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Chapter Title: Situation Awareness in Driving
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1. Abstract

Questions. What component processes, both perceptual and cognitive, make up the ability to maintain situation awareness during the real-time task of driving? How can researchers measure situation awareness, especially using driving simulators? What are the theoretical models and empirical evidence suggesting that: 1. we understand situation awareness and its component processes; and 2. these components are needed for safe driving? ***Answers.*** Maintaining situation awareness involves: processes of focal vision, including attention allocation within tasks, event comprehension, and task management across concurrent tasks; as well as ambient vision processes, including attention capture by sudden peripheral events. Situation awareness is a complex process that requires assessment by a variety of online (during driving) and offline (post-driving) measures. Research using these measures shows that most of the above components of SA can be trained, improve with driving experience, and correlate positively with safe driving.

2. Introduction

Driving is a very attention demanding task, isn't it? Either consciously or unconsciously, drivers attend to their route location, the shape of the road ahead, nearby traffic, signs and signals, unexpected hazards, the state of their vehicle, and how all these things are changing. As if that were not enough, drivers also attend to side tasks such as meals, radio shows, and conversations. In this chapter, I will make the argument, and provide evidence, that managing attention is the key to safe driving. Assuming for the moment that this claim is true, it becomes important to measure drivers' attention well. Good measures of attention will help both in increasing scientific understanding of the important task of driving, and in evaluating the safety effects of changes in the driving process—such as use of cell phones and collision warning systems—and changes in driver state—such as fatigue and drunk driving. Driving simulators can be used effectively to measure drivers' attention. However, many simulator studies neglect attentional measures and focus mainly on psychomotor aspects of driving such as steering and speed control.

In the first part of this chapter, I elaborate on the multifaceted construct I have been calling "attention" (which is similar to situation awareness, or SA), and discuss some psychological theories of the components of attention and SA as they have been applied to driving. Then I describe specific procedures that researchers can use to measure constructs related to attention and SA in their driving simulators. Finally, I review some empirical studies that applied these attentional and SA measures to the components of attention and SA identified earlier.

2.1 Definitions of Attention and Situation Awareness in Driving

Researchers studying human attention during real-time tasks such as driving and flying often use the related construct of SA. My definition of SA is: the updated, meaningful knowledge of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when engaged in real-time multitasking. In psychological terms then, SA is a type of ***knowledge***. For driving, the contents of this knowledge base are the items I listed above, the driver's route location, road curvature, location of nearby traffic and pedestrians, fuel level, and so on. Most cognitive psychologists assume that this knowledge is active in working memory during driving. Researchers have debated whether the knowledge an operator maintains is solely conscious or also unconscious. Endsley (1995) has argued that SA involves primarily conscious knowledge. Durso, Rawson and Girotto (2007) have argued that real-time knowledge can be conscious or unconscious; accordingly, they prefer the term *situation model* to refer to the knowledge aspect of SA. I agree with the latter group, but will still use the term SA.

However, in addition to focusing on SA as knowledge, researchers also need to understand the perceptual and cognitive ***processes*** that update and maintain this knowledge. Three levels of cognitive processing are probably involved in maintaining SA: 1) automatic, pre-attentive processes that occur unconsciously and place almost no demands on cognitive resources; 2) recognition-primed decision processes that may be conscious for brief periods (< 1 s) and place few demands on cognitive resources; and 3) conscious, controlled processes that place heavy demands on cognitive resources. In terms of visual perception, the automated processes are probably using ambient vision; while the recognition-primed and controlled processes are probably using focal vision (Leibowitz & Owens, 1977).

