucci & Beltowska, 2008) and extend the existing body of work. Salvucci and Beltowska (2008) found that memory rehearsal significantly affected driver performance as measured by lateral deviation from lane center. Our results also show that lane maintenance may be more dependent on conscious cognitive processes (working memory use) after hazard exposure. In general, Level 1 SA or perceptual skills and WM appear key to operational tasks (lane maintenance) under hazard conditions. This issue should be investigated further in future studies.

Regarding driver spatial and perceptual skills, perceptual processing speed (UFOV: divided attention) was related to operational task performance (lane deviations) under both normal and abnormal conditions (hazard exposure), supporting H9. Divided attention in the UFOV test is measured in terms of the time (*ms*) for peripheral visual information to be detected and localized at the same time a target appears in the central visual field (Ball, Beard, Roenker, Miller, & Griggs, 1988). As the processing time for divided attention decreases, drivers may be able to perceive more information using a wider field of view. Faster perceptual processing speed was associated with improvements in Level 1 SA and, consequently, better lane keeping.

Opposite to these results, cognitive-style (field-independence) does not appear to be related to lane deviations; this result refutes our expectation in H10. Field-independence means a relatively large capacity to overcome embedded stimuli in order to perceive relevant targets (Goodenough, 1976; Ward, Parkes, & Crone, 1995). Based on these observations, visual processing speed could be regarded as a key factor in performing continuous perceptual-motor coordination (lane maintenance), but cognitive-style does not appear to be influential under low-clutter visual environments, such as that examined in this simulator study.

4.2.2. Tactical and strategic performance

Limited WMS of drivers, compounded by engagement in the secondary cognitive activity via the cell phone, negatively influenced tactical task performance (i.e., number of successful passes) as well as strategic task performance (i.e., arrival time at the destination). These results supported H8. In general, to achieve a successful pass, drivers had to perceive surrounding vehicles as well as the type of dividing lines on the road, comprehend the overall traffic situation, and integrate this knowledge to project future roadway states. This complex process requires use of WM to compare vehicle positions and speeds, make estimates of passing distances, and manage motor scripts for making a pass. Any additional load on WM (e.g., exposure to a secondary cognitive activity) can deteriorate driver SA and passing performance. This inference is supported by significant correlations between tactical task performance and all levels of SA, which also supported H7.

To arrive at a destination in a limited time, drivers may need to perform complex spatial information processing and mental simulation during the driving task, including decisions to pass lead vehicles. These processes also require the use of WM to temporarily store acquired environment information, to combine the information with static knowledge derived from long-term memory, and to run mental simulations. Again, any secondary-task distraction to these processes may substantially degrade driving task performance (vehicle control, navigation efficiency). In general, our results showed that drivers with higher WMS produced higher levels of performance on both the tactical task (number of successful passes) and strategic task (arrival time). These findings highlight the disadvantages of secondary cognitive activity via cell phone during driving and suggest the possibility of occurrence of risky situations when drivers engage in a conversation and tactical (e.g., overtaking, passing) or strategic task (e.g., navigation to a destination using an in-vehicle aid) performance at the same time.

The visual processing and attention abilities of drivers (tested using the UFOV and EFT) were also found to play an important role in processing perceived information rapidly and in parsing parts of the visual field ("figure") from the organized background for successful tactical task performance (passing). The complexity of this process may require substantial perceptual processing capacity to rapidly sort embedded stimuli in visual fields in order to perceive relevant objects. However, none of the visual processing and perceptual style measures were related to strategic task performance (arrival time), partially refuting H9. This finding may be due to visual processing speed and roadway information extraction not being directly dependent on longer-term navigation planning and driving time management; however, there was a significant association of strategic task performance (arrival time) with WMS, possibly due to the need to keep track of map information and landmarks.

4.3. Relationships among response measures

Working memory was revealed to be a critical cognitive ability to respond to Level 1 SA (perception) queries. This is consistent with results of prior studies in the area (Endsley, 1995a, 2000b). The finding suggests perception depends particularly on the visibility and retention of information in the driving environment. (SAGAT requires freezes of a task simulation and display screens to be blanked while participants answer queries.) Working memory capacity must be used for perceiving and storing current information on the driving environment in order to respond to queries. However, working memory capacity did not significantly correlate with driver comprehension (Level 2 SA) or projection (Level 3 SA) of roadway states. These findings are also in agreement with the results of prior research. Gonzalez and Wimisberg (2007) found that a WMS measure was not relevant to answering comprehension (Level 2 SA) and projection (Level 3 SA) queries, as compared to perception (Level 1 SA) queries. Level 2 and 3 SA may require a more profound understanding of the task through the use of long-term memory (i.e., static knowledge or experience) than just use of working memory.