Some have argued that for very experienced drivers, most driving subtasks are highly automated and therefore that analysis of attention and SA are not needed to understand expert driving performance (D. Norman, personal communication, 2006). I argue that even very experienced drivers regularly use all three of the above levels of processing. For example, vehicle control—perceiving optic flow and the changing shape of the road and using this information to control speed and heading—is probably an automated process. At the middle level, even experienced drivers may need to use recognition-primed processes involving some, albeit brief, conscious awareness when they make routine decisions about whether to change lanes, back up, or stop in response to a yellow light. At the other extreme, making navigational decisions in unfamiliar territory while avoiding hazards in heavy traffic probably engages controlled, conscious processes in a sustained fashion. Horswill and McKenna (2004) reviewed studies demonstrating that experienced drivers used more cognitive resources for hazard perception than less experienced drivers, suggesting that hazard perception, a key process in SA, does not become automated with extensive experience, but instead remains a controlled process.

This three-level view of SA processes is at odds with the common view that maintaining SA involves recognition-primed and controlled processes, which use focal vision, but not automated processes such as ambient vision. However, SA may involve processes other than focal vision. Later, I will examine evidence suggesting a broader view of SA as involving focal processes but also more automatic, ambient processes. Readers are free to adopt the narrow or broader view.

The automated, recognition-primed, and controlled levels of processing outlined above are conceptually different from Endsley's (1995) three levels of SA: 1. perception, 2. comprehension, and 3. projection. However, in practice, perceiving the elements of a situation (Endsley's Level 1 SA) is probably highly automated in most situations, while comprehension and projection (Level 2 and 3) are more likely to use recognition-primed and controlled processes.

Since the output of the controlled processes, and sometimes the recognition-primed processes, is conscious recognition and comprehension of a meaningful event (e.g., "tailgater ahead"), the processes underlying event perception and comprehension are important ones for driving. Also, since the number of events that drivers may need to attend to using these processes is large (i.e., information overload), another important component process in driving is attention allocation. Attention allocation occurs both within tasks (e.g., when drivers determine their visual scan paths) and across tasks (e.g., when drivers multitask or divide attention among multiple tasks like driving, eating and conversing). These processes will be discussed further in the section on theories of attention and SA.

3. Theories of Attention and Situation Awareness in Driving

3.1 Focal and Ambient Vision

Schneider (1967) and others have distinguished between two modes of vision: focal vision, which uses foveal input and serial processing to subserve object identification and conscious awareness; and ambient vision, which used peripheral and foveal retinal input and parallel processing to subserve spatial localization and guidance of locomotion in an automated, unconscious manner. Leibowitz and Owens (1977) suggested that the main subtask of driving, vehicle control (or guidance), uses ambient vision; while other important driving subtasks, such as identifying hazards, use focal vision. They also hypothesized that, at night, focal vision degrades much more rapidly than ambient vision, so that drivers cannot identify hazards well but can follow the road easily. Empirical studies have supported these hypotheses (Owens & Tyrrell, 1999; Brooks, Tyrrell & Frank, 2005). The problem with this selective degradation of the two visual modes is that drivers become overconfident in their ability to perform the overall task of driving at night because their ambient vision allows them to perform the main subtask of vehicle control well, and because they are unaware of the severe degradation of their focal vision. This overconfidence leads them to drive too fast and have more crashes. Using the terminology of this chapter, night drivers overestimate their SA, because ambient vision allows them to easily perform the vehicle control subtask of driving. Wickens and Horrey (in press) have suggested that the problem of overestimating SA in the face of degraded focal vision is more general than the situation of night driving. That is, drivers may overestimate SA when experiencing other factors that degrade focal vision, such as driver distraction or multitasking.

It is important to see ambient and focal vision as interrelated rather than separate systems. An important example of cross-talk between ambient and focal vision is the phenomena of attention capture. In attention capture, conspicuous events in the environment (e.g., sudden movements) are detected by stimulus-directed, parallel perceptual processes (similar to ambient vision) without the need for a prior, focal attention shift to the stimulus (Yantis & Jonides, 1984). The result is that focal vision is "captured" and attends to the stimulus, which often leads to comprehension and conscious awareness of the event. For example, a car looming ahead of a driver can capture attention and SA immediately without waiting for the driver's normal scan pattern to detect it. The phenomenon of attention capture is a good example of how parallel ambient processes that are not usually considered as components of SA can be very important to maintaining SA.

Another example of focal-ambient interrelationships is the recent finding that abrupt visual onsets, which normally capture attention, no longer do so when cognitive load is elevated due to an auditory side task (Boot, Brockmole & Simons, 2005). This finding that attention capture is diminished under cognitive load argues against the firm distinction between ambient processes as demanding little or no cognitive resources (i.e., automated processing) and focal processes as resource demanding (i.e., controlled processing). Instead, both focal and ambient processes are affected by cognitive load. These two examples of interrelationships between focal and ambient processes support the broader, three-level view of SA mentioned earlier.

3.2 Models of Allocating Focal Attention Within Driving Sub-tasks

Of the three main driving sub-tasks of vehicle control, monitoring and hazard avoidance, and navigation, the latter two require focal vision. The task of monitoring the roadway for hazards requires sequential shifting of focal attention to task-relevant parts of changing events, i.e., attention allocation, as well as comprehension of the attended objects and the overall meaning of an extended event. Especially in cluttered, high-traffic situations, monitoring the roadway so that both routine traffic and hazards are detected is itself a complex task. My view is that the process of attention allocation is a critical sub-skill in maintaining SA.

Wickens and his colleagues have recently developed the SEEV model, which stands for Salience, Effort, Expectancy and Value (Horrey, Wickens & Consalus, 2006). SEEV is a stochastic model of how operators allocate their focal visual attention in real-time tasks such as driving. In other words, SEEV deals with how drivers make decisions (probably unconscious ones) about where to focus attention next. More specifically, SEEV estimates the probability of shifting focal attention to particular locations in an ongoing visual event. This probability is affected by the four SEEV factors according to the formula: $P = S - Ef + Ex + V$; where P is the probability of attending to a particular location, S is salience, Ef is effort, Ex is expectancy, and V is value. Salience refers to the visual conspicuity of objects in the visual field, and is affected by parallel perceptual processes such as attention capture. High contrast objects or sudden movements increase salience. Effort refers to the physical and mental effort to shift the visual focus to a particular new location, and is primarily affected by the visual angle between the current and new location. Thus, objects in the driver's blindspot that require large eye and head movements will be viewed relatively infrequently. Expectancy (also called bandwidth) refers to how frequently information is changing at a particular location. Thus, a vehicle moving erratically should be viewed relatively frequently. Value refers to the fact that operators seek task-relevant information, and is affected by the relevance of locations to particular driving subtasks (e.g., the rear-view mirror is highly relevant to the subtask of changing lanes) and the relative priority of subtasks within the overall task of driving (e.g., changing lanes safely is more important than navigating).

Based on eye tracking data, SEEV has been shown to accurately predict the frequency of looking at particular locations during driving and flying tasks (Horrey et al., 2006; Wickens, Goh, Helleburg et al., 2003). These model validation efforts have focused mainly on the Expectancy and Value parameters of SEEV; the Salience and Effort parameters need further validation. One limitation of SEEV is that it does not deal with the cognitive product that is the goal of attention allocation, a mental representation of a meaningful event. The models in the next section deal with this.

3.3 Models of Comprehension Within Driving Sub-tasks

Durso et al. (2007) have sketched out how Kintsch's (1988) construction-integration model of text comprehension can be adapted to describe the perceptual and cognitive processes by which a driver builds up a meaningful model of an ongoing driving situation. The initial step in this process is the perception of objects in a particular scene, leading to surface-level scene and object representations with little meaning. In the second step, spreading activation among these representations and related representations in long-term memory leads to a more meaningful, interconnected representation of the scene. This process repeats cyclically across scenes, with the most important (i.e., most activated) information from each scene carried over to the next cycle, until an integrated, meaningful representation of a particular event (the "eventbase") is built up in working memory. The eventbase would contain knowledge like "those two cars ahead are on a collision path." In the final step, domain-specific knowledge and expertise (e.g., "maybe the Porsche can speed up enough to avoid a collision") is used to further elaborate the eventbase into a richer representation called the situation model. The situation model contains information about causal, temporal, and spatial relationships among the objects comprising an event that drivers use to anticipate future events and guide their actions.