Selective attention and divided attention, measured based on UFOV tests, appeared to significantly support the perception of roadway information (Level 1 SA). This finding was in agreement with a prior study of the relation between driver SA and UFOV. Chaparro, Groff, Tabor, Sifrit, and Gugerty (1999) measured three forms of UFOV attention and SA (assessed with recall tests) on the number and location of cars in a driving scenario, and found greater UFOV to be associated with higher SA. Taken together, these findings suggest that drivers who have greater divided and selective attention abilities (i.e., faster visual processing speed) perceive more roadway information and, consequently, achieve greater total SA. In addition, in our study, the strength of association of each level of SA with attention was far greater after a hazard exposure than before (normal driving). Therefore, the speed of perception with a wide field of view becomes more important under non-normal driving situations. If drivers are able to successfully negotiate hazards, it can be inferred that they may have extra cognitive resources in dealing with normal driving situations.

We also found that visual perception style (i.e., EFT scores) was significantly related to perception of roadway information (Level 1 SA). Considering that the EFT measures one's ability to distinguish target objects from an organized visual field, a significant association with Level 1 SA makes sense. In addition, the strength of dependence of Level 1 SA on perceptual style significantly increased after hazard exposure, suggesting field independence became more important to accurate perception of the roadway environment. This finding could also be attributed to driver effort to deal with an apparently unstable situation by paying greater attention to the roadway. Overall SA also showed a significant association with EFT scores; that is, field dependence may be a general mediating factor in driver SA.

5. Conclusion

The main objective of this study was to investigate the role of cognitive abilities and driver SA in driving task performance under hazard conditions and in the presence of in-vehicle distracter tasks. The study revealed negative effects of the secondary cognitive task across all levels of SA, driver workload and performance of three types of driving behavior, including strategic (i.e., arrival time at a destination), tactical (i.e., number of successful passes) and operational (i.e., lane maintenance), under normal and hazard exposure conditions. Although prior studies have revealed negative effects of visual-manual cell phone use in driving, response measures have been limited to operational task performance, such as lane keeping and reaction time. This study showed that a secondary cognitive activity performed with a cell phone negatively affects tactical and strategic task performance as well as SA.

Regarding the role of SA in driving performance, results on lane maintenance accuracy indicated that low-level SA, specifically perception, may be key to operational driving task performance after encountering a roadway hazard. In general, driver SA increased after encountering a hazard. Regarding tactical task performance, all three levels of SA, including perception, comprehension and projection, appear to be relevant to successful passing. In general, tactical driving tasks (passing) appear to require higher SA and cognitive abilities for successful performance than operational (lane maintenance) and strategic (arrival time) tasks.

Regarding the significance of each of the cognitive abilities in driving performance and SA, the present experiment showed working memory to be most significant in all three types of driving tasks (operational, tactical, and strategic), as compared to visual processing speed and cognitive style. However, after hazard exposure, participants appeared to rely more on visual-cognitive skills for achieving low-level SA. Working memory was also used to a greater extent for SA after hazard exposure. These findings reveal the importance of visual-cognitive abilities and working memory under non-normal driving conditions. Working memory may also be regarded as a primary cognitive factor in driving task performance.

5.1. Limitations and future work

There are several limitations of the current study that influence the generalizability of results. First, specific representations of each type of driving task were selected for the experiment. The study measured driver lane maintenance, brake reaction time, vehicle passing, and navigation to achieve specific driving goals. It is possible that different magnitudes of effects might be obtained if other driving tasks were used to represent tactical performance, such as negotiating an intersection, or performing complex route selection using an advanced navigation aid as a type of strategic task. However, the general pattern of findings of the relation of cognitive abilities and SA to these types of behaviors is expected to be consistent. Related to variations in effect sizes, it is possible that the passing measure may be influenced by individual differences in willingness to take risks. Future research should either screen participants for risk acceptance or choose another metric to measure tactical behavior.

Second, the participants in this study were physically fit, young college students with relatively limited experience in driving. Driver SA has been found to increase with experience in that static knowledge stores are greater for predicting future driving environment states and deciding on driving actions (see Table 5; Endsley & Bolstad, 1994). Future study regarding the influence of experience could provide valuable insight into training and experience effects. Similarly, it is possible that differences in spatial navigation abilities may lead to differences in real world driving in comparison to the simulator results, as the simulator presented a novel route and environment; spatial navigation abilities may have confounding effects on the variables investigated in the study.

Third, based on the smaller sample size (16 participants) used in the current study, careful interpretation is necessary in generalizing findings to the overall driving population. Future study with a larger sample population with representation of different age groups could provide broader and more precise understanding of driver behaviors under hazard conditions. Related to this, the associations between the dependent variables can be used as a foundation for developing a theoretical framework relating driver cognitive ability, SA, and driving behavior that generalizes to the overall driving population.