A model of event and hazard comprehension is critical to understanding how people maintain SA; and Durso et al.'s adaptation of the construction-integration model to comprehending driving events seems promising. The main drawback of their model is that it has not been implemented in a specific computational model and validated against empirical driving data.

3.4 Models of Multitasking

Driving, even without side tasks, could be considered to involve multitasking, since it requires concurrent performance of at least three distinct subtasks: vehicle control, monitoring and hazard avoidance, and navigation. Side tasks such as conversation or eating only add to the multitasking load. Multitasking is made more difficult by the fact that in many multiple-task situations, tasks have unequal priorities and task priorities change over time. For example, drivers should not assign equal priority to maneuvering through heavy traffic and talking on their cell phone. Thus a key sub-skill during multitasking is task management (or task coordination), which can be thought of as cross-task attention allocation, and which includes setting subjective task priorities for a set of tasks that closely match changing objective priorities, and switching between tasks. In my view, effective task management during multitasking is another key sub-skill in maintaining SA.

Salvucci and Taatgen (in press) hypothesized that people have a general-purpose ability to multitask, distinct from their abilities to perform single tasks. They developed a process model of this general multitasking ability and integrated it into the ACT-R cognitive architecture. The new model, which they call threaded cognition, models the processing of multiple tasks as multiple goals (threads) in working memory, and allows interleaving and switching among the multiple tasks as each one builds towards its next response. In three studies, Salvucci and Taatgen validated this model against human performance during simulated driving along with side tasks. Thus, this model seems to provide an accurate description of how people allocate attention and cognitive resources across driving subtasks and side tasks. However, this conclusion may only hold for the relatively simple driving subtasks considered in these validation studies. Also, the threaded cognition model uses a very simple task management rule that gives each subtask equal priority. This rule may not work well in describing more complex and realistic driving situations involving unequal task priorities.

4. Measures of Attention and Situation Awareness in Driving

The prior discussion of the component processes of SA will, I hope, generate an interest in how to measure these components. In this section, I will describe a variety of SA measures and classify them as either online, where behavior is measured during a simulated driving scenario with little or no interruption, or offline, where behavior is measured when the driving scenario is not visible.

4.1 Online SA Measures

For almost 40 years, researchers have used eye trackers to monitor and record drivers' eye movements during real and simulated driving. Most researchers assume that overt eye movements (saccades) and fixations indicate the focus of attention most of the time, while understanding that focal attention can sometimes be shifted during a fixation without a saccade. The assumption that fixations track focal attention is especially safe for driving because drivers must gather information from about 270º around them using head movements and large saccades. The most common eye movement variable in driving studies is the percentage of time fixating on particular locations (dwell time).

In performance-based SA measures, the researcher makes inferences about a drivers' SA based on their driving actions during a scenario. For example, in a low-fidelity simulator, Gugerty (1997) used drivers' driving actions to assess their awareness of cars about to collide with them and of cars in the blindspot.

In event detection SA measures, drivers report (e.g., verbally or by pressing a button) whenever they see predefined events during a simulated drive (e.g., a car swerving) (Greenburg, Tijerana, Artz et al., 2003). The driving scenario is not interrupted by reporting the event. In one important kind of event detection measure, called a hazard perception test, drivers view or drive through a scenario and report whenever they see any hazardous events (Horswill & McKenna, 2004). The most common variables are the speed and accuracy of event or hazard detection.

In the Situation Present Awareness Method (SPAM), an ongoing driving scenario in a simulator is paused at unpredictable times, but the scenario remains visible. Then the driver responds to one or two questions about the scenario (Durso, Bleckley & Dattel, 2006). Response time is the main variable, since the answer to the question is visible and participants are very accurate.

The above SA measures are all probably best seen as assessing focal vision and attention processes. The Useful Field of View (UFOV; also called functional field of view) test was developed to assess ambient vision processes (Ball, Beard & Roenker, 1988). It does this by requiring people to perform a central (focal) visual task along with a peripheral event detection task. The peripheral stimuli are presented at varying eccentricities beyond 10° for a brief period that disallows saccades, thus emphasizing ambient vision. Frequency of reporting the peripheral stimuli is the main variable relevant to ambient vision. The central and peripheral visual stimuli in the original UFOV tests are not related to driving. However, Crundall, Underwood and Chapman (1999) have developed a version of the UFOV with a driving hazard perception task as the central task.

Subjective SA measures, in which participants rate their own SA, are not considered here due to lack of space.

4.2 Offline SA Measures

Endsley (1995) developed the Situation Awareness Global Assessment Technique (SAGAT) in which operators perform a simulated real-time task. At unpredictable times, the real-time scenario is interrupted and the simulator screen goes blank. Then, the operator is asked a series of questions about events in the scenario. Accuracy of responding to questions is the main variable in this test.

Strayer, Drews and Johnston (2003) used a post-drive memory test to assess drivers' SA during a simulated drive. In their post-drive test, participants saw pairs of driving scenes, with one scene in each pair from the previous drive and one not, and chose the one from the drive (i.e., a recognition memory test). Recognition accuracy was the main variable.

5. Using the SA Measures to Understand the Components of SA

In this section, research will be presented that uses these SA measures to understand the components of SA discussed earlier—within-task attention allocation, event comprehension, multitasking, ambient vision. The reader should not expect a mutually exclusive set of measures for each SA component, as many measures assess multiple components. This section will also present information about the validity of the SA measures by demonstrating, where possible, that they can detect expected skill differences between experts and novices, and that they correlate with driving performance (i.e., predictive validity). In addition to demonstrating the validity of the SA measures, expertise and training effects as well as correlations with real driving show the importance of these SA components to the overall task of driving.

5.1 Research on Within-Task Attention Allocation

Eye tracking studies comparing novice and experienced drivers are relevant to the question of whether attention allocation skill changes with experience. Some of these studies have found that experienced drivers look at their mirrors more than novices, look farther down the road than novices (who tend to focus close to the front of the vehicle), and have shorter fixations than novices (Chapman & Underwood, 1998; Mourant & Rockwell, 1972).

Eye tracking studies have also been used to show that eye movements and attention shifts are sensitive to characteristics of the driving environment, which is the main assumption behind attention allocation. The studies by Wickens and colleagues validating the SEEV model showed that eye movements are affected by characteristics such as the frequency of information change, the task relevance of information, and objects' conspicuity (Horrey et al., 2006). Chapman and Underwood (1998) showed that drivers' faced with dangerous situations narrowed their scan pattern to focus on the danger; and that drivers used shorter fixations and longer saccades in complex urban environments than in simple rural driving. Finally, eye tracking studies have looked at how side tasks affect attention allocation to the roadway. Recarte and Nunes (2000) showed that a spatial side task lead to a narrowing of visual search across the forward roadway, less use of the mirrors, and longer fixations. These studies show that drivers' attention allocation develops with experience and is affected in expected ways by characteristics of the driving environment and by concurrent tasks.

Falzetta (2004) used an event detection task to assess how drivers attention allocation was affected by the location and the type of events. Participants drove in a simulator while reporting (via a button press) swerves and sudden decelerations by traffic cars. The events occurred either ahead of the driver in the same or the oncoming lane, or behind the driver. As

Figure 1 shows, participants detected forward events better than rear events, and swerves better than decelerations. The location effect is consistent with an attention allocation strategy that gives higher priority to the road ahead. By testing other locations and distances from the driver, this event allocation task could be used to map out the areas of high and low attention allocation.

5.2 Research on Event Comprehension

As mentioned above, drivers must do more than scan the road well (i.e., allocate attention), they must read the road well (i.e., comprehend the information scanned). Since driving is a risky activity, probably the most important aspect of event comprehension during driving is risk comprehension. The measures and studies reported here will focus on risk comprehension, which is also called hazard (or risk) perception (Horswill & McKenna, 2004).