Finally, this study used a specific method of measuring driver SA that was based on Endsley's (1995a) three-level model and use of GDTA to develop SA queries. The SAGAT was used as it has been validated in several previous studies (e.g., Salmon et al., 2006). Recent investigations of driver behavior have demonstrated the utility of real-time probes for assessing influences of visual and cognitive distraction on specific aspects of SA (perception, comprehension and projection; Rogers, Zhang, Kaber, Liang, & Gangakhedkar, 2011). Other studies have pointed out limitations of the SAGAT technique (see Stanton, Salmon, Walker, & Jenkins, 2010). Future study using a battery of SA measures, including SAGAT and real-time probes (Jones & Endsley, 2004), is merited.

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Appendix A. Example of SA queries: a set

1. If a traffic light is visible, what is the current state? (Level 1 SA)

A. Green

B. Yellow

C. Red

D. No traffic light

2. What was your vehicle speed (mph) at the time the simulation stopped? (Level 1 SA)

A. Less than 30 mph

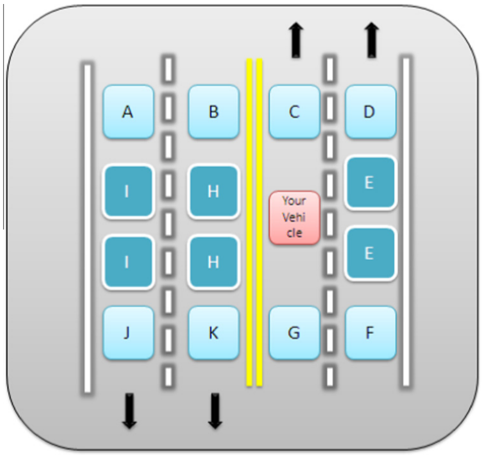
B. 30–40 mph

C. 40–50 mph

D. 50–60 mph

E. More than 60 mph

3. In which position are adjacent cars located relative to your vehicle (except parked cars)? (Level 1 SA) – circle all positions that apply.



4. What was the name of the last crossing roadway you passed? (Level 1 SA)
A.

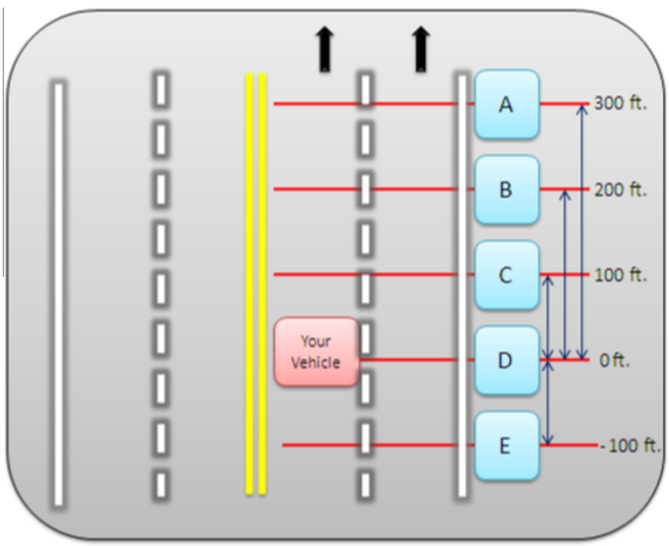
Second
B.

Third
C.

Fourth
D.

Fifth
E.

Sixth
5. What is the location of the parked cars adjacent to your vehicle? (Level 2 SA) – circle all that apply.



6. How does your car's speed compare to the lead car? (Level 2 SA)
A.

Faster than the lead car
B.

Slower than the lead car
C.

The same speed
D.

No lead vehicles
7. What do the current dividing lines between traffic directions indicate? (Level 2 SA)
A.

No passing
B.

Passing
8. How long has it been since you passed the last intersection? (Level 2 SA)
A.

Less than 15 s.
B.

15–30 s.
C.

31–45 s.
D.

46–60 s.
E.

More than 60 s.
9. How long will it take to reach the lead car at your current speed? (Level 3 SA)
A.

Less than 1 s.
B.

1–5 s.
C.

5–10 s.
D.

10–20 s.
E.

More than 20 s.
10. How long will you take to arrive at the destination? (Level 3 SA)
A.

Less than 2 min.
B.

2–5 min.

C.

5–8 min.
D.

8–11 min.
E.

More than 11 min.

11. When will you reach the next pedestrian crossing? (Level 3 SA)

A.

Less than 10 s.
B.

10–30 s.
C.

31–40 s.
D.

41–60 s.
E.

More than 60 s.

12. How many intersections do you need to pass through before reaching the destination? (Level 3 SA)

A.

Two
B.

Three
C.

Four
D.

Five
E.

Six
F.

More than six intersections

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