Horswill and McKenna (2004) cited a number of studies supporting the conclusion that better hazard perception ability, as measured by their video-based test, is associated with fewer on-road crashes, and that hazard perception ability increases with driving experience. These authors also reviewed a number of studies showing that performance on the hazard perception test can be improved by explicit training—using techniques such as learner-generated and expert commentaries while viewing driving scenarios—and that this training transfers to hazard perception during simulated driving. In a similar vein, Pollatsek, Narayanaan, Pradhan et al. (2006) showed that PC-based training where drivers practiced identifying high-risk locations in plan-view (2D) driving scenes markedly increased the frequency of looking at risky locations during a simulated drive. In keeping with the theoretical approach taken here, Horswill and McKenna claim that their hazard perception test measures SA for hazardous situations, and that hazard perception is an effortful, non-automated process in which drivers maintain a mental model of the driving situation.

Research on expert-novice differences and predictive validity for the SAGAT and SPAM measures is not available for driving tasks, so aviation and air-traffic-control (ATC) tasks will be used here. Sohn and Doane (2004) found that scores on a modified SAGAT test related to instrument flight were higher for expert than for novice pilots. Also, individual differences in the novices' SAGAT scores were predicted only by their spatial working memory ability; while differences in the experts' scores were predicted most strongly by long-term working memory (i.e., short-term memory aided by learned flying knowledge). This study suggests that experts' greater SA (compared to novices) is based on learned domain knowledge that allows experts to quickly comprehend and remember real-time information. Durso, Bleckley and Dattel (2006) assessed the incremental predictive ability of the SAGAT and SPAM measures in the domain of air traffic control. In this study, the online SPAM measure predicted additional variance in performance on a simulated ATC task, over and above the variance accounted for by basic cognitive and personality attributes. However, the offline SAGAT test accounted for little incremental variance.

Gugerty (1997; Gugerty, Rakauskas & Brooks, 2004) used SAGAT to assess SA in a low fidelity driving simulator in which participants viewed driving scenarios and responded to driving hazards. Periodically, the scenario was blanked and participants then recalled traffic car locations or identified hazardous vehicles. The hazard identification test measured risk comprehension. In two studies assessing the effects of concurrent conversation tasks on driving SA, drivers' ability to recall car locations and identify hazards was strongly degraded by conversation.

These studies of event and risk comprehension show that drivers' comprehension ability improves with experience, training, and the build-up of driving knowledge, and that drivers' event comprehension is seriously degraded by multitasking.

5.3 Research on Multitasking

As mentioned above, effective task management during multitasking—including allocating attention to multiple tasks over time in keeping with their changing priorities—is a key sub-skill in maintaining SA. Ackerman, Schneider and Wickens (1984) have pointed out the difficulties in measuring task management skill as a separate component of performing a complex task. One of the measurement difficulties is separating general (i.e., cross-task) task management skill from skill at performing the individual tasks. To date, effective measurement of how individuals vary in general task management skill has proven difficult even with abstract laboratory tasks, and has not been done using more complex tasks like simulated driving.

Nevertheless, a number of studies using abstract laboratory tasks and more realistic tasks (e.g., flight training) have shown that people can improve their multitasking performance as a result of training in task management (Gopher, Weil & Bareket, 1994; Gopher, Weil & Siegel, 1989; Kramer, Larish, Weber et al., 1999). This training, often called variable-priority training, involves giving people explicit instructions to assign varying priorities to two concurrent tasks along with practice and explicit feedback on how well their performance reflects these priorities. The effectiveness of variable-priority training helps demonstrate the importance of task management skills in multiple task performance.

Horrey et al. (2006) investigated how people responded to differences in task priorities in multitasking situations during driving. They looked at how well people could allocate attention to a simulated driving task and an in-vehicle side task in response to changing conditions. The driving task was a steering task involving ambient vision; while the in-vehicle task was a focal task requiring reading, speaking, and comparing digits on a dashboard display. These studies showed that drivers could follow explicit instructions to prioritize either the driving or the in-vehicle task. Whichever task was prioritized received the most visual scanning and showed the highest performance.

However, as task priorities change during realistic driving, drivers do not usually receive explicit instructions to change their attention allocation. A more realistic test of whether drivers can manage task priorities well occurs when they have to detect changing priorities on their own, e.g., by noticing changes in task difficulties. Accordingly, Horrey et al. varied the difficulty of the steering task (via crosswind variations) and of the in-vehicle task. Drivers were able to adjust their attention allocation and task accuracy in response to difficulty variations; although some of these adjustments did not seem to increase safety. For example, as the difficulty of the in-vehicle task increased, scanning to the road and steering performance decreased.

The Gugerty et al. (2004) study mentioned earlier also provided evidence that drivers could recognize when one side task (talking on a cell phone) was more difficult than another side task (talking to a passenger) and then allocate less attention to the more difficult side task in order to reduce its detrimental effect on a higher priority driving task. However, they also found that both types of conversation side tasks markedly degraded important driving tasks such as hazard identification, which suggests that peoples' ability to allocate attention away from conversation tasks during driving is limited.

These multitasking studies show that drivers have some ability to recognize and manage the varying priorities of their multiple tasks and this task management ability can improve with training. However, the studies also show that task management abilities during driving are quite limited. Performing side tasks like conversation while driving degrades multiple safety-critical driving subtasks.

5.4 Research on Ambient Vision

Under the broader view of SA mentioned earlier, ambient visual processes are important to maintaining SA. One important visual function performed by ambient vision is detecting salient peripheral events, such as sudden movements, and forcing focal vision to allocate attention to them (i.e., attention capture). A common measure of the ability to detect brief peripheral events that has been used in driving research is the UFOV test.

Individual differences studies have showed that reductions in the useful field of view, as measured by the abstract (non-driving) version of the test, correlate with increases in on-road crash involvement in older drivers (Owsley, Ball, Sloane et al. 1991). Practice on the abstract UFOV test improves performance on the test itself as well as on some measures of simulated and on-road driving (Roenker, Cissell, Ball et al., 2005). Using a driving-related UFOV test (where the central task involved perceiving hazards in a realistic driving video, and the peripheral task involved detecting peripheral visual onsets), experienced drivers detected the peripheral onsets more frequently than non-drivers (Crundall et al., 1999). These three studies show that the ambient-vision ability to detect sudden peripheral events while performing a focal task improves with experience and training and positively affects overall driving performance.

Crundall et al. (1999) also found that the frequency of detecting peripheral visual onsets decreased as the cognitive demand of the focal hazard-perception task increased. This supports the Boot et al. (2005) finding that ambient processes such as attention capture are degraded under cognitive load, and also supports the broader view of SA as including both ambient and focal processes. It seems important for tests of SA to document not only changes in focal attention but also when drivers' ability to detect peripheral events is changed.

6. Conclusion

In this article, I have defined SA as the updated, meaningful knowledge of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when performing a real-time, multitasking task. Driving is a prime example of a real-time multitasking task. Also, I have fleshed out this definition, which focuses on SA as knowledge, by describing the key perceptual and cognitive processes used in maintaining SA. These consist of processes of focal vision and attention, including attention allocation, event comprehension, and task-management (multitasking), and also, under a broader view of SA offered here, processes of ambient vision such as attention capture.

Given that SA involves maintaining rich knowledge of a dynamic environment by using attentional, comprehension, and executive control processes, it is not surprising that SA is difficult to measure. A variety of measures are used to understand SA, including: online measures such as eye tracking, performance measures, event detection, SPAM, and UFOV; and offline (memory-based) measures such as SAGAT and post-drive recognition tests. Most of these measures have been used extensively in conjunction with driving simulators, and all of them could be.

Although each of these SA measures can be used to study a variety of research questions related to driving, the following suggestions are offered. Eye tracking is useful for measuring how drivers allocate focal attention. Event detection measures (including focal events as assessed by hazard perception tests and peripheral events as assessed by the UFOV) are useful for measuring how SA for current (ongoing) events is affected by: 1. environmental factors such as the location, magnitude or type of an event; and 2. internal driver factors such as cognitive load, multitasking, distraction, or fatigue. Query techniques (including the offline SAGAT technique and the online SPAM measure) are useful for measuring how SA for past, current, and future events is affected by internal driver factors. Performance measures (and perhaps post-drive recognition memory tests) are useful for measuring the differences between implicit, unconscious and explicit, conscious aspects of SA.

Research using these SA measures has shown that peoples' ability to use focal processes related to SA including attention allocation, event and risk comprehension, and task management improves with training and with experience at a real-time task like driving. Also, ability at event and risk comprehension, a key component of SA, correlates positively with whole-task driving performance on the road or in a simulator. A similar pattern emerges for ambient processes that may be related to SA. Peoples' ability to detect sudden peripheral events improves with training and with driving experience, and is positively correlated with on-road driving performance. This overall pattern suggests that both the focal and the ambient processes presented here as the component processes of SA are critical components of safe driving.

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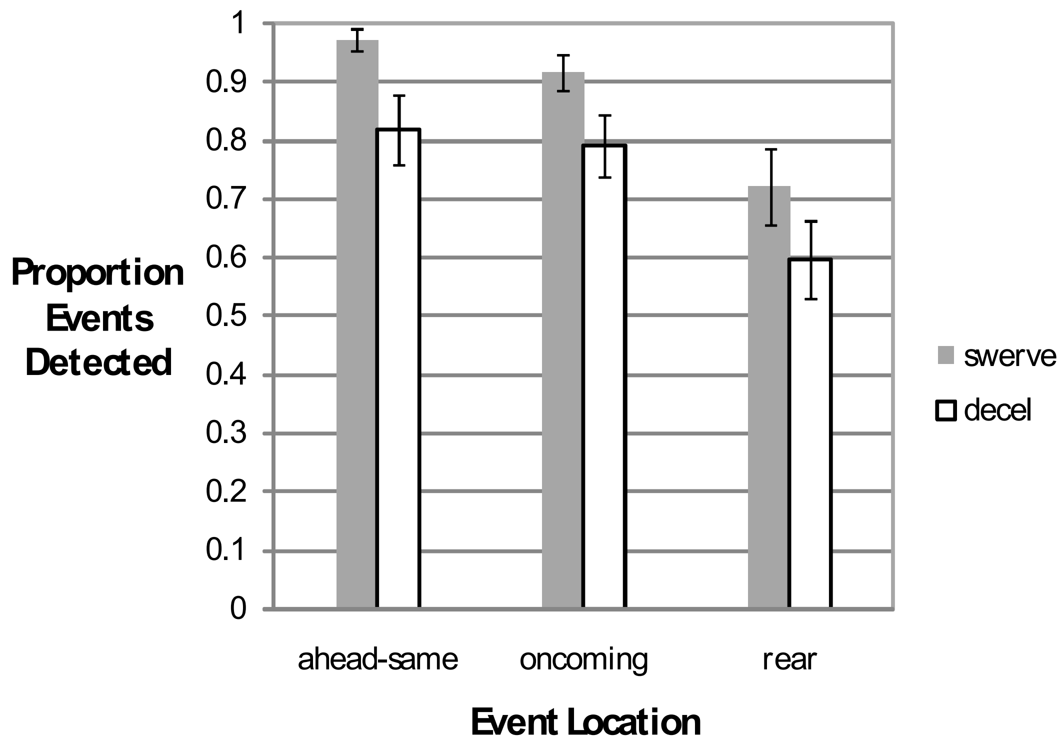

Figure 1. Proportion of swerve and deceleration events detected at three road locations, with standard error bars. From Falzetta (2004).